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A partially randomized field experiment on the effect of an acoustic gunshot detection system on police incident reports

Jerry H. Ratcliffe[1] · Matthew Lattanzio[2] · George Kikuchi[2] · Kevin Thomas[2]

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Abstract

Objectives To examine whether the introduction of an acoustic gunshot detection system (AGDS) allied to CCTV cameras increased the frequency of confirmed incidents of shots fired by bringing to notice gunfire events in public places that were not reported by the public.

Methods In a partially block-randomized experimental design, 17 acoustic sensors were co-located with CCTV cameras in a balanced design that matched the sensor camera sites with equivalent control locations. Gunshot-related incidents within 900 ft of both intervention and control sites for 8 months pre- and post-intervention were examined with multilevel negative binomial regression models.

Results After implementation of the AGDS, gunshot incidents increased by 259%; however, there was no significant increase in the number of confirmed shootings.

Conclusions The AGDS did not significantly affect the number of confirmed shootings, but it did increase the workload of police attending incidents for which no evidence of a shooting was found. While awaiting technological improvements and considering the operational goals, police departments may wish to reconsider the current operational plan and objective of an AGDS.

Keywords CCTV · Acoustic gunshot detection · Philadelphia · Experiment · Calls for service

✉ Jerry H. Ratcliffe
jhr@temple.edu

[1] Department of Criminal Justice, Temple University, Gladfelter 525, 1115 Polett Walk, Philadelphia, PA 19147, USA

[2] Philadelphia Police Department, Philadelphia, USA

Introduction

Random gunfire remains a persistent problem in US cities, and technological attempts to understand and address the problem have existed for at least two decades (Mazerolle et al. 1998). While there has been a significant body of research into the science of acoustic gunshot identification (for example, Deželak et al. 2016; Djeddou and Touhami 2013; George and Kaplan 2016; Irvin-Erickson et al. 2017; Luzi et al. 2016; Nguyen and Choi 2017; Ye et al. 2017), little study has been applied to the operationalization of acoustic gunshot identification. As Mazerolle et al. (1998) report, acoustic gunshot detection systems (hereafter AGDS) emerged in the 1990s as a way to detect gunfire and rapidly indicate the location to police, hoping that a rapid response from police might increase the chances of arresting the perpetrator and improving the survivability of the victim. AGDS are a surveillance mechanism in a situational crime prevention context (Welsh et al. 2017). They aim to increase *general* deterrence due to the suggestion of more likely police intervention should an incident occur and *specific* deterrence if investigators can use video surveillance footage to capture an offender. AGDS can be standalone units or, as in this article, extended to interact with a CCTV camera surveillance system. Although "rapid response seems to make intuitive sense as a strategy to apprehend criminals" (Mazerolle et al. 1998, p. 24), it is generally accepted that the rapid response of police does not significantly impact crime levels (Weisburd and Eck 2004; Weisburd and Majmundar 2017). Instead, much of the emphasis regarding AGDS has shifted to operational policing benefits, such as improved resource allocation and community trust (ShotSpotter Inc. 2018).

One study of the ShotSpotter Gunshot Location System (a commercial system owned by SST, Inc.) interviewed representatives from seven agencies that had deployed ShotSpotter for at least 1 year. Officers trusted the system and it enabled a faster response to gunshots, though false positives (system activation from sounds that are not gunshots) were a problem (CSG Analysis 2011). Every agency interviewed thought that the system enabled them to get a better picture of the true level of gunfire in communities, though the research was commissioned by ShotSpotter and the researchers investigated agencies hand-picked by the company.

In an independent study of one experimental area and two (non-randomly selected) control areas in Dallas, TX, the system evaluated by Mazerolle et al. (1998) reduced dispatch time to a random gunfire call by 16% with a modest decrease of about 1 min in the aggregate response time (a 7% decrease). When eight acoustic sensors were studied in the Redwood Village area of Redwood City, CA, police officers preferred using the acoustic system over public calls for service alone, and the system was able to detect and triangulate at least 80% of test firing (Mazerolle et al. 1999). Note that the system performed differently with different types of weapon and was more effective after multiple shots (Watkins et al. 2002).

Gunshot detection systems differ in how they are operationalized. In this article, the AGDS comprises a number of audio sensors located at a street location and electronically tied to an existing public CCTV camera owned by the city and operated by the police department. Like the cameras, the acoustic sensors are frequently attached to lampposts and other street furniture. On detecting a gunshot-type sound, the sensor takes control of its associated camera and pans it in the appropriate direction. The "patrol" function in many CCTV cameras can often mean the camera is facing the wrong direction when an incident occurs. An AGDS can overcome some of this limitation by panning the camera in the correct direction so that investigators can see what is occurring seconds after a shot is fired. Some AGDS route the information to a centralized control center run by the commercial company; however, the system evaluated here automatically controls the associated camera and sends an activation alert to the police department.

In the remainder of the article, we examine the introduction of a 17-sensor pilot AGDS in Philadelphia, PA, USA. The current research was designed to evaluate the impact of the AGDS on police calls-for-service and determine the value of the AGDS to police operations. Where applicable, this short report follows a CONSORT format for reporting randomized trials (Moher et al. 2010).

Methods

Outcomes

After internal police discussion and in line with previous research (Mazerolle et al. 1998), it was determined that the primary research objective would be to examine the impact on operational police workload. We test the hypothesis that the introduction of the acoustic gunshot detection system would be associated with a significant increase in confirmed (locally termed "founded") shooting events.

In the case of a 911 call to a "shots fired" event, if a responding officer does not find any shell casings, victims, witnesses, or evidence of bullet marks upon attending the incident, then the incident will likely be classified as "unfounded" with no further action taking place. If the officer finds any of these indications, the incident is classified as "founded" (and may receive a more serious classification as determined by the situation). Our two outcome measures are therefore the number of incidents and the subset number of founded incidents.

Trial design

The original project design called for a balanced [1:1] block randomized, controlled experiment. Blocked designs are popular in criminal justice evaluations because they generally result in improved statistical power and increase the likelihood that the random assignment process will be successful in creating initial probabilistic equivalence across treatment and control groups (Gill and Weisburd 2013). While this original design plan survived in part, operational realities of installing an AGDS in the urban milieu limited the ability to deploy a full randomization. These were only discovered after the experiment was designed and engineers attempted to deploy the system. This study should be more realistically described as a partially randomized and controlled field experiment, as will be explained.

Participants

The original pilot purchase involved 20 AGDS sensor units using a system called SENTRI. The researchers were given the opportunity to select the CCTV cameras to which the SENTRI sensors were collocated. Participant selection (i.e., CCTV camera site) therefore focused on identifying 40 suitable public street CCTV cameras owned and operated by the city of Philadelphia.

Study setting

Most of the CCTV camera locations in the city are in high-crime areas, and all are located within the boundary of the city of Philadelphia, PA. Philadelphia is the sixth largest city in the USA by population with about 1.5 million residents and comprises 135 $mile^2$ located on the east coast between Washington DC and New York City. Ninety percent of city residents are either white or black (equally split), and about one quarter of the city's population is classified as living in poverty. In 2015, the city had a homicide rate of 17.8 per 100,000 compared to a US rate of 4.9. The use of public CCTV surveillance in Philadelphia dates back to a pilot scheme that commenced in 2006 with 18 cameras (Ratcliffe et al. 2009). Subsequent growth saw the installation of more than 200 cameras by the end of 2011.

Sample size

Sample size was determined by the limited availability of only 20 pilot AGDS sensors; therefore, we identified 40 CCTV camera sites that were matched into pairs using a clustering approach. At the time this project commenced, there were 244 cameras in the city; however, after excluding cameras at Philadelphia International Airport, 216 remained available for selection.

Randomization

K-nearest neighbor statistics were calculated on the 216 camera locations, with weights based on standardized counts of gun crime, socio-economic status, and the percentage of residential land use. Geocoded gun crime data for the city was made available by the Philadelphia Police Department (PPD) and mapped to 800 ft buffers centered on all 216 camera locations. Eight hundred feet was selected as representative of approximately two city blocks, the distance over which it was believed the AGDS would be broadly effective. Violence data were accessed for the year 7 April 2013 to 7 April 2014 and comprised all gun-related homicides, gun-related robberies, gun-related aggravated assaults, and violations of the firearms act that prohibits the public carrying of a gun without a license (range 0–42, mean 12.47). Socio-economic status was determined from an index based on the percent households in a block group where the income is less than $20,000, the percent households where the income is greater than $50,000, a natural log of median house value, and a natural log of median household income (see Taylor et al. 2015). All variables were drawn from 2006 to 2010 American Community Survey estimates. The percentage of residential land use was determined for each camera's 800-ft buffer from publicly available land use zoning data. Socio-economic status and residential land use were included so that areas would be more closely matched on population characteristics and land use as well as gun crime. All data (gun crime, SES, and percentage residential land use) were standardized.

Because of the importance of violence to the strategic objectives of the PPD as well as its relationship to the outcome variables, the influence of gun-related crime was doubled to give it a 50% weighting (with SES and residential land use both weighing 25% respectively). K means analysis was conducted using Stata version 13 (StataCorp 2013) using the *cluster kmeans* command. Parameter settings instructed the software to seek 54 clusters; however, the clustering resulted in some variation. Visual inspection of the camera locations also identified that some optimal camera pairings matched cameras with overlapping viewshed areas. These digital viewsheds were GIS polygons that represented the viewable street areas of each CCTV camera in the city. The viewable area was defined by what could be seen and therefore ignored areas obscured by street furniture, trees, or buildings. The most distant point that it was determined the cameras could show identifiable activity was determined by whether a zoomed camera permitted the reading of a street name sign (see Ratcliffe et al. 2009). Camera pairs were selected such that there was no overlap with other experimental camera areas and some geographic space between control and experimental sites. Randomization within pairs was completed using a random number generator.

Changes to trial design

After the initial list of 20 pairs was passed from the researcher to the city management, some loss of randomization occurred due to operational factors beyond the control of the authors. Some sites were subsequently deemed to be unsuitable for AGDS installation due to technical reasons. In these cases, the treatment and control sites were swapped. In another instance, a camera tied to an AGDS failed, and in another, an errant car driver demolished the pole on which the CCTV camera and AGDS sensor had been mounted. We ended up with 17 paired sites, including eight pairs randomized as planned and five where the originally planned treatment and control had to be swapped. With two pairs of treatment and control sites, a miscommunication occurred with the city management such that the sensors were added to both treatment and control sites. These four sites were matched to their nearest acceptable control location from the kmeans analysis.

With regard to blinding, operational police personnel were not involved in the randomization or decisions regarding reassignment of CCTV camera sites to treatment or control, and operational officers in locations that were not selected for AGDS sensors were not informed that their camera sites had been under consideration. Operational police personnel near AGDS sites only became aware that AGDS sensors were in their district once the system became live and they started to receive AGDS gunshot notifications.

Interventions

The SENTRI sensors were estimated to cost between $15,000 and $20,000 for a single sensor and a one-time installation (Dent 2016). On detecting a possible gunshot, analysts at the PPD's Real Time Crime Center are alerted to view the video feed from the activated camera and determine if the incident is a real shooting and if medical assistance in required (Dent 2016). The city's standing policy on gunshot locating systems mandates that the analyst notifies the police radio system so an incident can be initiated in the police INCT incident database. This can be either confirmed by police (founded) or classified as unfounded, as explained earlier. Unfounded incidents will require no further action, while founded incidents will receive a code from a variety of options in the PPD system that reflects the type of incident and detectives will follow up.

Outcomes

One of the authors maintained a watch over all camera areas in the experiment and recorded (for treatment and control sites) a spreadsheet with all recorded gunfire incidents within 900 ft of study cameras.[1] A specific SQL query captured gunshot events and identified all incidents in the city's INCT database that fulfilled the criteria of being within the project time frame, having a nature code of "gunshot" or "shots," or a disposition of "shooting," or where the number of shooting victims was greater than zero. Two outcome variables were derived from this query: INCIDENTS indicated the total number of gunshot-related events from all sources (AGDS and otherwise) and FOUNDED indicated the number of founded incidents.

Statistical methods

The first implementation of AGDS occurred on 28 December 2015 and post-implementation data capture concluded on 31 August 2016 because the PPD had to reassign the lead analyst. This covered a period of 248 days (a little over 8 months), and so we balanced this with 248 days of data capture prior to implementation, starting 25 April 2015. All incidents were recorded in a spreadsheet by the project's lead analyst. Monthly counts of two outcome variables (INCIDENTS and FOUNDED) were analyzed alongside two dummy variables; *agds* was coded 0 for control and 1 for intervention locations, and a *prepost* variable identified if the time period was prior to the AGDS implementation (0) or after (1). The interaction term (*agds* × *prepost*) represented any effect of the AGDS intervention independent of other variables.

Examination of the monthly count data for all sites (see Fig. 1) showed relatively low event frequencies, and this necessitated collapsing of counts into a single pre-implementation and post-implementation count for each camera ($n = 34$). Negative binomial regression models were initially run in Stata version 15.0 (StataCorp 2017); however, post-estimation statistics indicated significant between-camera variance. Therefore, multilevel negative binomial regression models were employed and are reported below using incidence rate ratios.[2] Because each camera and (where relevant) its associated AGDS sensor had differing levels of crime prior to the study, each camera was modeled with a random intercept at level 2. The two dependent variables are related so statistical significance is set to 0.025 to reflect the increased experiment-wise error rate.

[1] While the preliminary data capture for purposes of the cluster analysis was a distance of 800 ft, for the actual implementation, the effective range of the acoustic sensors was subsequently expanded by 100 ft on the advice of technical specialists familiar with the AGDS.

[2] A likelihood ratio test did not explicitly favor the multilevel model over a single level negative binomial model for the "incidents" outcome; however, because the multilevel negative binomial model was shown to be a significant improvement for the "founded" model (LR test $\bar{\chi}^2 = 4.52, P = 0.017$), it is used here for consistency. There were no substantial differences in outcomes between the models.

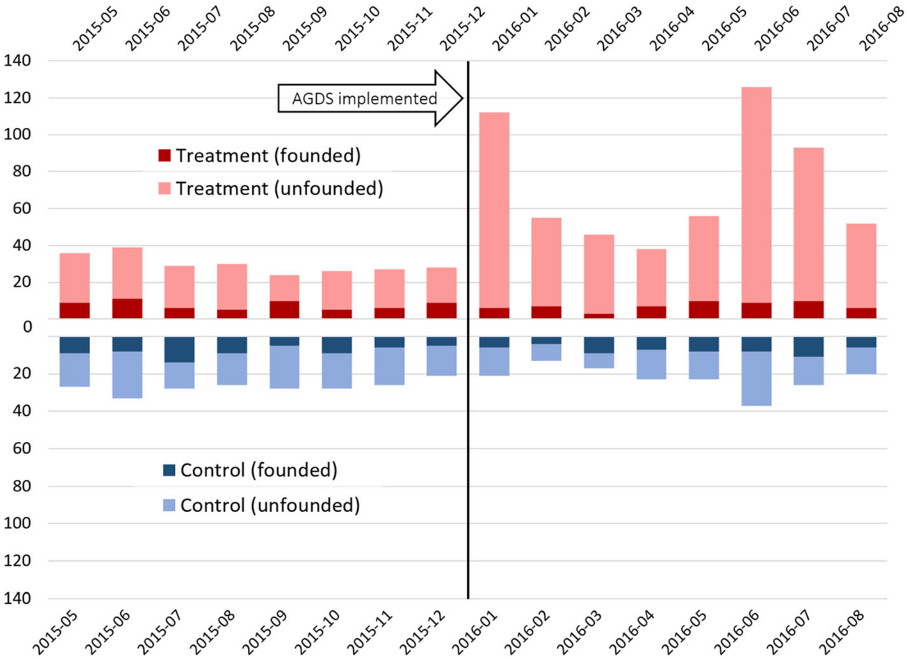

Fig. 1 Monthly gunshot-related incidents by founded and unfounded in treatment and control locations, May 2015 to end August 2016

Results

Controlling for other variables, there is no significant difference between intervention areas (*agds*) and their controls or in the pre- to post-intervention periods of time (*prepost*) (Table 1). The interaction term (*agds* × *prepost*) indicates that the introduction of the AGDS increased gunshot-related incidents over the 8 months post intervention across the aggregated AGDS sites by an estimated 259%, holding other variables constant.

Table 2 shows the multilevel negative binomial results for only the founded incidents. Controlling for other variables, again, there is no significant difference between intervention areas (*agds*) and their controls or in the pre- to post-intervention periods

Table 1 Mixed effects negative binomial results for gunshot-related incidents

Fixed effects	IRR	Std. Err.	Conf. interval	*P*
agds	0.911	0.251	0.531–1.564	0.736
prepost	0.795	0.205	0.480–1.318	0.374
agds × prepost	3.586	1.274	1.787–7.198	0.001*
Random effect				
camera	0.085	0.097	0.009–0.799	

*$P < 0.025$

Table 2 Mixed effects negative binomial results for founded gunshot-related incidents

Fixed effects	IRR	Std. Err.	Conf. interval	*P*
agds	0.880	0.266	0.486–1.591	0.672
prepost	0.847	0.202	0.531–1.351	0.486
agds × prepost	1.180	0.399	0.608–2.291	0.625
Random effect				
camera	0.289	0.153	0.102–0.818	

(*prepost*). The interaction term (*agds* × *prepost*) does not indicate any significant effect of AGDS on the number of founded incidents across all intervention sites, holding other variables constant.

Discussion

Limitations

As Farrington et al. (2002, p. 14) note "a randomized experiment has the highest possible internal validity because it can rule out all threats to internal validity, although in practice differential attrition and contamination may still be problematic." This project started with the intent of being a fully randomized experiment; however, it is more realistic to describe the experiment as partially randomized, and readers should be cautioned appropriately regarding this degradation of research methodological quality. It would have been preferable to continue data collection for a longer period, but in dynamic policing environments where changing crime levels demand support from a limited pool of qualified analysts, an ethical decision was made to end data collection so that personnel could be reassigned.

Interpretation

Given the 259% increase in incidents was not matched by a significant increase in founded events, this suggests a substantial increase in events where there was no independent evidence of gunfire. Police workload increased but without an associated increase in founded incidents. In some cases, it was possible that the gunfire occurred within audible range of the system but out of visual range of the cameras, such as inside a residence. It is also possible that gunfire originated in a moving vehicle. Shell casings are difficult to find when the exact location of the shooting is not known or in inclement weather. We therefore caution that just because an incident was administratively classified as unfounded, it does not follow that gunshots did not occur and it should not be assumed that the AGDS did not correctly identify a gunshot.

False indications are also a possibility. As Dent (2016, p. 1) notes "False alarms happen. In the first couple of months, they accounted for about 80-90 percent of the sounds registered. What can set it off? Slamming manhole covers, garbage dumpsters, loud trucks. In North Philly last month, a detector went off when a bird hit a power line and fell dead on the hood of a car."[3]

While there is evidence that CCTV systems can enhance investigations (Ashby 2017), false positive or uncorroborated indications may reduce the enthusiasm that police officers have to respond quickly to the scene of incidents. In high-crime areas, officers prefer to remain available for more serious incidents (Klinger 1997) and may downgrade their response to AGDS activation calls if they attend enough of them but find no evidence of any significant incident having taken place.

Over the course of the study, anecdotal stories of active shooting incidents caught on cameras equipped with the AGDS were reported, but overall, as found in this study, the data suggest that the way in which the AGDS is currently implemented needs to be reconsidered. In light of this finding, the PPD has started a strategic discussion on camera placement and resource allocation, by taking into account not only the level of crime, but also street layout and other contextual factors. Furthermore, the objective of the AGDS perhaps needs to be redefined; rather than aiming to uncover otherwise unreported gunshot incidents, the value added to current policing by the AGDS may be its investigative, evidential value. For example, given that the AGDS gets activated based on the acoustic sound of a gunshot, it can also capture incidents behind a building that is blocking any camera video recording. By clustering cameras with the AGDS around the street corners and surrounding streets of the city's highest volume of gun crimes and by taking advantage of the automatic panning function of cameras, AGDS may aid in capturing the entire sequence of active shooting incidents from the moment incidents happen, including any perpetrators' subsequent movements. Future studies may evaluate such an alternative objective and camera placement plans.

Other information

The police department analysts and supervisors who participated in the study did so as part of their analytical duties. The academic did not receive any compensation for this study. The views in this article do not necessarily represent the opinion or position of the city of Philadelphia or the Philadelphia Police Department.

References

Ashby, M. P. J. (2017). The value of CCTV surveillance cameras as an investigative tool: an empirical analysis. *European Journal on Criminal Policy and Research, 23*(3), 441–459.

CSG Analysis (2011*). ShotSpotter Gunshot Location System Efficacy Study.* 43: CSG Analysis.

Dent, M. (2016). Philly police have used secret gunshot detection tech since January. https://billypenn.com/2016/06/16/philly-police-have-used-secret-gunshot-detection-tech-since-january/ (accessed 29 August 2018). 'BillyPenn'; Philadelphia, PA: SpiritedMedia.

Deželak, F., Čurović, L., & Čudina, M. (2016). Determination of the sound energy level of a gunshot and its applications in room acoustics. *Applied Acoustics, 105*, 99–109.

[3] Dent is not associated with the system and his source for this comment is unclear; however, he does quote Mike Vidro, the public safety special projects manager for the police department, who was integral to the introduction of the AGDS sensors and who kindly liaised at length with the authors for this project.

Djeddou, M., & Touhami, T. (2013). Classification and modeling of acoustic gunshot signatures. *Arabian Journal for Science & Engineering (Springer Science & Business Media B.V.), 38*(12), 3399–3406.
Farrington, D. P., Gottfredson, D. C., Sherman, L. W. & Welsh, B. C. (2002). The Maryland Scientific Methods Scale. In L. W. Sherman, D. Farrington, B. Welsh & D. L. MacKenzie (Ed.). *Evidence-Based Crime Prevention*. New York: Routledge (pp. 13–21).
George, J., & Kaplan, L. M. (2016). A finite point process approach to multi-target localization using transient measurements. *Information Fusion, 32*, 62–74.
Gill, C. E. & Weisburd, D. (2013). Increasing equivalence in small-sample place-based experiments. In B. C. Welsh, A. A. Braga & G. J. N. Bruinsma (Eds.). *Experimental Criminology: Prospects for Advancing Science and Public Policy.* Cambridge: Cambridge University Press (pp. 141–162).
Irvin-Erickson, Y., LaVigne, N., Levine, N., Tiry, E., & Bieler, S. (2017). What does Gunshot Detection Technology tell us about gun violence? *Applied Geography.*
Klinger, D. (1997). Negotiating order in patrol work: an ecological theory of police response to deviance. *Criminology, 35*(2), 277–306.
Luzi, L., Gonzalez, E., Bruillard, P., Prowant, M., Skorpik, J., Hughes, M., Child, S., Kist, D., & McCarthy, J. E. (2016). Acoustic firearm discharge detection and classification in an enclosed environment. *Journal of the Acoustical Society of America, 139*(5), 2723–2731.
Mazerolle, L. G., Frank, J., Rogan, D. & Watkins, C. (1999). A field evaluation of the ShotSpotter Gunshot Location System: final report on the Redwood City field trial. 64 Washington DC: National Institute of Justice.
Mazerolle, L. G., Watkins, C., Rogan, D., & Frank, J. (1998). Using gunshot detection systems in police departments: the impact on police response times and officer workloads. *Police Quarterly, 1*(2), 21–49.
Moher, D., Hopewell, S., Schulz, K. F., Montori, V., Gøtzsche, P. C., Devereaux, P. J., Elbourne, D., Egger, M., & Altman, D. G. (2010). CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *British Medical Journal, 340*(c869), 1–28.
Nguyen, Q., & Choi, J. (2017). Matching pursuit based robust acoustic event classification for surveillance systems. *Computers & Electrical Engineering, 57*, 43–54.
Ratcliffe, J. H., Taniguchi, T., & Taylor, R. B. (2009). The crime reduction effects of public CCTV cameras: a multi-method spatial approach. *Justice Quarterly, 26*(4), 746–770.
ShotSpotter Inc. (2018). Real-time intelligence to fight gun violence. Vol. 2018. http://www.shotspotter.com/law-enforcement.
StataCorp. (2013). *Stata statistical software: release 13*. College Station: StataCorp LP.
StataCorp. (2017). *Stata statistical software: release 15*. College Station: StataCorp LP.
Taylor, R. B., Ratcliffe, J. H., & Perenzin, A. (2015). Can we predict long-term community crime problems? The estimation of ecological continuity to model risk heterogeneity. *Journal of Research in Crime and Delinquency, 52*(5), 635–657.
Watkins, C., Mazerolle, L. G., Rogan, D., & Frank, J. (2002). Technological approaches to controlling random gunfire: results of a gunshot detection system field test. *Policing: An International Journal, 25*(2), 345–370.
Weisburd, D., & Eck, J. (2004). What can police do to reduce crime, disorder, and fear? *The Annals of the American Academy of Political and Social Science, 593*(1), 43–65.
Weisburd, D., & Majmundar, M. K. (Eds.). (2017). *Proactive policing: effects on crime and communities*. Washington, DC: National Academies of Sciences Consensus Study Report.
Welsh, B. C., Zimmerman, G. M., & Zane, S. N. (2017). The centrality of theory in modern day crime prevention: developments, challenges, and opportunities. *Justice Quarterly.*
Ye, J., Kobayashi, T., & Murakawa, M. (2017). Urban sound event classification based on local and global features aggregation. *Applied Acoustics, 117*, 246–256.

Matthew Lattanzio is a Research and Information Analyst with the Philadelphia Police Department where he performs data-oriented crime analysis. His primary research focus involves the geography of gangs and social network analysis.