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Spatial accessibility to gun violence exposure on walkable routes to and from school

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ABSTRACT

This study investigates the spatial accessibility of gun violence exposure along walkable routes to and from schools in Englewood, Chicago. Focusing on both direct and indirect forms of gun violence, the study uses acoustic detection technology to quantify the cumulative burden of gun violence exposure potentially encountered by students during their commute to and from school. We examined the spatial distribution of shooting incidents in proximity to schools using network-constrained kernel density estimation, secondary spatial analysis, and rapid realistic routing. G-function analysis revealed that shooting incidents cluster along streets, including safe passage routes, near schools. An average of 1.30 and 18.06 gunshots were reachable within 5- and 15-min commute times in the morning and afternoon, respectively Our findings underscore the urgent need to reframe the narrative around ‘school gun violence’ to consider exposures that occur in proximity to school boundaries to more effectively reduce violence exposure for youth who walk to school in violence-prone neighborhoods.

“Outside their homes, the sound of gunshots is common.” This quote was taken from a 2021 NY Times article describing the epidemic of gun violence in Chicago neighborhoods.

1. Introduction

School gun violence exposure is a significant public health crisis in the United States. In 2022, the National Center for Education Statistics (NCES) reported 188 school shootings with injuries or fatalities—the highest annual count on record (Keierleber, 2023). The 2021-22 school year alone saw a 124% rise in school shootings compared to the previous year, marking the highest numbers since 2000. Exposure to school gun violence is strongly linked to poor academic and social outcomes, including lower scores on standardized math and English tests, increased absenteeism, decreased enrollment, and lower graduation rates (Beland & Kim, 2016). Given the scale and severity of this issue, schools have become sites of violence exposure that shape students’ experiences, expectations, and long-term outcomes, particularly for youth in high-crime neighborhoods (Barboza-Salerno & Meshelemiah, 2023).

Developing effective school violence prevention policies requires a thorough understanding of students’ increasing exposure to shootings—whether through hearing, witnessing, or direct victimization—that profoundly shapes their experiences and outcomes, especially in light of research showing that gun violence frequently clusters near schools. For instance, a study in Boston, Massachusetts, found that the average distance from a school to a nearby shooting was only 0.35 km, with 56% of schools having experienced at least one shooting within a 400-m radius—a mere 5-min walk (Barboza, 2018). A comparable study from Compton, California, provided compelling evidence that gun violence clusters along walkable routes near schools. This study reported that most schools had at least one shooting incident within a 5-min walk; 37.8% had incidents occurring closer than 400 m; and approximately 250 incidents occurred within this short distance (Barboza-Salerno & Meshelemiah, 2023). Similarly, research on mass school shootings reveals that these incidents also tend to occur within half a mile of the nearest school, with most incidents happening within a 0.3–0.4-mile range (Sen-Crowe et al., 2022). Kravitz-Wirtz and colleagues documented the prevalence of gun homicide exposure within the general youth population, revealing significant racial and socioeconomic disparities. Their research found that between 2% and 18% of youth lived within 600 m of a gun homicide occurring in the past year, with those percentages increasing to between 3 and 25% within 800 m and 5–37% within 1300 m (Kravitz-Wirtz et al., 2022). Black and Latinx youth were 3–7 times more likely than white youth to experience a gun homicide near their homes in the past year and faced such events more

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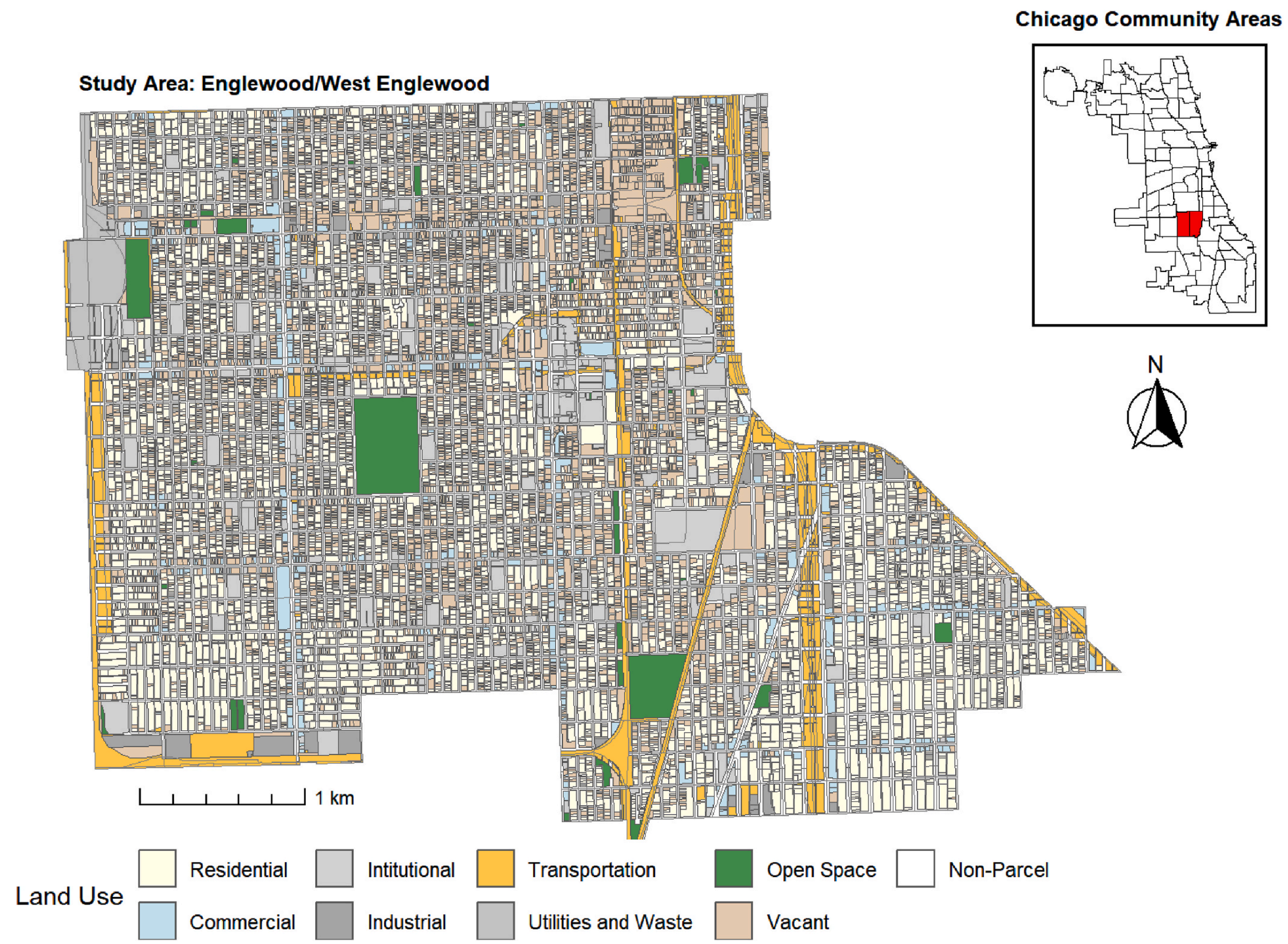

Fig. 1. Land use patterns in the Englewood-area of Chicago downloaded from the Chicago Metropolitan Agency for Planning (CMAP) website (https://datahub.cmap.illinois.gov/). Data were recoded in R using the classification scheme provided by CMAP (https://cmapgis.maps.arcgis.com/home/item.html?id=9ff569e9a5f54f098c38d3b8003c7888).The area is 43% residential (single-family housing and multi-family housing units), followed by vacant lots (24%) and green spaces (5%). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

recently and at closer distances. Additionally, youth in high-disadvantage neighborhoods had a much higher probability of exposure to gun violence than their peers in more affluent areas - youth living in disadvantaged neighborhoods had a probability of gun violence exposure that was 0.50 higher compared to those in more affluent neighborhoods.

Youth are primarily exposed to indirect gun violence in their immediate communities, neighborhoods, or near schools (Holloway et al., 2023). Indirect exposure to gun violence presents unique developmental risks, significantly impacting the mental health of children and adolescents (Foster & Brooks-Gunn, 2009). Proximity to gun violence is linked to an increased risk of post-traumatic stress symptoms, physical disabilities, substance use, suicidal behaviors, and externalizing disorders, including aggression, conduct disorder, and impulsivity (Harper, 2023; McGee et al., 2017). In one study, a nearby gun homicide was associated with elevated anxiety symptoms among adolescents, with differences observed based on the distance to their home or school (Christine Leibbrand et al., 2020). Even among very young children, gun violence exposure has been associated with acute mental health symptoms, increased stress, psychological disturbances, and maladaptive coping behaviors (Theall et al., 2017; Travers et al., 2018). Community violence exposure has broader physical health consequences that extend into adulthood. Higher rates of indirect gun violence exposure during adolescence—such as witnessing or hearing gunshots—have been linked to asthma, obesity, smoking, sleep disorders, physical inactivity, and hypertension later in life (Ford & Browning, 2014; Semenza & Stansfield, 2021).

“School gun violence” is defined as an incident in which a gun is fired on school property, a bullet hits school property for any reason, or an individual suffers a bullet wound *regardless of the time of day,* number of victims, or the motivation behind the shooting (CHDS School Shooting Safety Compendium, n.d.; Kolbe, 2020). Nevertheless, we know very little about direct and indirect violence exposure during travel times before and after school. This is significant as research has shown that children living in the most disadvantaged environments, such as those in poverty, are more likely to walk to school (Su et al., 2013). A qualitative study conducted by Meyer and Astor (2002) found that children and parents in high-crime, high-poverty neighborhoods fear death, violence, and gang activity along school routes. Other research shows that Black and Brown youth who live in economically disadvantaged areas are disproportionately affected by gun violence both in and around their schools (James et al., 2021). However, few studies have systematically examined gun violence near schools during commute times, when children are most likely present, despite the significant risks to their physical and mental health. Thus, more research is essential to understand the cumulative impact of both direct and indirect gun violence exposure near schools—particularly in socio-economically deprived areas with higher levels of violence—and to develop interventions that

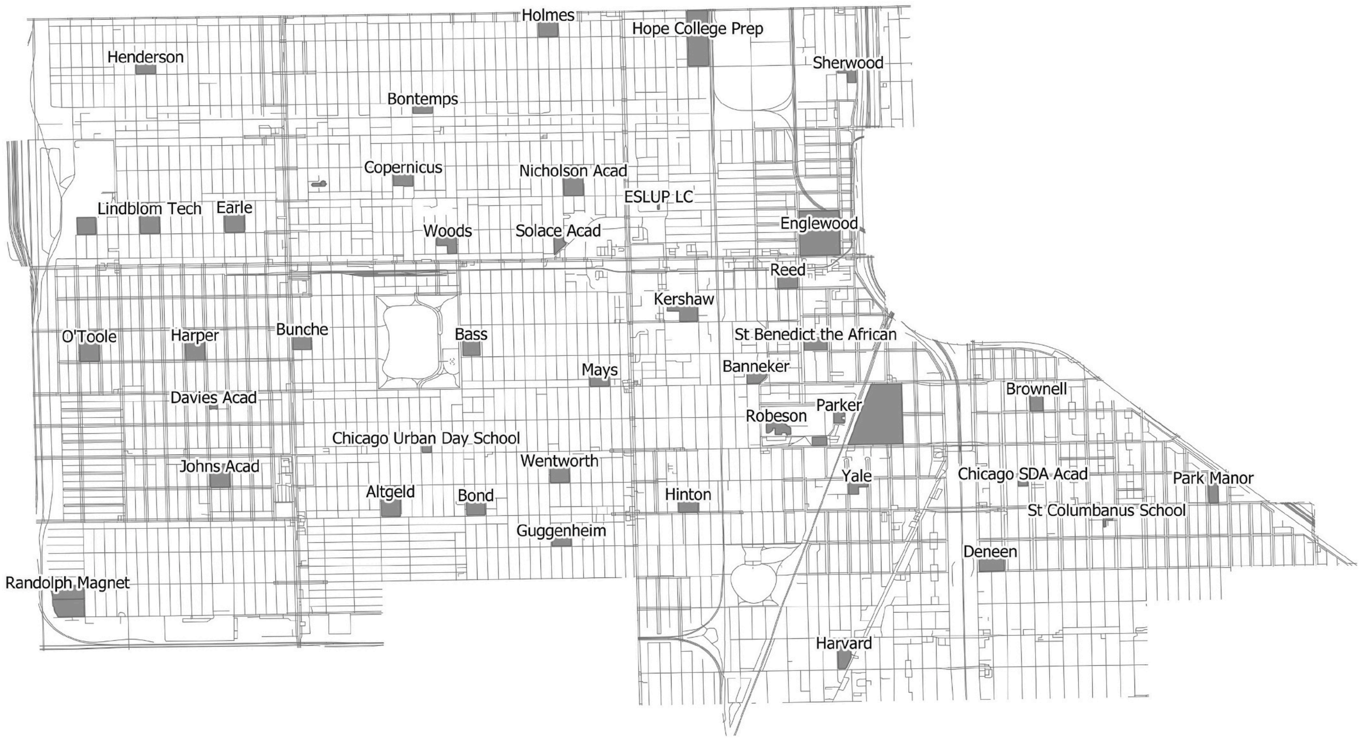

Fig. 2. Englewood Public School Boundaries (grey) overlaid onto the walkable street network. The street network was thoroughly cleaned using the *sfnetworks* package in R. The composition of streets is characterized by a series of square or rectangular blocks indicative of a grid-like layout.

protect students from violence both on school grounds and during their commutes.

1.1. Present study

This paper contributes to the burgeoning research on indirect gun violence, which is a growing subfield, especially as it pertains to youth who attend schools in socioeconomically deprived neighborhoods with high levels of violence exposure. We fill the gaps in existing research in several ways. First, we measure both direct and indirect gun violence exposure rather than focus on injury or death using crime incident data from police reports. Second, we use computational network strategies to identify dangerous streets and routes near schools in one of the most violent neighborhoods in Chicago - Englewood. Third, we measure spatial accessibility to gun violence by examining how much gun violence is reachable within certain walk times conditioned by the unique land use patterns and street layout in Englewood. We address the following research questions: (1) Does gun violence exposure cluster during the morning and afternoon commute along the walkable street network in Englewood, Chicago, and if so, at what spatial scale?; (2) Does the spatial distribution of gun violence exposure vary within 100–400 m of school during morning and afternoon commutes?; (3) How much violence exposure is accessible, on average, within 5- and 15-min travel times by foot during the morning and afternoon commute?; and (4) How much gun violence exposure characterizes the SPP routes near school during the morning and afternoon commute?

2. Methods

2.1. Setting

This study focuses on a community area in Chicago called Englewood, located on the city's south side (see Fig. 1). In 2020, the population was around 24,369, within 3000 square kilometers. Over the past two decades, Englewood experienced a population decline of about 40% (Chicago Metropolitan Agency for Planning, 2022). Englewood is primarily residential, consisting of a mix of single-family housing (25%), multi-family housing (18%), and commercial areas (5%), especially around significant intersections (Fig. 1). The neighborhood also has several vacant lots (24%) and a few green spaces (5%) (Miller, 2022). An average of about 3000 vehicle miles are traveled per household per year, less than the city of Chicago. Almost half of Englewood residents live in households without vehicular access, leaving residents heavily dependent on public transit and walking. According to CMAP, 100% of the population of Englewood resides in highly walkable areas. Englewood is 94.6% Black and ranks 206/225 on median income across Chicago (The Demographic Statistical Atlas of the United States - Statistical Atlas, n. d.). In Englewood, 15.4% of the population aged 25 years or older have an associate degree or higher (compared to 47.7% for Chicago), and about 63% of those aged 20–64 participate in the workforce. We chose Englewood, Chicago based on our analysis of over 57,000 incidents of fatal and non-fatal gun violence in the city that occurred between 2014 and 2022. On average, there were approximately 1.63 fatal incidents (=88/9/6) and 9.33 nonfatal incidents of gun violence among youth between 0 and 19 every two months during this period (See Supplementary Fig. 1). In 2022, more children were shot in Englewood than any other neighborhood in Chicago, making it among the most dangerous places in the United States for children to live (See Supplementary Fig. 2). The Englewood area accounted for about 10% of all gun violence that occurred in the city in 2022 (See Supplementary Fig. 3).

2.2. Measures

Gun violence exposure. Gun violence exposure measures incidents of confirmed gunfire within the Englewood area as detected by acoustic technology, providing the location, time, and frequency of gun discharges during specific timeframes. It is a measure of both direct and indirect gun violence. Confirmed gunfire incidents are detected via an algorithm that analyzes the recorded sound and determines whether it was gunfire or another loud noise, such as construction or fireworks. If

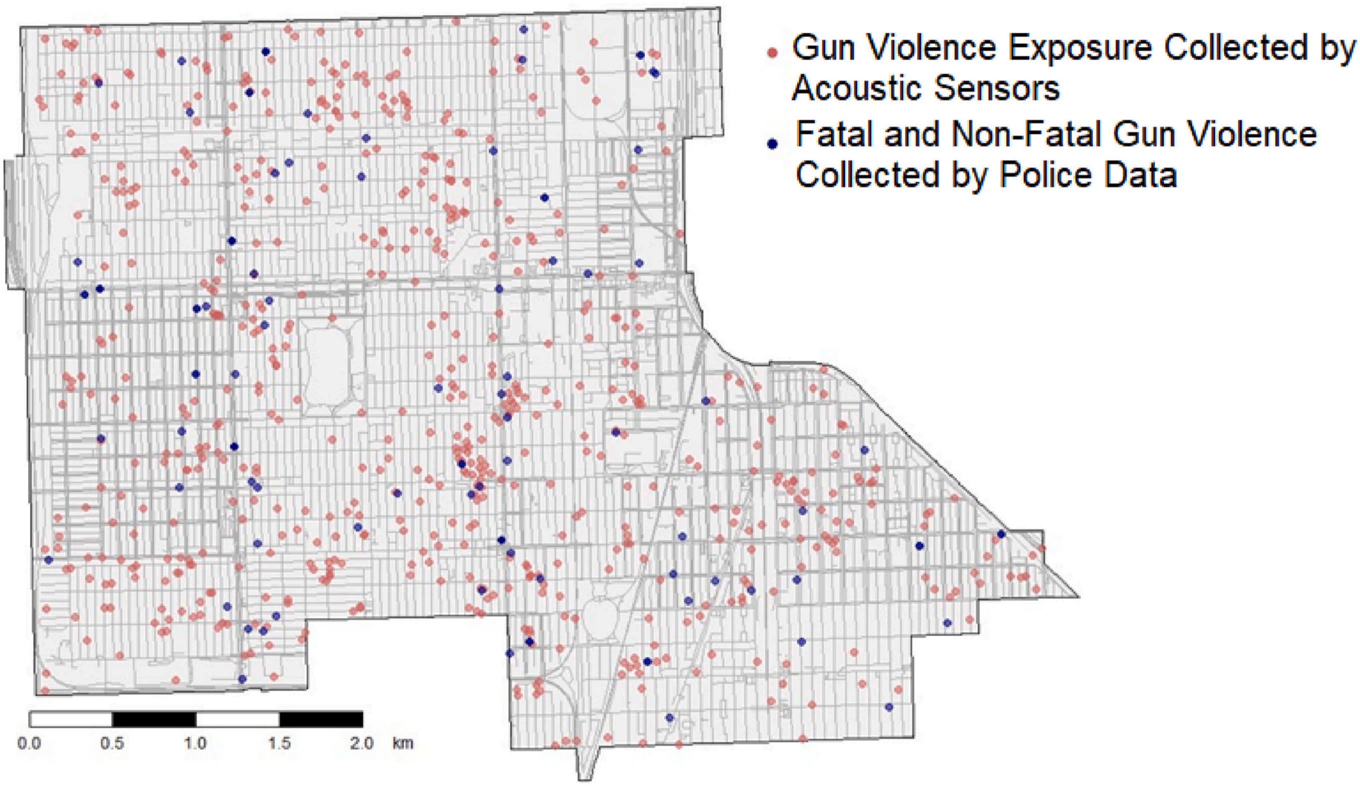

Fig. 3. Spatial distribution of police incident data on fatal and nonfatal gun violence (blue; $N = 101$) and gun violence detected from acoustic sensor technology (red; $N = 610$) during SY 2021-22 for times when school was in session, overlaid onto the walkable street network in Englewood, Chicago. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

gunfire is confirmed by dispatch centers, relevant information (including time, location, and a recording of the incident) is provided to the police so they can respond. The use of acoustic technology offers several advantages over police data. While it does not directly capture the full scope of indirect violence exposure, it is a critical tool for identifying and analyzing areas affected by indirect gun violence (such as hearing a gun being fired). Furthermore, acoustic detection compensates for the underreporting of gun violence common in crime reports, such as those collected during a 911 call (Carr, 2016). Acoustic detection also provides more accurate and granular information, particularly useful in areas where trust in the police is low. Any concern about the use of acoustic technology (few arrests made, placement in high crime areas, increases in racial profiling, and failure to prevent injury, among other things) is irrelevant to our study because we are only using the data to detect gun violence exposure in places where the sensors are located (i.e., Englewood). We downloaded acoustic detection data on firearm discharges from the Chicago open data portal. We eliminated all cases attributed to sounds other than gunfire. We used the Chicago Public School (CPS) calendar for the 2021–2022 school year to remove all days students were absent (e.g., due to a holiday, teacher conferences, and other times school would not be in session). The morning commute was defined as the period from 6 to 9 AM, and the afternoon commute was defined as the period between 3 and 6 PM.

Walkable Street network. The walkable street network is defined as the accessible pedestrian street network within the Englewood School District, including streets identified from OpenStreetMaps data and filtered to include only walkable roads. We downloaded the street network data from OpenStreetMaps (OSM; OpenStreetMap contributors, 2024) using the OSM extract package in R (R Core Team, 2020) with the *geofabrik* provider. We created an extract of OSM data corresponding to the Englewood School District using the BBBike.org website (https://extract.bbbike.org/). We converted the extract into a GeoPackage file and cropped it to the Englewood neighborhood before processing (see Supplementary Fig. 4). We selected the walkable roads using OSM tags detailing access restrictions on roads used for routing purposes.

Safe Passage Program (SSP) Routes. The SPP routes are designated routes created to ensure safer travel for students walking to and from school during the 2021–2022 school year. They correspond to the routes monitored during morning and afternoon commutes and are identified by route numbers. We downloaded shapefiles for the SPP routes for the 2021–2022 school year from the City of Chicago open data portal. The data contains the school identifiers along with the route number.

Census Blocks. We downloaded geographic boundaries corresponding to census blocks from the Chicago open data portal. We used the *sf* package (Pebesma, 2018) in R to calculate the centroid for each block, which served as our origin in the accessibility analysis.

School boundaries. School boundaries refer to the geographic outlines of schools in the Englewood area. We downloaded school boundaries from the Chicago Open data portal and overlaid them onto the street network. The school centroid was the destination in our accessibility analysis. Fig. 2 shows the location of each school in the Englewood and West Englewood area of Chicago overlaid onto the cleaned pedestrian street network. The map shows that a series of square or rectangular blocks indicative of a grid layout characterize the street composition.

2.3. Statistical analysis

We used the network-constrained G-function to analyze shootings along the street network. The G-function measures the distribution of nearest neighbor distances between shooting incidents to examine the distance from each shooting to its closest neighbor. The function *bw.diggle* from the *spatstat* library (Baddeley & Turner, 2005) was used to calculate the optimum bandwidth for kernel density estimation based on the spatial distribution of points. Additionally, 999 simulations were performed to generate 95% confidence envelopes to assess whether the observed spatial patterns significantly differ from a random distribution.

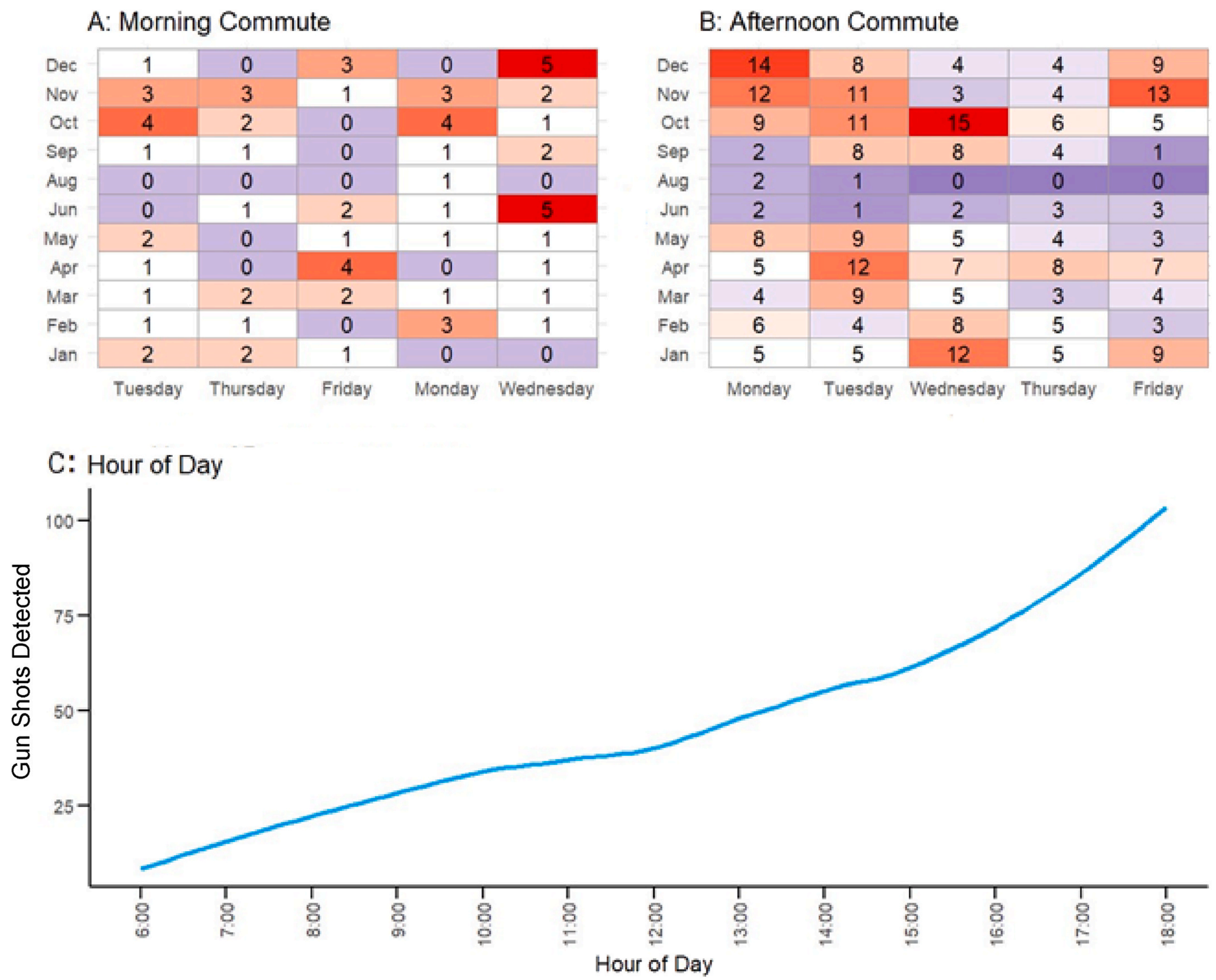

Fig. 4. Temporal distribution of gunshots by month and day of the week during morning (A) and afterschool (B) commute times, and hour of day (C), during times when school is in session. Counts range from lowest (purpose) to highest (red). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Using network constraints is important because most shooting incidents take place on streets, roads, sidewalks, or alleys. In the network-constrained G-function, distances are measured along the network as follows:

$$G_N(r) = \frac{N_{NND} \leq r}{T},$$

where NND = the number of incidents with nearest neighbor distances ≤ r along the network and T = the total number of incidents.

We conducted a network kernel density estimation (NKDE) analysis using the *nkde* function from the *spNetwork* package (Askeland et al., 2021) in R (RStudio Team, 2022) to estimate the density of shootings along the walkable street network. To identify areas with higher concentrations of incidents within a localized area, we used a quartic kernel to calculate the concentration of incidents within 200-m and 400-m radii at specific locations along the street network. By doing so, only events within a 200-m and 400-m radius around each sample point on the network were considered, with closer incidents having a higher influence on the density value than those further away.

Accessibility to shooting incidents along the pedestrian network near schools for a 5- and 15-min commute time (3.8k/hr) was calculated and mapped based on cumulative exposures using the *r5r* package (Pereira et al., 2021) in R. To calculate accessibility, *r5r* constructs routable multimodal networks from OSM data using the travel time matrices as inputs. We calculated travel times matrices using 5- and 15-min time thresholds for morning and afternoon commutes. We set the mode of transportation to 'walking only,' a travel time cutoff between 5 and 15 min, a max trip duration of 20 min, and specified the median, or 50th percentile, travel time estimate. The function returns a measure of the number of shooting exposures accessible from all census blocks (i.e., home locations), considering the median of multiple travel time estimates up to 20 min. Travel time matrices and accessibility measures were spatially interpolated and overlaid onto safe passage routes to school for the 2021-22 school year. The cumulative exposure measure is calculated as follows:

$$A_i = \sum_{j=1}^{n} O_j f(c_{ij})$$

$$f(c_{ij}) = \begin{cases} 1 \text{ if } c_{ij} \langle 0 < \\ 0 \text{ otherwise} \end{cases}$$

where A_i is accessibility at origin i, O_j is the number of gunshot

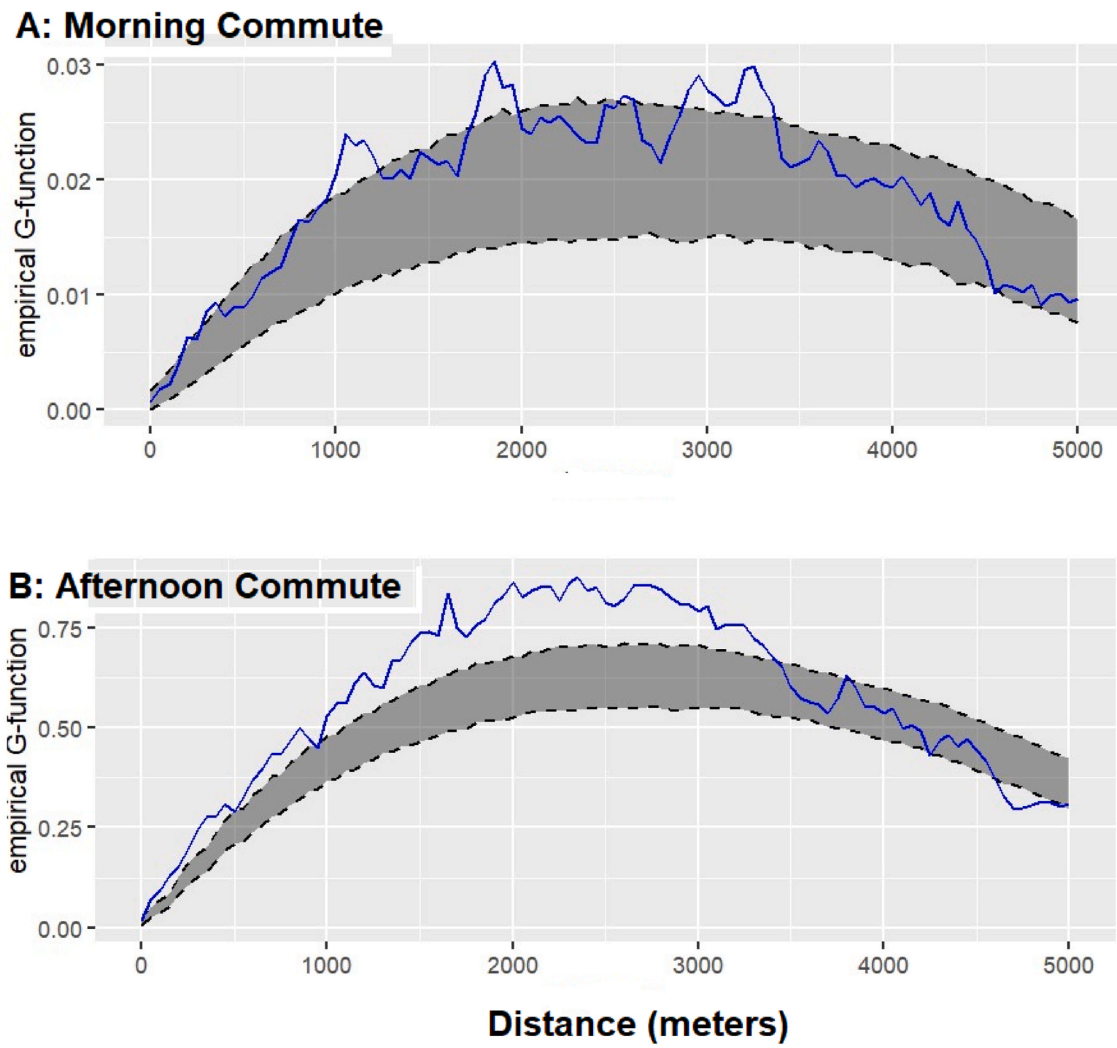

Fig. 5. Empirical G-function analysis of gunshot exposure incidents clustered along the walkable street network in Englewood Chicago during the (A) morning and (B) afternoon commutes.

exposures at destination j, n is the total number of destinations in Englewood, and $f(c_{ij})$ is a binary function that is 1 if the travel time (c_{ij}) from location i to location j is less than or equal to the specified travel time cutoff c, and 0 otherwise.

We created 100–400-m buffers around safe routes and counted the number of shootings within buffers. We calculated all distances in meters from each route to each exposure for the morning and afternoon commutes, respectively. We then calculated each SPP route's mean, standard deviation, minimum, and maximum distance to the gunshots fired for morning and afternoon commutes.

3. Results

Spatial distribution of shooting incidents. In Englewood, acoustic sensors detected $N = 610$ gunshots fired during the 2021–2022 school year when school was in session,12% of the total number of gunshots detected during school hours. Fig. 3 shows the spatial distribution of the gunshots detected from acoustic technology and police incident data overlaid onto the walkable street network in Englewood, Chicago. Of the 610 gunshots detected by acoustic sensors, $N = 320$ took place during the afternoon commute between 3 p.m. and 6 p.m., and $N = 76$ took place on the morning commute between 6 a.m.–9 a.m. The median number of rounds fired was 3 (Q1 = 1; Q3 = 7). We estimated that about 4.58 times more gun violence was detected using the acoustic sensors compared to police data for the period under investigation (after removing N = 147 cases, we calculated (610-147)/101); See Supplementary Fig. 5 for the comparison across the city). Because we are interested in both direct and indirect exposure to gun-related violence, the rest of our analysis uses the gunshot data captured by acoustic sensors only.

Temporal distribution of shooting incidents. Fig. 4 shows the distribution of shooting incidents for the morning (4A) and afternoon (4B) commutes when school is in session. More shootings occurred during the afternoon commute, with the highest counts being on Wednesdays in October and Mondays in December. The lowest counts in August and June are due to the fewer days when school is in session. October and November had the highest overall counts for mornings (11, 12) and afternoon commutes (46, 43). The number of gunshots fired increased throughout the school day and was highest during the afternoon commute (Fig. 4C).

Clustering of shooting incidents along the street network. Fig. 5A and B shows the results from the empirical G-function on the y-axis (blue line) with distance (in meters) plotted along the x-axis up to 5000 m in 50-m increments for the morning (5A) and afternoon (5B) commute, respectively. The shaded grey area represents the confidence interval envelope based on the simulations, with the dashed lines showing the upper and lower bounds. Fig. 5A shows a significant clustering of gunshots during the morning commute at distances between 1000 and 1250, 1750–2000,

Fig. 6. Density of gun violence exposure during the 2021–2022 school year during school hours (7AM-6PM) within a 200m (left) and 400m (right) radius of the street network during the morning (left) and afternoon (right) commutes.

and 2800–3400 m. In Fig. 5B, the G-function line associated with the afternoon commute is above the expected curve for all distances up to 3500 m. This means that gunshots cluster along the street network up to about 3500 m, indicating that certain streets, sidewalks, or intersections experience a high concentration of incidents occurring close together. On the other hand, the G-function shows evidence of inhibition starting at about 4500 m, suggesting that the incidents are more evenly spread out over larger distances. The ratio of observed to expected counts at each distance indicated that 1.67 and 60.2 times more gunshots were detected within 400 m of streets during the morning and afternoon commute, respectively, than would be expected if the gunshots were randomly distributed throughout the area.

The G-function only estimates global patterns of clustering across the entire area. Therefore, we also calculated the density of gunshot exposure to examine the local intensity within 200—and 400—meter buffer zones along the street network. Fig. 6A and B shows the density of gunshot exposures during the morning commute within 200—and 400-m radii of the street network. As shown by the figures, high-density areas (red hue) are concentrated in the central and southern regions of Englewood during both morning and afternoon commutes.

Spatial distribution of gun violence exposure near schools. The distribution of gunshots within 100- to 400-m buffers of schools is shown in Table 1. An average of 0.067-0.422 and 0.222–1.578 gunshots were fired within 100- to 400- meters of school during the morning and afternoon commutes, respectively occurred during the SY2021-2022; 40% and 62.222% of schools had at least one gunshot fired within 400 m during the morning and afternoon commute. Fig. 7 shows the exposure to shootings within 100- to 400-m buffers of school for the morning (Fig. 7A) and afternoon (Fig. 7B) commutes. These figures show that as the distance buffer increases from 100 to 400 m, the number of schools affected by gunshot exposure increases significantly. Furthermore, the clusters of incidents near schools are evident, particularly within 300–400 m and during the afternoon commute (7B).

Accessibility to shooting incidents. Table 1 shows the results from the spatial accessibility analysis. During the morning commute, 0.308 (SD = 0.525, Min = 0, Max = 3.559) and 4.322 (SD = 2.937, Min = 0, Max = 13.99) gunshots were reachable within 5- and 15-min walk times, respectively. During the afternoon commute, 1.300 (SD = 1.533, Min =

Table 1
Gun violence exposure encountered en route to school.

	Mean	Standard deviation	CV	IQR	% schools	Min	Max
Morning							
Buffer length							
400m	0.422	0.543	0.777	1.000	40.000	0	2.000
300m	0.356	0.529	0.673	1.000	33.333	0	2.000
200m	0.111	0.318	0.349	0.000	11.111	0	1.000
100m	0.067	0.252	0.266	0.000	6.667	0	1.000
Afternoon							
Buffer length							
400m	1.578	2.072	0.762	2.000	62.222	0	12.000
300m	1.111	1.721	0.646	2.000	51.111	0	10.000
200m	0.533	1.057	0.504	1.000	28.888	0	5.000
100m	0.222	0.765	0.290	0.000	11.111	0	4.000
Accessibility							
Morning							
5-min walk	0.308	0.525	1.703	0.5021	–	0	3.559
15-min walk	4.322	2.937	0.679	4.402	–	0	13.99
Afternoon							
5-min walk	1.300	1.533	1.1783	1.743	–	0	11.15
15-min walk	18.057	10.650	0.5898	15.775	–	0	55.17

0, Max = 11.15) and 18.057 (SD = 10.65, Min = 0, Max = 55.17) gunshots were reachable within 5- and 15-min walk times, respectively. Each gunshot incident increased the likelihood of another incident occurring within a 15-min walking distance by 1.6 ($t = 17.40$, $p < .001$). To make the results more straightforward, we provide an illustration of a detailed itinerary for our travel time estimate from one school, Mays Elementary, to two randomly selected gunshot incidents (SST-7917159, with a distance, $d = 459$ m from the school) and SST-669290 ($d = 1310$ m) both of which are within the 20-min travel time cutoff (Fig. 8). The figure shows the route one could take from the school to each incident within 5- and 15 min.

Distribution of shooting incidents along SPP routes. Fig. 9 shows the distribution of gunshots during the morning and afternoon commutes overlaid onto the walkable street network, school boundaries, and SPP routes. Overall, there is a startling number of shootings in the area, but also in proximity to schools *and* along SPP routes. The figure shows (1) schools that are closer to streets with a high density of shootings during the commute period regardless of whether the school is located near an SPP route; (2) SPP routes that appear to have higher levels of shooting exposure as shown by the proximity of the high-density streets (red lines) near the SPP routes (black dashed lines); and (3) schools near streets with a high density of shootings but no SPP routes covering them are evident, most notably the area between Wentworth High School and Mays Elementary School in the center of the map. We counted the number of exposures on the SPP routes. In the morning, $N = 27$ gunshots occurred along the SPP routes (Mean = 1.5; SD = 1.38; Range = 0–4) and in the afternoon $N = 109$ gunshots occurred along the SPP routes (Mean = 6.06; SD = 4.14; Range = 1–16).

Table 2 presents descriptive statistics of distances from the gunshot incidents to the closest SPP routes during the school year for both morning and afternoon commutes. Schools with the shortest average distances of shootings to safe routes include Wentworth High School in the morning (1013.84 m) and afternoon (1149.216 m), followed by Bass Elementary (morning: 1260.362594 m, afternoon: 1193.795 m). Wentworth High School had the most shooting incidents along any SPP route for the morning ($N = 4$) and afternoon ($N = 10$) commutes. We overlaid the interpolated spatial accessibility results for 15-min thresholds onto the SPP routes and school boundaries for the morning (Fig. 10A) and afternoon (Fig. 10B) commute. This analysis confirms the presence of many shooting incidents in proximity to both schools (outlined in red) and safe passage routes near schools.

4. Discussion

This paper presents a deeper understanding of the cumulative burden of gun violence exposure on communities using novel geostatistical methodologies. It represents the first study to examine spatial accessibility to gun violence exposure in proximity to schools using rapid realistic routing on a pedestrian network. Our significant findings are that (1) Englewood accounted for 12% of all shootings that occurred during school hours; (2) gun violence exposure is clustered at small distances along the pedestrian street network during the afternoon commute from school; (3) 40% and 62.2% of schools had at least one gun incident within 400 m during the morning and afternoon commute, respectively; and (4) accessibility to gun violence exposure is highest during the afternoon commute, with about 18.1 incidents reachable within 15 min by foot. Our results highlight the chronic gun violence exposure near schools in violence-prone areas, particularly affecting children of color.

Efforts to keep children safe rely heavily on understanding how street layouts can support walking while minimizing exposure to violence. Research has shown that the physical configuration of streets can significantly influence the spatial distribution of crime, including violent incidents. Our findings align with studies indicating that grid-like street patterns, like those in Englewood, tend to have increased violence due to their high connectivity (Boeing, 2021). While these configurations support walking and offer multiple route choices, they also pose greater risks in areas with high crime, as higher connectivity has been associated with greater outdoor violence exposure. Streets with high-choice segments—often main thoroughfares that facilitate movement—attract more foot and vehicle traffic, increasing the likelihood of violent incidents (Summers & Johnson, 2017). In our analysis, the Network Kernel Density Estimation (NKDE) revealed that streets near schools, specifically within 200- to 400-m segments, had higher densities of gun violence. For instance, West 66th Street, located between two schools, showed elevated exposure to gun violence. Enhancing student safety in these environments will depend on targeted violence reduction strategies for high-choice street segments, which could balance the benefits of walkability with the imperative to protect children from violent exposure.

Indirect gun violence exposure, such as witnessing or hearing gunfire, is a traumatic experience (Turner et al., 2019). The amount of indirect gun violence exposure found in this study is consistent with previous research (Bancalari et al., 2022; Bancalari, 2021; Marsh et al., 2024). Indirect exposure to gun violence is a unique developmental risk factor among youth (Leventhal & Brooks-Gunn, 2000) with a broader impact on youth development. Students who experience gun-related violence near school have worse symptoms of anxiety and depression (Christine Leibbrand et al., 2020). Repeatedly hearing reports about gun violence in schools can stoke fear, anxiety, and social contagion (Kolbe,

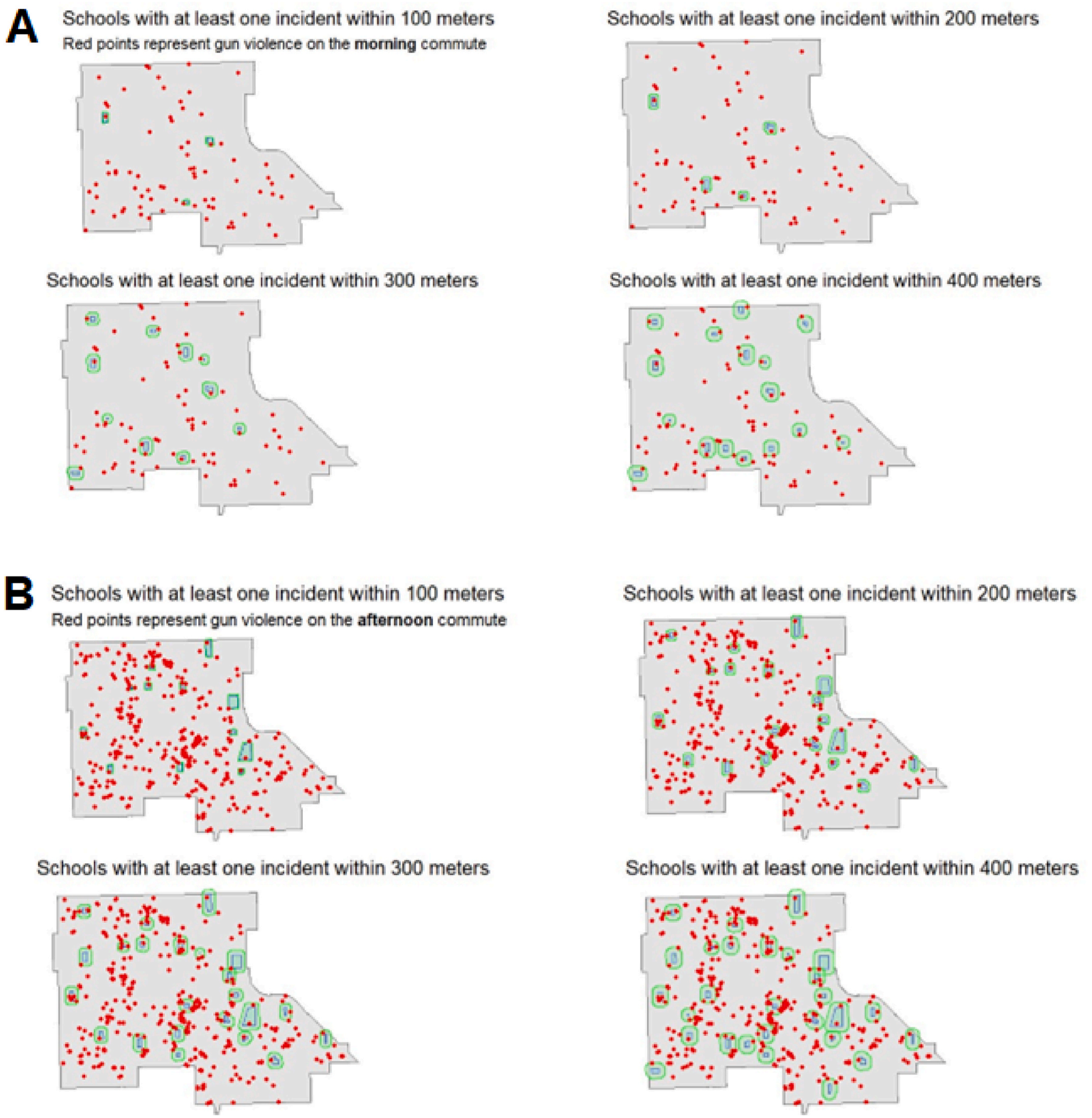

Fig. 7. Shooting incidents within 100- to 400- meter buffers (green) of school boundaries (blue) for the morning (Fig. 7A) and afternoon (Fig. 7B) commutes; 40% and 62.222% of schools had at least one gunshot incident (red dots) within 400 m during the morning and afternoon commute. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2020). Our results should alert lawmakers and policymakers to refocus resources on violence prevention rather than targeting the top 1% of perpetrators in violence-prone areas.

4.1. Implications for public health policy and practice

Our findings suggest that community- or place-based violence interventions near schools in high-violence areas are needed to minimize the negative consequences of violence exposure during school hours and commutes. Policy and practice should address the public health crisis of gun violence in and around schools. By failing to account for indirect forms of gun violence, critical information is excluded, affecting resource allocation and intervention implementation. The School Shooting Safety and Preparedness Act (H.R. 5428, 2021) directs the U.S. Department of Education to collect and report on school safety indicators, including demographics. However, the definition of school gun violence must be revised to include witnessing and hearing gun violence. Existing definitions overlook the *threat* of physical harm or injury, which has the same effect on youth as direct gun violence exposure. Broadening the definition to include shootings within 400 m of a school will be more effective in reducing the impact of indirect gun violence exposure.

Our findings also have implications for programs like the SPP that

Fig. 8. Travel time estimates from Mays Elementary School to two gunshot incidents during school hours within a 5- and 20- minute travel commute by foot. The string starting with letters "SST" is the unique code for the gunshot detected by the acoustic sensor; d = distance; 500-m is an approximate 5 min travel time by foot.

aim to minimize violence exposure on students' commutes. While previous studies found reductions in crime following SPP implementation (McMillen et al., 2019; Sanfelice, 2019), our findings indicate that youth in violence-prone areas are not safe on SPP routes. Importantly, no previous study to date has examined the distribution of gun violence along SPP routes or the neighboring streets, nor has any study measured changes in indirect gun violence exposure following the implementation of the SPP. Anecdotal evidence suggests that youth living in violence-prone areas in the city of Chicago are not safe on SPP routes. For example, in December 2022, students at Benito Jaurez High School staged a classroom walkout to protest gun violence just days after a shooting near their campus left two teenagers dead and two others wounded (News, n.d.). In 2023, a teenager was shot and wounded near North Lawndale College Prep. (Boy, 2023). Both schools were part of the Safe Passage program. Our results give life to the accounts in these news stories and provide empirical evidence that while these routes may be *safer* following the SPP implementation, they cannot be considered *safe*.

Children who must walk to school have increased safety risks that the SPP program may be unable to accommodate. As discussed above, Englewood has a high percentage of persons without access to a vehicle. Studies have shown that students feel safer en route to school if they drive rather than walk (Meyer & Astor, 2002). Previous studies have highlighted that crime, fear of crime, and disorder are significant obstacles to walking and bicycling in communities nationwide (Hino et al., 2021; Kramer et al., 2013). Despite these recommendations, implementing Crime Prevention Through Environmental Design (CPTED) in bicycle and pedestrian policies, safe routes to school, transit, parks, and open spaces in places like Chicago has been limited. To address these concerns, a recent report identified best practices for implementing CPTED in planning streets and public spaces (Jain et al., 2020). The report recommends engaging with community members and providing them with the required skills to effectuate change as a promising way to advance CPTED efforts in highly vulnerable neighborhoods. In the present context, evaluation strategies could engage local youth to evaluate perceptions of safety in and around schools and work with school officials to address the impact of violence on students, including ways to increase academic performance and support mental health.

Educators and school personnel play a critical role in supporting students exposed to gun violence. Trauma-informed approaches focus on minimizing trauma impacts and fostering healing, growth, and change (Avery et al., 2021). In high-violence districts, being trauma-informed requires teachers and staff to extend their roles beyond education, necessitating substantial training. Illinois House Bill 342 mandates the development of a Children's Adversity Index to measure community childhood trauma exposure and requires proficiency in trauma-responsive practices for Professional Education License requirements. Federal regulations like Section 504 and the Individuals with Disabilities Education Act (IDEA) protect the rights of children with disabilities, including those with mental health concerns from community violence exposure. Students exposed to gun violence must receive emotional support, accommodations, and services aligned with their trauma exposure. Legal scholars agree that these experiences constitute a disability under Section 504 and the Americans with Disabilities Act, compromising the Constitutional right to an equal education (Dowd, 2017; Lawson, 2017).

4.2. Limitations and directions for future research

The present findings must be considered in light of the study's limitations. We did not undertake a comparative analysis of gun violence exposure but purposefully selected a high-violence area in Chicago. Future research should replicate our analyses in other areas or regions. Examining gun violence exposure in higher-income areas with larger percentages of White people would be particularly fruitful. Nor did we undertake an evaluation of gun violence exposure before and after implementation of the SPP routes. Therefore, we do not know what the

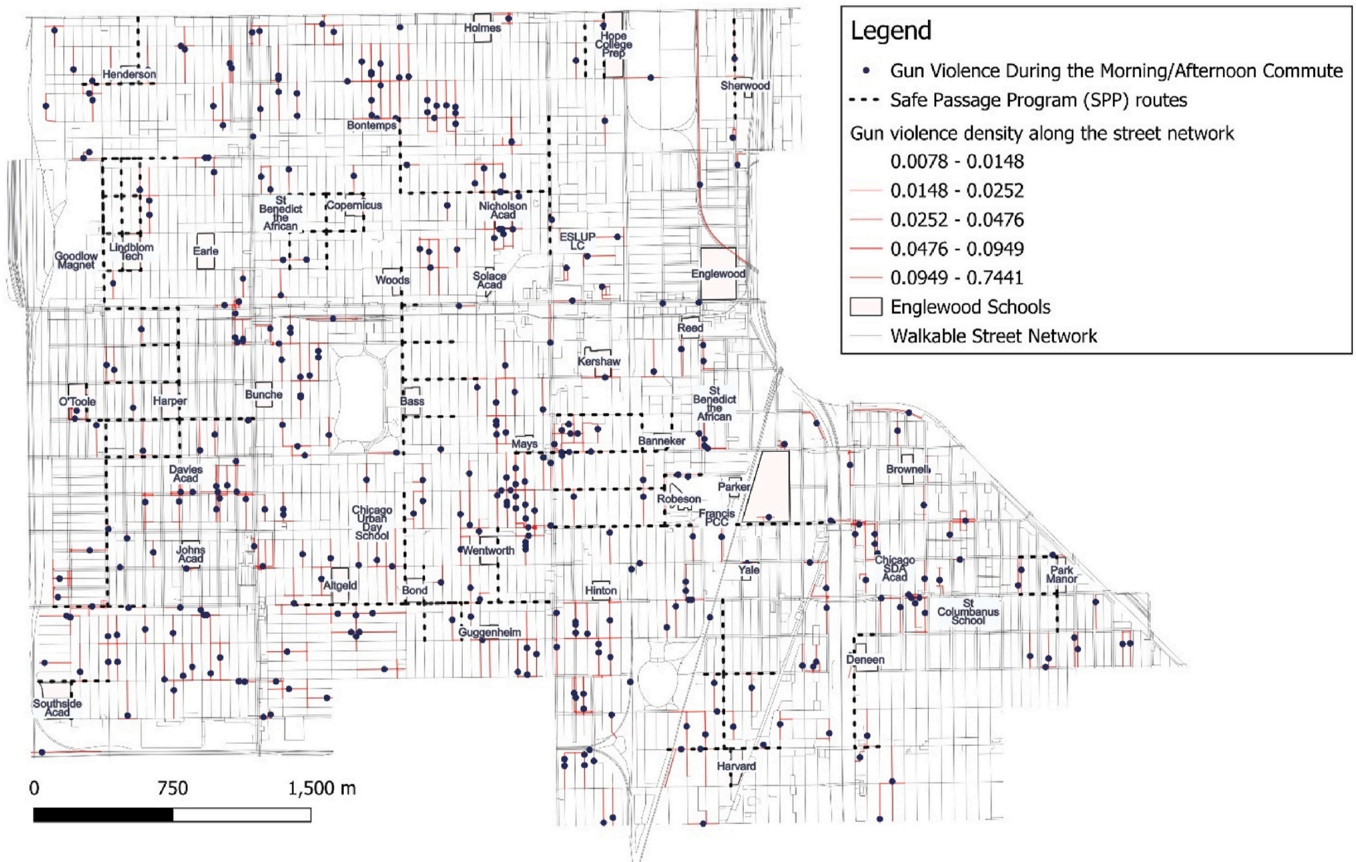

Fig. 9. Englewood Public School Boundaries overlaid onto the walkable street network, acoustic sensor data detecting gunshot locations (blue), and safe routes to school (red -dash). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Descriptive statistics of distances from shooting incidents to closest school SPP route during the morning and afternoon commute among schools with SPP routes.

Route	School	Morning Commute					Afternoon Commute				
		Mean	SD	Min	Max	N	Mean	SD	Min	Max	N
4	Sherwood	2761.051	943.6700	0	4971.842	2	2581.515	875.665	0	4645.768	2
12	O'Toole	1911.702	1225.711	0	4807.220	2	1990.670	1192.423	0	5222.721	12
16	Harvard	1843.017	1138.868	0	4258.620	3	1951.070	1171.122	0	4639.982	6
22	Wentworth	1013.838	789.071	0	2715.664	4	1149.216	793.016	0	3018.775	10
23	Mays	1341.374	732.580	35.165	2915.883	0	1310.063	774.214	35.164	3272.519	16
24	Nicholson	1712.989	915.306	0	3478.257	4	1487.189	909.867	0	3663.436	7
26	Bass	1260.363	738.603	0	3345.590	1	1193.795	748.264	0	3696.275	1
27	Earle	2089.811	1139.157	51.001	4984.135	0	1928.663	1247.458	51.010	5348.460	4
65	Langford	1819.952	971.327	152.105	4272.446	0	1613.657	1058.303	152.105	4595.187	8
89	Harper	1648.108	1027.566	0	4396.966	1	1597.372	1071.464	0	4779.658	7
91	Hope	2582.900	989.280	295.015	4569.189	0	2363.015	952.135	295.015	4191.618	2
114	Bond	1416.338	840.888	0	3090.818	2	1547.88	832.0139	0	3501.253	4
125	Lindblom	2317.691	1186.545	0	5248.197	3	2156.974	1282.137	0	5607.631	4
129	Randolph	2403.694	1265.059	0	4997.880	1	2611.151	1145.500	0	5420.016	3
138	Henderson	2868.368	1249.997	0	5642.360	1	2621.43	1375.465	0	5958.743	7
148	Park Manor	3109.809	1392.036	30.612	5469.116	0	3131.793	1407.089	30.612	5844.248	4
154	Deneen	2431.000	1336.884	0	4934.262	1	2523.363	1327.376	0	5315.602	2
157	Englewood	1270.246	872.987	0	3177.388	3	1294.732	896.565	0	3557.960	11

Notes. Distance is in meters. Not all schools have a SPP route. N = the number of shootings detected along the SPP route. SD = standard deviation.

level of gun violence was along or in proximity to these routes before the program began. Future research should evaluate the effectiveness of the SPP as a violence prevention strategy. We only analyzed one year of data, but gun violence incidents likely fluctuate over time. The reliability of acoustic detection technology remains unknown, with some arguing that it overestimates gun violence. Non-scientific reports suggest its accuracy is between 80 and 97% (Risinger et al., 2024), potentially underestimating firearm discharges in this study. Notably, most arguments against the use of this technology are based on ethical arguments that it is used to over police already vulnerable communities. In this study, we use this data for a different purpose and argue that the misuse of the data does not reduce its utility in capturing indirect gun violence exposure.

In conclusion, this study comprehensively incorporates multiple data streams to address the gun violence epidemic. Addressing the crisis requires a commitment to an integrated approach that includes student

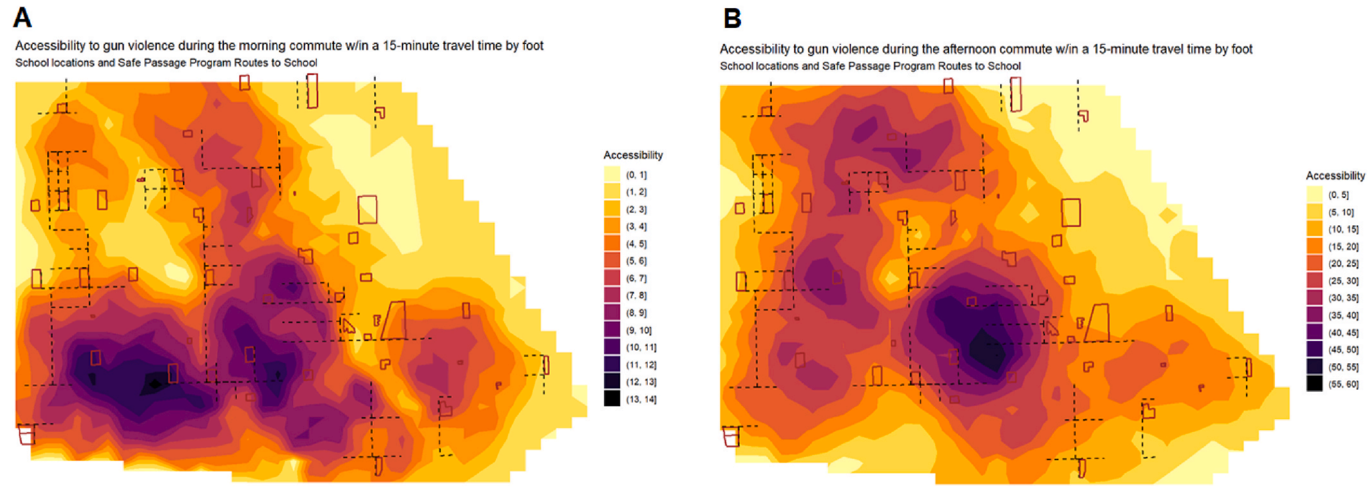

Fig. 10. Interpolated accessibility to shooting incidents in Englewood, Chicago for 15- minute thresholds along SPP routes for the (A) morning and (B) afternoon commute overlaid onto SPP routes and school boundaries. The SPP routes are represented by the black dotted lines. This analysis confirms the presence of high amounts of gun violence exposure in proximity to both schools (outlined in red) and safe passage routes near schools. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

safety, educational reform, and community engagement to tackle systemic issues associated with gun violence exposure in and around schools.

CRediT authorship contribution statement

Gia Barboza-Salerno: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Data curation, Conceptualization. **Sharefa Duhaney:** Writing – review & editing, Writing – original draft, Conceptualization. **Hexin Yang:** Writing – review & editing, Writing – original draft, Conceptualization.

Ethical statement

As this study involved the secondary analysis of publicly available, de-identified data, it was not considered as human subjects research, as defined by federal regulations, and did not require approval from an ethics committee or institutional review board.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2024.101730.

Data availability

Data will be made available on request.

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