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Deadly Gun Violence, Neighborhood Collective Efficacy, and Adolescent Neurobehavioral Outcomes

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Abstract

Gun violence is a major public health problem and costs the United States \$280 billion annually (1). Although adolescents are disproportionately impacted (e.g., premature death), we know little about how close adolescents live to deadly gun violence incidents and whether such proximity impacts their socioemotional development (2, 3). Moreover, gun violence is likely to shape youth developmental outcomes through biological processes – including functional connectivity within regions of the brain that support emotion processing, salience detection, and physiological stress responses – though little work has examined this hypothesis. Lastly, it is unclear if strong neighborhood social ties can buffer youth from the neurobehavioral effects of gun violence. Within a nationwide birth cohort of 3,444 youth (56% Black, 24% Hispanic) born in large U.S. cities, every additional deadly gun violence incident that occurred within 500 meters of home in the prior year was associated with an increase in behavioral problems by 9.6%, even after accounting for area-level crime and socioeconomic resources. Incidents that occurred closer to a child's home exerted larger effects, and stronger neighborhood social ties offset these associations. In a neuroimaging subsample ($N = 164$) of the larger cohort, living near more incidents of gun violence and reporting weaker neighborhood social ties were associated with weaker amygdala-prefrontal functional connectivity during socioemotional processing, a pattern previously linked to less effective emotion regulation. Results provide spatially-sensitive evidence for gun violence effects on adolescent behavior, a potential mechanism through which risk is biologically-embedded, and ways in which positive community factors offset ecological risk.

Keywords: gun violence; collective efficacy; delinquency; adolescence; corticolimbic connectivity

Significance Statement

Adolescents are disproportionately impacted by community violence, yet evidence for the behavioral and biological impacts of deadly gun violence has not been examined in nationwide samples using spatially-sensitive exposure measures. In a large, well-characterized U.S. sample of youth, we find that adolescents living near more incidents of deadly gun violence within 500 meters of their home evince greater delinquent behaviors and weaker amygdala-prefrontal connectivity during socioemotional processing. Incidents that occur farther away exert weaker effects, and youths' perceptions of strong community social ties offset these associations. This study adds to a growing literature highlighting the strength of neighborhood social ties while also shedding light on gun violence as a public health concern for adolescent neurobehavioral development.

Introduction

Nearly 60% of adolescents in the U.S. experience exposure to community violence (ECV) in their lifetime (2). ECV increases risk for maladaptive outcomes, including delinquent behaviors such as aggression and rule-breaking (4). One common form of ECV is gun violence (1), which accounts for 75% of all homicides in the U.S. (5). Despite an overall reduction in violent crime since the 1990s, gun-related homicides have risen steadily during the COVID-19 pandemic (6), highlighting an urgent need to understand the neurobehavioral effects of gun violence among adolescents, who experience ECV at much higher rates than other age groups (2).

Existing research linking ECV to youth delinquency has relied on self-report (4) or area-level crime rates at coarse geographies (e.g., Census tracts, zip codes) (3). Without incident-level data, it is difficult to know whether the behavioral effects of ECV are spatially linked (i.e., incidents that occur closer to a child's home exert larger effects) or reflect confounded area-level resources (e.g., concentrated poverty) that similarly increase risk for delinquency (7). Moreover, measures of ECV typically include a variety of violent crimes (3); the policy relevance of gun violence in the United States necessitates documentation of how this specific and extreme form of ECV sculpts youth outcomes.

Research is beginning to show that environmental adversity shapes neural function during socioemotional processing (8), and may be one mechanism through which exposure to adversity increases risk for maladaptive mental health outcomes, including delinquency and antisocial behavior (7, 9). Through dense structural and functional connections, the amygdala and regions of medial prefrontal cortex (mPFC) guide attention towards salient environmental cues (e.g., facial expressions of fear and anger) and coordinate the propagation of physiological

stress responses (10, 11). Weaker negative amygdala – mPFC connectivity, reflecting less efficient top-down prefrontal regulation of subcortical amygdala activation, has been linked to externalizing disorders (12) and childhood adversity within the family context (8, 13, 14). Recent work (9, 15) has demonstrated that concentrated disadvantage within neighborhoods is linked to corticolimbic activation and connectivity over-and-above family-level adversities (e.g., household poverty, harsh parenting, interparental conflict), but the proximal mechanisms (e.g., ECV) of these neighborhood-level associations remain unclear.

Neighborhood disadvantage also impacts youth delinquency through the erosion or maintenance of strong social ties (16–20). Collective efficacy reflects the combination of social cohesion and shared socialization goals among neighbors (e.g., living in a safe community) (20). High neighborhood collective efficacy has been linked to fewer youth externalizing behaviors (21), even after accounting for neighborhood-level confounds (e.g., ECV, concentrated disadvantage). Still, it is unclear whether cohesive neighborhoods can also exert protective effects in the context of extreme forms of ECV like gun violence. Moreover, despite calls for scholars to focus on how positive social experiences sculpt brain function, no studies have evaluated whether the protective effects of neighborhood social ties on adolescent brain development (22).

Though ECV and collective efficacy are likely to exert direct effects on adolescent neurobehavioral development, strong neighborhood social ties have also been shown to moderate or buffer the harmful behavioral effects of ECV (16–18, 23). In neighborhoods characterized by strong social ties, residents are able to curb the effects of problematic behaviors such as crime through activism, adaptive caregiving strategies, and the promotion of shared values (19, 20). Ultimately, neighborhoods high in collective efficacy can promote the desistance of youth

delinquency despite concentrated disadvantage and community violence (16), but whether strong neighborhood social ties can buffer against neurobehavioral effects of extreme ECV (i.e., deadly gun violence) warrants further examination.

The current study leverages a large U.S. population-based birth cohort of children and their families followed from birth through adolescence to evaluate the behavioral and neural consequences of living in close proximity to deadly gun violence. We hypothesized that greater indirect exposure to past year deadly gun violence incidents and lower perceived neighborhood collective efficacy would be related to greater youth externalizing behaviors and weaker threat-related amygdala-prefrontal connectivity during adolescence, over-and-above family- and neighborhood-level socioeconomic resources. In addition to exerting main effects, we also hypothesized that stronger collective efficacy would offset the negative effects of deadly gun violence.

Results

Using data from a nationwide sample of 3,444 youth recruited at birth from U.S. cities of 200,000 or more, with oversampling for sociodemographic risk (24), we constructed a geographically-precise measure of past year deadly gun violence incidents using participant addresses harmonized to incident-level data from the Gun Violence Archive (<http://www.gunviolencearchive.org/>) from 2014 to 2017. Nineteen percent of youth were indirectly exposed to at least one deadly gun violence incident within 500 meters of their home address in the prior year, with exposure ranging from 0 to 3 incidents (Fig. 1A). Using a 1-mile radius, which is smaller than county-level data provided by the FBI, 52% of youth were indirectly exposed to at least one deadly gun violence incident and exposure ranged from 0 to 17 incidents (Fig. S1). Consistent with previous research (1), a descriptive report (25) found that

Figure 1. Nearly 20% of the sample exposed to deadly gun violence within 500 meters home, and the number of incidents is associated with fear of crime, socioeconomic resources, and youth delinquency

(A)

(B)

Note. (A) Histogram of the number of deadly gun violence incidents within 500 meters of the child's home in the year before the age 15 visit; $N = 3,409$; (B) Zero-order associations between analytic constructs; $3,146 < N < 3,39$

adolescents who identify with marginalized ethno-racial groups in this sample were exposed at substantially higher rates than white adolescents.

Deadly gun violence within 500 meters of the home was more common among youth living in areas marked by high neighborhood socioeconomic disadvantage, among youth who reported greater fear of crime (SI Methods), and among youth living in low-income households (Fig. S1). Youth exposed to greater incidents of deadly gun violence also reported lower neighborhood collective efficacy, but the association was small in magnitude ($r = -0.09$), highlighting the distinct nature of these two neighborhood-level processes.

Deadly gun violence is associated with youth delinquency and does not reflect confounded area- or family-level socioeconomic resources

Each additional deadly gun violence incident that occurred within 500 meters of a child's home was associated with a 9.6% increase in youth delinquency (Table 1), accounting for city fixed effects, maternal marital status at birth (i.e., to account for the sampling design), youth race-ethnicity (a social, not biological, construct that reflects differential access to resources, structural inequities, and historical and present discrimination), youth pubertal development and child sex. Deadly gun violence continued to be associated with youth delinquency in more a stringent model that accounted for constructs linked to youth delinquency (7), including family poverty, neighborhood socioeconomic disadvantage, and violence exposure in the home (model 2). Furthermore, once parent-reported child externalizing behaviors at age 9 were included in the model, every additional gun violence incident was associated with a 5.2% increase in delinquency (though not statistically significant at $p < 0.05$), suggesting that average exposure to deadly gun violence was marginally related to mean increases in externalizing behaviors over time (model 3; Table 1).

Table 1. Associations between past year gun homicides within 500 meters of home and youth delinquency at age 15 in the nationwide Fragile Families and Child Wellbeing Study

	Model 1		Model 2		Model 3	
	B (SE) [95% CI]	β	B (SE) [95% CI]	β	B (SE) [95% CI]	β
# past year gun homicides	0.135 (0.043) [0.050, 0.220]	0.096**	0.094 (0.046) [0.004, 0.184]	0.067*	0.074 (0.049) [-0.002, 0.170]	0.052
Neighborhood collective efficacy	-0.041 (0.006) [-0.054, -0.029]	-0.029***	-0.038 (0.006) [-0.050, -0.025]	-0.027***	-0.038 (0.007) [-0.051, -0.024]	-0.027***
Early pubertal timing	0.314 (0.075) [0.167, 0.461]	0.224***	0.298 (0.075) [0.152, 0.445]	0.212***	0.266 (0.080) [0.109, 0.422]	0.189***
Late pubertal timing	0.171 (0.083) [0.010, 0.332]	0.122*	0.177 (0.082) [0.016, 0.338]	0.126*	0.161 (0.089) [0.013, 0.335]	0.115
Female	-0.477 (0.062) [-0.599, -0.355]	-0.340***	-0.489 (0.062) [-0.611, -0.368]	-0.348***	-0.449 (0.067) [-0.581, -0.317]	-0.319***
Family income-to-needs ratio			-0.069 (0.017) [-0.102, -0.037]	-0.049***	-0.078 (0.019) [-0.115, -0.041]	-0.056***
Neighborhood disadvantage			0.008 (0.008) [-0.007, 0.022]	0.005	0.001 (0.008) [-0.015, 0.017]	0.006
Home violence			0.201 (0.062) [0.079, 0.323]	0.143**	0.163 (0.067) [0.032, 0.294]	0.116*
Age 9 Externalizing					0.028 (0.005) [0.019, 0.037]	0.020***

Note. 2,973 < *N* < 2,460. Negative binomial regression models with youth self-reported delinquency as the dependent variable. All models covary for maternal marital status at birth and age 15 state fixed-effects (i.e., due to the sampling frame of the study), and youth racial-ethnic group (i.e., due to disparities in gun violence exposure). Not shown, collective efficacy did not moderate the association between past year gun violence exposure and youth delinquency (*p* > .10).

p* < .05; ** *p* < .01; * *p* < .001.

We replicated these results in a neuroimaging subsample of 237 youth from the Detroit, Toledo, and Chicago cities, using a deeper-phenotyped multi-informant measure of antisocial behavior that included clinician-rated psychiatric symptoms of Oppositional Defiant Disorder and Conduct Disorder, parent-reported rule-breaking and aggressive behaviors, and youth self-report of delinquency (12). Every additional deadly gun violence incident was associated with a 6.5% increase in youth antisocial behavior, and these associations were robust to individual- (e.g., pubertal development), family- (e.g., family income-to-needs), and community-level (e.g., neighborhood socioeconomic resources) covariates (Table S1 and Fig. S1).

Deadly gun violence incidents that occur closer to a child's home exert larger effects and are distinct from area-level violent crime rates

We next tested whether gun violence incidents that occur closer to a child's home exert larger effects on youth delinquency than incidents that occur farther away, and whether associations reflect broader patterns of neighborhood crime. First, we re-examined our models using a 1-mile diameter around the child's home. The association between the number of past year deadly gun violence incidents and youth delinquency was much weaker than the estimates using a 500-meter diameter (i.e., a 1.8% increase versus a 9.6% increase in delinquency for every additional incident of gun violence; the 95% confidence intervals of these estimate do not overlap) and did not remain statistically significant after accounting for socioeconomic resources and earlier youth externalizing behaviors (Table S2). Second, we accounted for county-level violent crime rate during the year of the age 15 visit, which reflects exposure to community danger at a macro scale. Not only was the county violent crime rate not associated with youth delinquency ($B = 0.0001$, 95% CI $[-0.00009, 0.0003]$, $\beta = 0.0001$, $p = 0.23$), but the number of deadly gun violence incidents within 500 meters of the child's home continued to be marginally

associated with youth delinquency over and above area-level crime ($B = 0.085$, 95% CI [-0.006, 0.176], $\beta = 0.085$, $p = 0.060$). These results suggest that the behavioral effects of indirect exposure to deadly gun violence may be spatially-linked and tied specifically to fatal gun incidents.

Strong neighborhood social ties counteract the behavioral effects of gun violence

Although indirect exposure to deadly gun violence was robustly related to an increase in youth delinquency, neighborhood collective efficacy exerted opposing protective effects (Table 1). Youth who perceived greater collective efficacy in their neighborhood also reported fewer delinquent behaviors. Every additional unit increase in collective efficacy was associated with a 2.9% reduction in youth delinquency. This effect was similar in models that accounted for deadly gun violence within a 1-mile radius of the child's home (Table S2), and in the neuroimaging subsample using a multi-informant measure of antisocial behavior (Table S1). In contrast to our hypotheses, there were no significant interactions between past year indirect exposure to deadly gun violence and collective efficacy, either the nationwide sample or neuroimaging subsample.

Deadly gun violence and strong neighborhood social ties exert opposing associations with corticolimbic connectivity

We next examined the unique and interactive effects of past year deadly gun violence and neighborhood collective efficacy on amygdala-prefrontal connectivity while adolescents viewed ecologically-valid expressions of distress (fearful), threat (angry), and ambiguity (neutral; Figure S2). One-hundred sixty-four youth contributed valid neuroimaging and behavioral data (Table S3).

Accounting for baseline covariates (i.e., youth gender, race-ethnicity, pubertal development, city fixed-effects, maternal marital status at birth), greater past year deadly gun

Figure 2. *Collective efficacy is associated with stronger negative amygdala-prefrontal connectivity during fearful face processing*

Note. $N = 164$; (A) Greater youth's perceptions of neighborhood collective efficacy was associated with stronger negative right amygdala – right superior medial frontal gyrus connectivity during fearful face processing versus baseline. (B) Target region centered on $[x, y, z] = [-6, 46, 20]$; T extent threshold = 4.43; k cluster size = 161.

violence was associated with weaker negative amygdala - mPFC connectivity (superior frontal gyrus; $[x, y, z] = [18, 66, 22]$; T extent threshold = 3.82; k cluster size = 22) during fearful face processing versus baseline. Conversely, youth perceptions of neighborhood collectivity efficacy were associated with stronger negative amygdala – mPFC connectivity (superior medial frontal gyrus; $[x, y, z] = [-6, 46, 20]$; T extent threshold = 4.43; k cluster size = 164; Fig. 2; Table S4). The pattern of results for both dimensions of the neighborhood context revealed specificity for fearful facial expressions, as there were no associations between past year deadly gun violence or collective efficacy and amygdala-prefrontal connectivity during angry or neutral face processing (i.e., no suprathreshold clusters were identified). Lastly, once both gun violence and collective efficacy were included in the same model, only youth's perceptions of neighborhood collective efficacy continued to be associated with amygdala-prefrontal connectivity, which additionally persisted after accounting for family- and neighborhood-level socioeconomic disadvantage (superior medial frontal gyrus; $[x, y, z] = [-6, 46, 20]$; T extent threshold = 4.47; k cluster size = 164; Table S4).

A double-hit of high deadly gun violence and weak neighborhood social ties in pathways to corticolimbic connectivity

In contrast to behavioral analyses, there was a significant interaction between the number of deadly gun violence incidents and neighborhood collective efficacy (superior frontal gyrus; $[x, y, z] = [42, 54, 0]$; T extent threshold = 4.09; k cluster size = 66). Gun violence was only associated with amygdala-prefrontal connectivity during fearful face processing at low levels of collective efficacy (Fig. 3), suggesting a “double-hit” of weak social ties and high indirect exposure to deadly gun violence.

Figure 3. Youth with exposure to any gun violence and low levels of neighborhood collective efficacy showed stronger positive amygdala-prefrontal connectivity during fearful face processing

Note. $N = 164$. The shaded regions of the figure indicate values of collective efficacy wherein gun violence exposure was significantly related to amygdala – prefrontal connectivity (i.e., the regions of significance). Collective efficacy was associated with amygdala – prefrontal connectivity for youth with any exposure to gun violence ($t = -5.41, p < .001$), but not for youth without exposure to gun violence ($t = -0.91, p = 0.36$).

Discussion

Using a nationwide sample of 3,444 youth, the current paper documents robust effects of neighborhood-level risk and protective factors on youth delinquency. Every additional deadly gun violence incident that occurred within 500 meters of a child's home was associated with a 9.6% increase in youth delinquent behaviors. Moreover, the behavioral effects of gun violence

were weaker as indirect exposure occurred farther away and were not due to area-level violent crime or confounded socioeconomic resources. By contrast, greater perceptions of collective efficacy were related to fewer delinquent behaviors, highlighting the importance of strong neighborhood social ties in sculpting adolescent behavioral outcomes. These experiences showed potential neural embedding, as both deadly gun violence and collective efficacy were related to differences in amygdala-prefrontal connectivity during socioemotional processing, though weaker effects were found for gun violence. Collective efficacy appeared to moderate the neural effects of this neighborhood-level adversity, such that youth living close to multiple incidents of deadly gun violence and who perceived lower collective efficacy among their neighborhoods evinced weaker amygdala-prefrontal connectivity while viewing fearful facial expressions. Our results adding to a growing body of literature documenting the harmful effects of gun violence on America's youth, while also highlighting neighborhood collective efficacy as an important consideration in promoting adaptive youth neurobehavioral development.

By measuring geographically precise incidents of deadly gun violence harmonized to participant home addresses, the current paper builds on previous research linking area-level crime rates at coarse geographies to youth externalizing behaviors. That we found comparably no associations between youth delinquency and county-level crime rate and significantly weaker effects of incident-level gun violence at farther distances from a child's home (i.e., 1-mile versus 500 meters) suggests spatial sensitivity of gun violence effects on youth outcomes (26). Although we do not know whether the youth in our sample witnessed or heard about each deadly gun violence incident, even living in a high-crime neighborhood (independent of direct victimization) increases risk for behavioral dysregulation and psychopathology (27, 28). Indirect ECV is thought to increase risk for mental health challenges by heightening fears of crime (29)

and concomitant behaviors (e.g., affiliating with deviant peers) that youth employ to cope with the threat of violence (3). Neighborhoods characterized by high levels of violence are also associated with lower street efficacy (i.e., youth's ability to navigate violent contexts) which, in turn, has been linked to adolescent perpetrations of violence and affiliation with deviant peers (30). Importantly, our estimates remain meaningful (though statistical significance was attenuated) when accounting for previous youth externalizing behaviors, thus partially countering concerns that the findings are due to selection effects (i.e., that individuals with high levels of delinquency select into contexts characterized by high gun violence).

We also found that greater neighborhood collective efficacy was related to fewer delinquent behaviors during adolescence. Though the effect size of this association was modest (i.e., a 2.9% reduction in delinquency with every 1-unit increase in collective efficacy), results are consistent with several studies that have found that residents' perceptions of collective efficacy are related to greater youth street efficacy (30), lower violent crime (19), and fewer suggestions by parents to use aggression to cope with taxing neighborhood situations (31). Although we also tested whether youth's perceptions of collective efficacy moderated the effects of gun violence exposure on youth delinquency (23), this hypothesis was not supported. Instead, our results point to unique (and opposing) behavioral effects of neighborhood collective efficacy and incident-level gun violence.

Our results also suggest that one potential mechanism through which neighborhood qualities shape youth behavioral outcomes is via neural function within the corticolimbic system. We build on a large body of work that has focused on neural function within isolated regions of interest (8, 13, 32) by examining corticolimbic connectivity as a *circuit-level* mechanism of environmental effects on youth socioemotional development. Our examination of circuit-level

functional connectivity is consistent with contemporary neuroscience perspectives that complex disorders arise from deficits in functional networks rather than single regions of interest (33).

Youth indirectly exposed to more deadly gun violence incidents evinced weaker negative amygdala-prefrontal connectivity during fearful faces processing, a neural phenotype previously linked to greater antisocial behavior and delinquency (12). Developmentally, as functional and structural connections between the amygdala and prefrontal regions strengthen with age, task-based amygdala-prefrontal connectivity has been shown to switch from positive to negative during adolescence (34). Our results could suggest that ECV undermines maturation of the corticolimbic circuit such that amygdala-prefrontal connectivity was positive among youth indirectly exposed to high levels of deadly gun violence, plausibly indicative of an immature, less efficient regulatory circuit (14). Larger neuroimaging studies with adequate statistical power should be leveraged to test this mechanistic pathway, as the required sample size for testing indirect effects models was much larger than the current study.

By contrast, greater neighborhood collective efficacy was associated with stronger negative amygdala-prefrontal connectivity during fearful face processing. Moreover, the protective neural effects of greater collective efficacy were relatively more robust than the effects of gun violence in that they remained statistically significant after accounting confounded socioeconomic resources (15, 35). Although most research examining the associations between environmental conditions and corticolimbic function have focused on adverse childhood experiences, our results contribute to an emerging literature highlighting the power of promotive contexts (e.g., perceptions of social support) in shaping affective brain development (36, 37).

Lastly, our results revealed that neighborhood collective efficacy and ECV may jointly impact corticolimbic connectivity over-and-above their main effects: youth who lived within 500

meters of any deadly gun violence and who reported low levels of collective efficacy evinced the strongest positive amygdala-prefrontal connectivity during fearful face processing. As we did not observe a similar interaction in the behavioral data, these interaction results should be seen as preliminary.

Limitations

Despite leveraging a large population-based sample with enrichment for families facing substantial ecological disadvantage, a novel measure of incident-level ECV, and pairing behavioral analyses with an examination of neural mechanisms, several limitations should be considered alongside the current results. First, although we leveraged longitudinal data, our study is observational and cannot be used to assign causality. Second, both collective efficacy and youth AB were reported by the same person in the nationwide sample (i.e., adolescents), leading to concerns for shared method variance. However, using a multi-informant measure of antisocial behavior (12) in the neuroimaging subsample, we found effects of similar magnitude. Lastly, despite the strength of pairing large-scale survey data with a neuroimaging subsample, the sample size of participants with valid imaging data was relatively small. Even so, concerns for protecting participant confidentiality in larger neuroimaging studies make it difficult to harmonize incident-level data with participant addresses. For example, although the ABCD study (38) has published county-level violent crime rates, the current results suggest that such gross estimates of ECV are unlikely to explain significant variation in adolescent developmental outcomes.

Implications and Conclusions

There are several policy-relevant implications of the current study, stemming from the recognition that risk and protective factors within the neighborhood are critical for shaping adolescent neurodevelopment.

First, gun legislation may be enacted to restrict the availability of firearms and reduce adolescent exposure to gun violence. Requiring licenses to possess a gun, or permit-to-purchase laws, have been shown to reduce firearm-related deaths (39). A recent empirical analysis reported that the adoption of right-to-carry laws (RTC) across 33 states significantly increased violent crime by 13 – 15% in the 10 years following adoption of RTC (40). Our results, combined with the fact that adolescents with behavioral problems consume nearly \$70,000 more per child in public services (41), reiterate the importance of gun legislation in promoting public health.

Second, our results suggest that policies to increase neighborhood collective efficacy could have trickle-down effects on adolescent neurobehavioral development. Civic engagement, such as participating in neighborhood organizations (42), promotes resident's perceptions of collective efficacy. Moreover, study protocols that leverage youth participation increase adolescent's perceptions of neighborhood social cohesion (43). Thus, interventions to increase community social capital should be considered alongside policies to reduce gun violence in the United States.

Neighborhoods are critical contexts for youth socioemotional and neurobiological development. Results emphasize the neural and behavioral consequences of indirect exposure to deadly gun violence in the United States while also demonstrating the power of strong neighborhood social ties in promoting adaptive youth outcomes.

Materials and Methods

Sample

Participants were part of the Fragile Families and Child Wellbeing Study, a longitudinal, stratified, multistage probability sample of 4,898 children (52.4% boys) born in 20 large U.S. cities between 1998 and 2000 (24). Parents were interviewed at the hospital shortly after the birth of the target child, and again (by phone or in-person) at ages 1, 3, 5, 9, and 15 years old. At age 15, 3,444 youth (52% male; 46% Black Non-Hispanic) participated (SI Methods).

After the nationwide study, families from the Detroit, Toledo, and Chicago subsamples were asked to participate in the Study of Adolescent Neurodevelopment. Two-hundred and thirty-seven adolescents aged 15 to 17 (52.3% female; Black Non-Hispanic 75.5%; median annual household income \$25,000 to \$29,999) and their primary caregiver agreed to participate.

Measures

Gun violence. Deadly gun violence data sourced from the national Gun Violence Archive (<http://www.gunviolencearchive.org/>). Incident-level data was collected from 2014 to 2017, which overlapped with the age 15 visit in the nationwide sample and was harmonized to the interview date. Our estimates characterize the prevalence of indirect exposure to deadly gun violence that occurred within 500 meters (0.31 miles) of the adolescent's home in the year prior to the nationwide study's age 15 interview (SI Methods).

Neighborhood collective efficacy. In both the nationwide sample and the neuroimaging subsample, neighborhood collective efficacy (20) was measured by youth-reported degree of *Informal Social Control* (e.g., neighbors would intervene if a fight broke out in front of their home) and *Social Cohesion* (e.g., this is a close-knit neighborhood). Items from each scale were averaged, standardized, and then summed into one measure of collective efficacy (SI Methods).

Youth Delinquency and Antisocial Behavior. In the nationwide sample, youth delinquency was measured using a sum of 13 self-reported items (e.g., *Deliberately damage property that didn't belong to you?*) rated on a scale from 0 = never to 2 = often. We also created a multi-informant, multi-method measure of antisocial behavior in the neuroimaging subsample that captured youth antisocial behaviors from minor rule breaking incidents to more severe symptoms of psychiatric diagnoses (20). To account for a history of aggressive and rule-breaking behaviors, we controlled for parent reports on the externalizing subsample of the Child Behavioral Checklist (CBCL) (44) when the target child was age 9 (SI Methods).

Covariates. All analyses controlled for state-of-birth (nationwide sample) or city-of-birth (neuroimaging subsample) fixed effects, and youth self-reported race-ethnicity, gender, and pubertal development at age 15. We also accounted for socioeconomic resources within the family and neighborhood contexts and possible violence within the home at age 15 (SI Methods). In sensitivity analyses, we also accounted for county-level violent crime rate per 100,000 people.

Neuroimaging Data

fMRI task. Participants completed an implicit emotion face processing task during continuous fMRI acquisition. There were 100 pseudo-randomized trials, 20 trials each of fearful, happy, sad, neutral, and angry facial expressions. Total task time was 8.75 minutes (SI Methods; Fig. S2).

Data acquisition and pre-processing. MRI images were acquired using a GE Discovery MR750 3T scanner with an 8-channel head coil. Of the 237 participants in the neuroimaging study, usable fMRI data was available for 167 (70%) participants (Table S3). Participants without usable fMRI data did not differ from participants with usable fMRI data with respect to primary or control variables (SI Methods).

Functional connectivity analysis. Generalized psychological-physiological interaction analysis in SPM12 was used to measure the association between neighborhood constructs and left and right amygdala-prefrontal connectivity during angry, fearful, and neutral faces versus baseline (SI Methods).

Statistical Analysis

Reproducible code and the data are publicly-available (SI Methods). Neuroimaging analyses were completed in SPM12; all other analyses were conducted in R version 4.0.2 (45). Behavioral data outliers were winsorized to $\pm 3SD$. Less than 10% of missing data was handled via listwise deletion. Analytic sample sizes for behavioral aims were $2,460 < N < 3,144$ in the nationwide sample and $223 < N < 226$ in the neuroimaging subsample ($N = 164$ for imaging analyses).

Stepwise negative binomial regression models were used to evaluate the effects of gun violence exposure and collective efficacy on youth delinquency. Negative binomial regression models are appropriate for over-dispersed (i.e., variance much larger than mean) and non-normal zero-inflated data (46, 47). Successfully more stringent models were tested: (1) # of deadly gun violence incidents, collective efficacy; (2) youth pubertal development, race-ethnicity, and gender; (3) family and neighborhood socioeconomic resources, and potential violence within the home; (4) age 9 externalizing behaviors; (5) gun violence X collective efficacy interactions. To interpret the coefficients as % change, we standardized the betas by the base rate of antisocial behavior (i.e., the mean). Thus, standardized coefficients in the nationwide sample can be interpreted as the % change in delinquency predicted by every additional gun violence incident, for a child with average levels of delinquency. The analytic approach in the neuroimaging subsample was similar except that models were estimated using ordinary least squares

regression, owing to the normal distribution of the latent factor of antisocial behavior, which we first log-transformed so that unstandardized coefficients could be interpreted as % change. In addition, there was not a similar measure of family violence exposure to include in model 2 (i.e., wherein other forms of adversity were added as covariates).

SPM12 was used to evaluate the associations between neighborhood constructs and task-dependent amygdala-prefrontal connectivity. Covariates were similarly entered in a stepwise manner (SI methods). The PFC mask was defined as one large prefrontal mask that included Brodmann's areas 9, 10, 11, 47, 24, 32, and 25, consistent with previous studies in this sample (15, 48). Only ipsilateral connections between the amygdala and PFC were examined (49). Multiple comparisons were corrected using 3dClustSim program (50) in AFNI (SI methods) to provide thresholds that achieve a family-wise error correction threshold of $p < .05$ within the left or right prefrontal mask ($k = 22$).

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During the resubmission of this paper, our co-author Dr. Sara McLanahan (1940-2021) passed away. We dedicate this paper to her memory. Dr. McLanahan's leadership and innovation in co-founding the Fragile Families and Child Wellbeing Study made this work, and that of dozens of other scholars, possible.

Author Contributions

AB developed the initial idea. LWH, CM, CSM, SM, and JB-G provided intellectual feedback and guidance. AG cleaned data, completed the analyses, and wrote the manuscript. LWH, CM, and CSM acquired funding for the neuroimaging subsample. SM and JB-G acquired funding for the nationwide sample. All authors discussed the results and commented on the manuscript.

Competing Interests statement

The authors declare no competing interests

Data Availability Statement

Reproducible code is available (<https://osf.io/rct6q/>). Data from the nationwide sample is publicly-available (<https://opr.princeton.edu/archive/>); restricted access is required for some components (e.g., geographical identifiers). Data from the neuroimaging subsample is also publicly-available (https://nda.nih.gov/edit_collection.html?id=2106).

SUPPLEMENTAL MATERIALS

Deadly Gun Violence, Neighborhood Collective Efficacy, and Adolescent Neurobehavioral Outcomes

Supplemental Methods

Sample

Fragile Families and Child Wellbeing Study. Due to the rise of single-parent households in the United States, the Fragile Families and Child Wellbeing Study oversampled for non-marital births (~3:1); the term “fragile families” refers to these nonmarital births and underscores that these families are at a greater risk of breaking up and living in poverty, than are more advantaged and historically privileged family structures (1). At childbirth, mothers identified as Black non-Hispanic (N = 2,326, 47.5%), White non-Hispanic (N = 1,030, 21.1%), Hispanic (N = 1,336, 27.3%), or other (N = 194, 4.0%). Nearly 40% of the mothers reported less than a high school education at the birth interview, 25.3% with a high school degree or equivalent, 24.3% some college or technical training, and 10.7% who earned a college degree or higher. Retention of the baseline sample was generally high at each of the assessment periods (77% to 90% for mother or primary caregiver interviews, 62% to 72% for home visits) (<https://fragilefamilies.princeton.edu>). At age 15, youth self-reported as non-Hispanic Black or African American (46%), Hispanic or Latino (24%), non-Hispanic White (17%), non-Hispanic multiracial (5%) or other non-Hispanic (2%). Participants were reimbursed for their participation, and procedures were approved by the IRB of Princeton University (IRB protocol #5767).

Study of Adolescent Neurodevelopment. Of the 237 families who participated, teens self-identified as Black Non-Hispanic (N = 179, 75.5%), Black Hispanic (N = 2, 0.8%), White Non-Hispanic (N = 30, 12.7%), of Hispanic or Latino/a origin (N = 10, 4.2%), biracial (N = 13, 5.5%), or other Non-Hispanic (N = 3, 1.3%). Median annual family income was between \$25,000 to \$29,999, with some primary caregivers reporting annual incomes below \$4,999

(13%) and others reporting annual incomes above \$90,000 (10.2%). Primary caregivers (91.1% biological mothers) and adolescents in the SAND subsample participated in a one-day protocol that included collection of self-report, interviewer, observational, and neuroimaging data. Parents provided written consent and adolescents provided verbal assent for their participation. Families were reimbursed for their participation. All assessments and measures were approved by the Institutional Review Board of the University of Michigan (IRB protocol HUM00074392).

Measures

The current paper uses data from both the nationwide sample and the neuroimaging subsample. Interviews from the neuroimaging subsample were conducted, on average, 206.83 days (Min – Max = 20 – 787) following the nationwide sample core interview. The number of days between interviews was not associated with any construct of interest.

Gun Violence. Detailed information on attaining, appending, and validating this data is provided by FFCWS staff in documentation available at <https://fragilefamilies.princeton.edu/restricted>. In brief, the measures of exposure to gun violence used in these estimates were developed by (1) calculating the geodetic distances (in meters) between adolescents' geocoded home addresses and geocoded locations of deadly gun violence incidents and (2) comparing the date of the deadly gun violence incident to the date of the core FFCWS adolescent interview. Data were then summarized to produce measures of exposure to gun violence varying by distance (from incident to residence), time (relative to interview date), and frequency (number of incidents within a given time frame and distance).

Neighborhood Collective Efficacy. In the nationwide sample, 4 items (4-point Likert scale) were used to measure *Informal Social Control* (Mean [SD] = 2.86 [0.67], $\alpha = .87$) and 4 items (4-point Likert scale) were used to measure *Social Cohesion* (Mean [SD] = 2.93 [.83], $\alpha =$

.78). In the neuroimaging subsample, 5 items from each scale were included, and all items were rated on a 5-point Likert scale (*Informal Social Control*: Mean [SD] = 3.07 [1.09], $\alpha = .87$; *Social Cohesion*: Mean [SD] = 3.18 [0.83], $\alpha = .78$). The *Informal Social Control* scale asked youth to rate the degree to which neighbors would intervene in several situations (e.g., children skipping school, budget cuts closed fire station, fight broke out in front of their house). The *Social Cohesion* scale assessed the degree of shared values and expectations among neighbors (e.g., “This is a close-knit neighborhood”, “People in this neighborhood can be trusted”). In both samples, two items (e.g., “People from this neighborhood do not share the same values”) from the *Social Cohesion* scale were reverse-coded before the measure of collective efficacy was constructed (2).

Youth Externalizing Behaviors. Our primary dependent variable, youth self-reported delinquency, was measured using 13 items drawn from the Self Report of Delinquency (3) and the Wave 1 and Wave II visits of the National Study of Adolescent Health. Age 9 externalizing behaviors were accounted using a sum of 17 items from the rule-breaking subscale and 18 items from the aggression subscale of the Child Behavioral Checklist (4). Parents reported the frequency of each child behavior on a three-point scale from 0 = never to 2 = often (Mean [SD] = 6.22 [6.91], Min – Max = 0 – 70, $\alpha = .91$). This measure of earlier child externalizing behaviors was used in analyses in both the nationwide sample and the neuroimaging subsample.

Youth Antisocial Behavior (Neuroimaging Subsample). Confirmatory factor analysis in Mplus version 7.3 (5) with maximum likelihood estimation with robust standard errors was used to combine the following measures: (1) parent-reported rule-breaking and (2) aggressive behaviors from the CBCL (4), (3) total score of the youth SRD (3), and (4) combined lifetime

symptom count of the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)* conduct disorder and oppositional defiant disorder (6) on the basis of clinician-ratings assessed via a modified version of the Kiddie Schedule for Affective Disorders and Schizophrenia (7).

Covariates. In the nationwide sample, race-ethnicity was coded as three dummy codes (Hispanic, White Non-Hispanic, Other), with the largest category (Non-Hispanic Black [46%]) as the reference group. In the neuroimaging subsample, due to the smaller sample size, race-ethnicity was coded as one dummy code for the largest group in the sample (Non-Hispanic Black [75.5%] = 1). In the nationwide sample, pubertal development was measured using two dummy codes (1 = earlier [22.85%], 2 = later [18.68%]) constructed in reference to teens who rated their pubertal development as “about the same” as their male/female peers [58.47%]. In the neuroimaging subsample, pubertal development was measured at age 15 using youth report on the Pubertal Development Scale (8), which includes two gender-specific items (e.g., for boys: voice changes; for girls: breast development), and three items for both genders (i.e., changes in height, skin, pubic hair). All items were rated on a 4-point Likert scale (1 = *process has not started*, 4 = *seems completed*), except for the menarche question for girls, which was dichotomous (1 = *not started*, 4 = *started*). Total pubertal development score was calculated as a mean of the five items for each gender (girls: Mean [SD] = 3.58 [.46]; boys: Mean [SD] = 2.86 [.50]). In both samples, household poverty at age 15 was measured as a ratio of income to needs, based on U.S. Census Bureau poverty thresholds from the prior year (Mean [SD] = 2.40 [2.68], Min – Max = [0 – 41.89]). Neighborhood disadvantage was measured by geocoding participant addresses (i.e., addresses provided at age 15 for the nationwide analyses; addresses provided at the time of the neuroimaging visit for analyses in the neuroimaging subsample) to Census tracts

from the 2010 Decennial Census. A composite score was created of a seven tract-level indicators from the 2011 – 2015 American Community Survey: (1) median family income (reversed-scored by multiplying by [-1], to maintain the direction of all of the indicators), (2) percent families below poverty line, (3) percent households on public assistance, (4) percent unemployed, (5) percent single-mother households, (6) percent African American, and (7) percent Bachelor degree and higher (9, 10). Lastly, to account for possible violence exposure within the home at age 15, we constructed a multi-informant measure of physical violence within the parent-child dyad. In the nationwide sample only, primary caregivers and youth responded to one item from physical aggression subscale of the Conflict Tactics Scale (11) – “Please tell me whether in the last year your {PRIMARY CAREGIVER} hit or slapped you?” Research assistants also made observer reports of the home environment and rated whether the primary caregiver “Hit or slapped the youth during the visit”. We combined the three informant responses into a single dichotomous measure of possible violence exposure in the home. If the primary caregiver, youth, or observer endorsed the item as occurring, possible violence exposure in the home was coded as “1”. A similar measure was not available in the neuroimaging subsample.

Imaging Data

fMRI task. Participants completed an implicit emotion face processing task during continuous fMRI acquisition (see Supplementary Figure X), in which they were asked to identify the gender of the actor by pressing their thumb for male or index finger for female (12). Faces from the NimStim set (13) were counterbalanced for gender and race (European American and African American). There were 100 pseudo-randomized trials, 20 trials each of the following emotions: fearful, happy, sad, neutral, and angry. Each trial consisted of a 500ms fixation cross followed by a face presented for 250ms. A black screen then appeared for 1500ms, during which

participants responded to the stimulus presentation, followed by a jittered inter-trial interval (2000, 4000, or 6000ms). Total task time was 8.75 minutes. Accuracy and response times were collected using a non-metallic fiber optic transducer linked to a response box.

Acquisition and Preprocessing. High resolution T1-weighted gradient echo (SPGR) images were collected (TR = 12ms, TE = 5ms, TI = 500ms, flip angle = 15°, FOV = 26cm; slice thickness = 1.4mm; 256 x 192 matrix; 110 slices) and used for pre-processing. Functional T2*-weighted BOLD images (TR = 2000ms, TE = 30ms, flip angle = 90°, FOV = 22cm; slice thickness = 3mm; 64 x 64 matrix; 40 axial slices) were acquired using a reverse spiral sequence, which has been shown to improve signal recovery in frontal regions (14). Slices were prescribed parallel to the AC-PC line (same locations as structural scans). Slices were acquired contiguously, which optimized the effectiveness of the movement post-processing algorithms. Images were reconstructed off-line using processing steps to remove distortions caused by magnetic field inhomogeneity and other sources of misalignment to the structural data, which yields excellent coverage of subcortical areas of interest.

Anatomical images were homogeneity-corrected using SPM, then skull-stripped using the Brain Extraction Tool in FSL (version 5.0.7) (15, 16). Functional data were pre-processed in the following steps: removal of large temporal spikes in k-space data (> 2 std dev), field map correction and image reconstruction using custom code in MATLAB; and slice-timing correction using SPM12 (Wellcome Department of Cognitive Neurology, London, UK). To address head motion, functional images were realigned to the AC-PC plane in the mean image. Using SPM12, anatomical images were co-registered to the functional images. Functional images were normalized to the MNI Image space using parameters from the T1 images segmented into gray and white matter, cerebrospinal fluid, bone, soft tissue and air using a Tissue Probability Map

created in SPM12. Images were then smoothed using an isotropic 8-mm full width at half maximum Gaussian kernel. Following preprocessing, the Artifact Detection Tools (ART) software package (http://www.nitrc.org/projects/artifact_detect) identified motion outliers ($>2\text{mm}$ movement or 3.5° rotation); outlier volumes were individually regressed out of the participant's individual model. Additionally, because of the relatively extensive signal loss typically observed in the amygdala, single-subject BOLD fMRI data were only included in subsequent analyses if there was a minimum of 70% signal coverage in the left and right amygdala, defined using the Automated Anatomical Labeling (AAL) atlas in the WFU PickAtlas Tool, version 1.04 (17). As the current paper additionally examined amygdala-prefrontal connectivity, participants with less than 70% coverage in the prefrontal lobe (defined using the AAL atlas) were removed. Lastly, to ensure participants were engaged in the task, participants were excluded if accuracy on the task was less than 70%. Of the 237 participants in the SAND neuroimaging study, usable fMRI data was available for 167 (70%) participants (Supplemental Table X).

Functional Connectivity Analyses. The generalized psychological-physiological interaction (gPPI) toolbox (18) in SPM12 allows for the simultaneous specification of all task conditions and interactions with the seed region time series in the same individual-level model (82), thus reducing the number of specified models and the overall type I error rate. The left and right amygdala were defined as seed regions using the AAL definition within the WFU PickAtlas Tool (80). Two general linear models at the individual level were constructed (i.e., one for each seed region). The time series of the left or right seed region was entered as the physiological variable in the design matrix, the explanatory variables for each of the five conditions in our task (i.e., facial expressions of fear, anger, happy, sad, and neutral faces) were entered as

psychological variables, and the five product terms between the amygdala seed and conditions were entered as the interaction terms. Three primary contrasts were specified at the individual level: fearful facial expressions interaction term > baseline, angry facial expressions interaction term > baseline, neutral faces interaction term > baseline.

Statistical Analyses

Reproducible code is available (<https://osf.io/rct6q/>). Data from the nationwide sample is publicly-available (<https://opr.princeton.edu/archive/>); restricted access is required for some components (e.g., geographical identifiers). Data from the neuroimaging subsample is also available (https://nda.nih.gov/edit_collection.html?id=2106). All steps in the modeling framework accounted for maternal marital status at birth (i.e., to account for the sampling design) and state fixed effects at age 15 (but city of birth for the neuroimaging sample).

SPM12 (Wellcome Department of Cognitive Neurology, London, UK) was used for all neuroimaging analyses. Fearful, angry, and neutral faces versus baseline contrasts from individual level models were used in random effects group-level general linear models to evaluate the associations between neighborhood constructs and task-dependent amygdala-prefrontal connectivity. These models assessed whether gun violence/collective efficacy was associated with the difference in connectivity between conditions (or the difference in slopes) and, second, whether the association between gun violence and changes in amygdala-prefrontal connectivity were moderated by collective efficacy. Covariates were entered in a stepwise manner: (1) city-fixed effects (i.e., 2 dummy codes for Toledo & Detroit), maternal marital status at birth, youth race-ethnicity, youth gender, pubertal development, # gun violence incidents within 1-mile of the child's home at the core age 15 visit / collective efficacy; (2) collective efficacy / # gun violence incidents; (3) family income and Census-derived neighborhood

disadvantage; (4) collective efficacy X # gun violence incidents interaction. The PFC mask was defined by Brodmann's areas 9 (dorsolateral), 10 (dorsomedial), 11 and 47 (orbitofrontal), 24 and 32 (dorsal anterior cingulate), and 25 (subgenual cingulate), using the WFU PickAtlas Tool, version 1.04 (78). We used this broad PFC mask to: (1) compare our results to existing studies that used different definitions of the mPFC (79, 80) and to broaden the PFC regions examined, and because (2) the seven Brodmann's Areas we identified have each been shown in non-human primate neural tract-tracer studies to be structurally connected to the amygdala (81, 82) and have been linked structurally to the amygdala in the current sample (83). Only ipsilateral connections between the amygdala and PFC were examined (e.g., left amygdala – left PFC), because neural tracer studies in non-human primates suggests that first order amygdala connections are primarily ipsilateral (82).

Multiple comparisons were corrected using the 3dClustSim program (19) in AFNI (20). Consistent with recommendations (19), we implemented the spatial autocorrelation function (i.e., the `-acf` option) to model the spatial smoothness of noise volumes. Group-level smoothing values (left amygdala: $x = 0.55$, $y = 6.46$, $z = 13.48$; right amygdala: $x = 0.56$, $y = 6.44$, $z = 13.48$) were estimated from a random 10% of participants' individual-model residuals, using the program 3dFWHMx. 3dClustSim uses a Monte Carlo simulation to provide thresholds that achieve a family-wise error (FWE) correction threshold of $p < .05$ within the prefrontal mask ($k = 22$).

Figure S1. Frequency of past year deadly gun violence exposure within 1 mile of the child's home and associations with socioeconomic resources and youth behavioral outcomes

Note. Histograms of past year exposure to deadly gun violence within 1 mile of the child's home and associations with study variables in the (A) overall Fragile Families and Child Wellbeing Study, and (b) the Study of Adolescent Neurodevelopment

Figure S2. Implicit emotion face processing task

Participants were asked to complete an event-related implicit emotion face processing task. The task included 100 trials, 20 each of the following facial expressions: angry, fearful, sad, neutral, and happy. Faces from the NimStim set (13) were counterbalanced for gender and race (European American and African American). Total task time was 8.75 minutes.

Table S1. Associations between past year gun homicides within 1 mile of home and youth antisocial behavior at age 15 in the Study of Adolescent Neurodevelopment

	Model 1		Model 2		Model 3	
	B (SE) [95% CI]	β	B (SE) [95% CI]	β	B (SE) 95% CI	β
# past year gun homicides	0.053 (0.025) [0.004, 0.101]	0.159*	0.057 (0.028) [0.001, 0.112]	0.171*	0.046 (0.025) [-0.005, 0.096]	0.138†
Neighborhood collective efficacy	-0.022 (0.006) [-0.035, -0.010]	-0.234***	-0.023 (0.006) [-0.036, -0.010]	-0.239***	-0.026 (0.006) [-0.038, -0.015]	-0.272***
Pubertal Development Score	-0.130 (0.109) [-0.344, 0.085]	-0.095	-0.130 (0.109) [-0.346, 0.085]	-0.095	-0.067 (0.098) [-0.261, 0.126]	-0.049
Female	-0.080 (0.130) [-0.337, 0.177]	-0.049	-0.083 (0.131) [-0.342, 0.176]	-0.051	0.010 (0.119) [-0.225, 0.242]	0.005
Family income-to-needs ratio			-0.010 (0.029) [-0.067, 0.048]	-0.026	-0.002 (0.026) [-0.050, 0.053]	-0.004
Neighborhood disadvantage			-0.007 (0.016) [-0.038, 0.024]	-0.040	-0.020 (0.015) [-0.049, 0.008]	-0.117
Age 9 externalizing					2.35 (0.294) [1.77, 2.93]	0.484***

Note. $223 < N < 226$. Linear regression models with a multi-informant measure of antisocial behavior as the dependent variable. Antisocial behavior was log-transformed so that unstandardized B coefficients can be interpreted as % change for every additional gun violence incident within 1-mile of the child's home. All models covary for maternal marital status at birth and age 15 state fixed-effects, due to the sampling frame of the study, and youth racial-ethnic group, due to disparities in gun violence exposure. Not shown in the table, collective efficacy did not moderate the association between past year gun violence exposure and youth delinquency ($p > .10$). † $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Table S2. Associations between past year gun homicides within 1 mile of home and youth delinquency outcomes at age 15 in the nationwide Fragile Families and Child Wellbeing Study

	Model 1		Model 2		Model 3	
	B (SE) [95% CI]	β	B (SE) [95% CI]	β	B (SE) [95% CI]	β
# past year gun homicides	0.026 (0.009) [0.009, 0.043]	0.018**	0.016 (0.010) [-0.004, 0.035]	0.011	0.005 (0.011) [-0.017, 0.026]	0.003
Neighborhood collective efficacy	-0.041 (0.006) [-0.053, -0.028]	-0.029***	-0.038 (0.006) [-0.050, -0.025]	-0.027***	-0.037 (0.007) [-0.051, -0.024]	-0.027***
Early pubertal timing	0.316 (0.075) [0.168, 0.463]	0.225***	0.299 (0.075) [0.153, 0.446]	0.213***	0.268 (0.080) [0.111, 0.425]	0.191***
Late pubertal timing	0.172 (0.082) [0.011, 0.333]	0.123*	0.177 (0.082) [0.016, 0.338]	0.126*	0.161 (0.089) [0.013, 0.335]	0.115
Female	-0.481 (0.062) [-0.603, -0.360]	-0.343***	-0.491 (0.062) [-0.612, -0.369]	-0.349***	-0.446 (0.067) [-0.578, -0.315]	-0.318***
Family income-to-needs ratio			-0.069 (0.017) [-0.101, -0.036]	-0.049***	-0.077 (0.019) [-0.114, -0.040]	-0.055***
Neighborhood disadvantage			0.007 (0.008) [-0.009, 0.023]	0.005	0.003 (0.009) [-0.014, 0.021]	0.002
Family violence			0.205 (0.062) [0.083, 0.326]	0.146***	0.160 (0.067) [0.029, 0.292]	0.114*
Age 9 externalizing					0.028 (0.005) [0.019, 0.037]	0.020***

Note. 2,973 < N < 2,460. Negative binomial regression models with youth self-reported delinquency as the dependent variable. Standardized β estimates were calculated as the unstandardized beta estimates scaled by the base rate of delinquency (i.e., sample mean); thus, β values can be interpreted as % change in average delinquency for every 1-unit increase in the predictor. All models covary for maternal marital status at birth and age 15 state fixed-effects, due to the sampling frame of the study, and youth racial-

ethnic group, due to disparities in gun violence exposure. Not shown, collective efficacy did not moderate the association between past year gun violence exposure and youth delinquency ($p > .10$).

* $p < .05$; ** $p < .01$; *** $p < .001$.

Table S3. Sources of data loss in the fMRI analyses

	Number lost	Participants with data
Original sample		237
Sample with imaging data		
- Refused MRI	8	
- Exceeded MRI table weight limit	5	
- Medical restriction	2	
- Braces	12	
- Risk of pregnancy	1	
- Endorsed metal in body	1	
- Excluded for diagnosis of Autism Spectrum Disorder	2	
- Incomplete fMRI data	3	
- Pilot version of faces task	2	
Total lost	36	201
Sample with usable imaging data		
- Low amygdala coverage (< 70% left or right amygdala)	7	
- Low prefrontal cortex coverage by visual inspection	4	
- Distortion on functional scans	4	
- Low accuracy (< 70%)	19	
- Missing behavioral data	3	
Total lost	34	164

Table S4. Associations between collective efficacy, past year gun violence exposure, and right negative amygdala-prefrontal connectivity during fearful face processing

	Past Year Exposure to Deadly Gun Violence	Collective Efficacy
Model		
Youth gender, race-ethnicity, pubertal development score, recruitment city fixed-effects	(-) Right superior frontal gyrus (BA10); (x,y,z) = (18,66,22) $k = 22, T = 3.82$	(+) Right medial superior frontal gyrus (BA9); (x,y,z) = (-8,42,20) $k = 164, T = 4.48$
+ collective efficacy / gun violence exposure	<i>no suprathreshold clusters</i>	(+) Right medial superior frontal gyrus (BA9); (x,y,z) = (-6,46,20) $k = 161 T = 4.43$
+ family income-to-needs ratio, Census-derived neighborhood disadvantage	<i>no suprathreshold clusters</i>	(+) Right medial superior frontal gyrus (BA9); (x,y,z) = (-6,46,20) $k = 164, T = 4.47$

$N = 164$. k = cluster size; T = peak voxel extent threshold. Six linear regression models (two predictors, either past year exposure to deadly gun violence or collective efficacy; each with increasingly stringent covariates, as listed in the leftmost column) with right negative amygdala – prefrontal connectivity during fearful face processing. Analyses were conducted within the MATLAB toolbox SPM12 (Wellcome Department of Cognitive Neurology, London, UK). Collective efficacy was measured as a sum of two 5-item youth-reported measures of social cohesion and informal social control (2). Past year deadly gun violence was measured as the number of incidents that occurred within 1-mile of the child's home in the year before the age 15 visit of the original study protocol. Suprathreshold clusters were corrected for multiple comparisons across the entire right prefrontal mask (composed of Brodmann's areas 9, 10, 11, 47, 24, 32, and 25) at a family-wise error (FWE) correction threshold of $p < .05$ using a voxel-wise threshold of $p < 0.001$ (minimum cluster size $k = 22$).

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