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Too far for comfort? Situational access to emergency medical care and violent assault lethality

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Abstract

This research demonstrates the relationship between situational access to emergency medical care and assault lethality, by comparing attempted and completed murders in Greater London, England, over a five-year period (N = 1512 victims). Access to emergency care was operationalised using the time taken to contact emergency services, the distance from the nearest ambulance station, and the distance to the nearest emergency department. Notification lags in excess of 1 h were associated with significantly higher lethality, after controlling for offence and victim characteristics. The distance predictors were non-significant, which could be due to observed distances in our urban setting being overwhelmingly short (< 5 miles) and homogeneous.

Keywords: Murder, Attempted murder, Lethality, Emergency medical care, Geographic analysis

Introduction

Homicide prevention and harm minimisation are critical areas of study and research, with harm reduction in particular being one of the core tenets of crime science (Cockbain and Laycock 2017). Studies have shown the likelihood of victims surviving an assault can be affected by situational factors such as the type of place where the crime occurs, weapon use, and the presence of social controls such a bystanders (e.g., Altheimer et al. 2019; Felson and Messner 1996; Felson and Steadman 1983; Finlay-Morreale et al. 2009; Weaver et al. 2004). Another situational factor that has been explored, mainly within the field of emergency medicine, is the availability and accessibility of emergency medical care following a traumatic injury (e.g., Barlow and Barlow 1988; Crandall et al. 2013; Gonzalez et al. 2006, 2009; Harmsen et al. 2015; Newgard et al. 2010). Most studies in this area have employed health data and, as such, fail to differentiate between criminal assaults and other events such as accidents and (attempted) suicides. Such distinctions are important, as different types of incidents have been shown to be associated with different lethality rates. For instance, Fowler et al. (2015) reported lethality rates of 18.8% for assault, as compared to 84.7% for self-harm and 4.8% for unintentional firearm injuries. This research contributes to the current evidence base by examining the impact of situational access to emergency medical care on the lethality of *serious violence*, by comparing attempted and completed murder cases as recorded by police.

In the current study, we operationalise situational access to emergency medical care using three separate variables, namely the time it took to request emergency assistance (i.e., notification lag), the distance from the nearest ambulance station, and the distance to the nearest emergency department. In line with the literature referenced above, and a separate body of longitudinal and comparative studies suggesting improved medical care is responsible for changes in aggregate homicide rates (e.g., Chon 2010; Doerner 1983; Harris et al. 2002; Giacopassi et al. 1992), we hypothesised that lethal outcomes would be more likely to be associated with: (1) longer notification lags; (2) longer distances from the nearest ambulance

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Table 1 Schematic representation of the chronology of a violent event and its subsequent emergency medical care acess

Time	Event	Time period			Geographic proxy
	Crime occurs				
	Emergency assistance is requested	*Notification lag*			
	Emergency assistance is dispatched	Mobilisation time		Overall response time	
	Emergency responders arrive at scene	Time to scene			*Distance from nearest ambulance station*
	Emergency responders leave for hospital with victim	Time at scene	Treatment time		
	Emergency responders arrive at hospital with victim	Transport time			*Distance to nearest emergency dept.*

Time period categories sourced from Barlow and Barlow (1988)

Measured variables are displayed in italics

station; and/or (3) longer distances to the nearest emergency department. The present study adds to our existing knowledge by measuring the impact of emergency medical care access at the individual-event level, focusing solely on cases of serious interpersonal violence, and controlling for offence and victim characteristics.

Literature review

Access to emergency medical care and violent assault lethality

The availability and accessibility of emergency medical care is widely thought to influence the lethality of traumatic injuries, and to contribute to differences in homicide rates across time and space. For instance, greater medical resources have been shown to be associated with lower homicide rates at various level of aggregation, including country (Chon 2010), U.S. state (Doerner 1983), and county levels (Doerner 1988; Doerner and Speir 1986; Harris et al. 2002; Long-Onnen and Cheatwood 1992). In a similar way, longitudinal studies have set out to test the hypothesis that the homicide drop observed in recent decades can be largely attributed to technological advances in medicine and improved access to emergency medical care. Overall, supportive evidence has emerged but only when large enough periods are considered (Aebi and Linde 2010; Estrada 2006; Giacopassi et al. 1992; Harris et al. 2002; Linde, 2017). In contrast, longitudinal studies spanning 15 or fewer years have tended to yield non-significant findings (e.g., Granath 2011; Lattimore et al. 1997). Some authors have argued the decrease in the homicide-to-assault ratio over time could be due to an increase in assault reporting rates (Blumstein 2000; Tonry 2014).

Apart from the aggregate-level studies just described, research has also been conducted using the individual incident as the unit of analysis. In such cases, several variables are considered to account for the full process involved when accessing emergency medical care. Barlow and Barlow (1988) offered a useful framework which breaks down the process into five distinct phases: (1) the notification lag; (2) the mobilisation time; (3) the time taken to arrive at the scene; (4) the time spent at the scene; and (5) the time taken to transport the injured to the nearest emergency department (see Table 1).

The *notification lag* refers to the (estimated) time that passes between the timing of a violent event and the point at which emergency services are called, which can sometimes be difficult to establish. When available, notification lags tend to conform to a positively skewed distribution. Most incidents were reported within a very short time of the event, and very few cases long after it occurred (e.g., if a body is not found for some time). For example, in Barlow and Barlow's (1988) examination of 248 assaults in St. Louis, MO, the mean notification lag was just over 11 min, and the median just under 7 min. Barlow and Barlow (1988) failed to detect a simple linear association between the notification lag and assault lethality but noted that, when emergency responders arrived at the scene within 3 min of the call, longer notification lags were associated with higher fatality rates.

While not many studies have measured this notification lag specifically, research has shown violent assault lethality can be influenced by other variables that can impact such a notification lag, including the timing and location of the assault and the presence of social controls. In general, higher lethality rates are associated with indoor private settings such as residential locations (Bankston 1988; Finlay-Morreale et al. 2009; Weaver et al. 2004), night-time events (Weaver et al. 2004; although other have reported non-significant effects, e.g., Ganpat et al. 2013, 2017), and the absence of bystanders (e.g., Ganpat et al. 2013). If too many bystanders are present, however, this can sometimes be counterproductive, due to a perceived diffusion of responsibility (Ganpat et al. 2013; also see Decker 1995, for a discussion of the possible roles that may be adopted by bystanders to a homicide).

Mobilisation times (i.e., how long it takes to dispatch a unit following an emergency call) tend to be very short nowadays, mainly due to advances in technology such as sophisticated communication networks and geographical positioning systems (Stratmann and Thomas 2016). In contrast, the amount of *time taken to arrive at the scene* can often be slightly longer and subject to greater variation (Barlow and Barlow 1988). While some authors have reported a positive association between lethality and the time-to-scene lag (Feero et al. 1995; Funder et al. 2011; Sanchez-Mangas et al. 2010), others have reported null findings (Jones and Bentham 1995; McGuffie et al. 2005; Newgard et al. 2010; Sacra 2015), and yet others significant negative correlations (Petri et al. 1995).

Similar inconsistent research findings have been reported for *transport (to hospital) times*, whose relationship with lethality most often fails to reach statistical significance (Eachempati et al. 2002; Newgard et al. 2010; Sacra 2015; for exceptions, see Feero et al. 1995). Gonzalez et al. (2006, 2009) detected an increase in mortality rates with longer distances to the scene of traffic accidents, and from the scene to the nearest emergency department, as well as with longer travelling times. However, this only applied in rural settings, where both distances and travel times were significantly longer and more varied than in urban settings (also see Lu and Davidson 2017).

More *time spent at the scene* administering first aid to the wounded may be hypothesised to either increase or decrease mortality risk, depending on whether the injured can be stabilised (Harmsen et al. 2015). This could potentially pose a methodological issue when the on-scene time is included in measures of overall response times. Some studies have provided evidence of a positive association between overall response times and lethality (Barlow and Barlow 1988; Dinh et al. 2013; Feero et al. 1995; Kidher et al. 2012), while others have reported non-significant (Härtl et al. 2006; Lerner et al. 2003; McGuffie et al. 2005; Newgard et al. 2010; Pepe et al. 1987), or even significant, negative associations (e.g., Osterwalder 2002; Petri et al. 1995; for a recent review of studies exploring the relationship between pre-hospital times and lethality, see Harmsen et al. 2015).

The present study

To further our understanding of the relationship between access to emergency medical care and the lethality of serious violence, this study analysed data for all attempted and completed murders recorded in Greater London, England, over a five-year period (N = 1289 crime events involving 1512 victims). More specifically, hypotheses were formulated that fatal outcomes (i.e., murders) would be more likely to be associated with: (1) longer notification lags; (2) longer distances from the nearest ambulance station (a proxy for Barlow and Barlow's "time-to-scene"); and/or (3) longer distances from the nearest emergency department (a proxy for Barlow and Barlow's "transport time"). Unfortunately, no data were available to estimate mobilisation time, or the time spent at the scene, and this limitation is briefly considered in the Discussion.

Offence and victim descriptor variables known to be associated with the outcome of serious violence were controlled for; this includes the timing of the offence, the type of location where the crime occurred, the type of weapon used (if any), and the age, gender, and race of the victim. The study uses the victim as the unit of analysis, which is the approach adopted by most studies within the emergency medicine field. However, unlike those studies, the focus here is solely on serious interpersonal violence. A further contribution of the current research is its emphasis on geography, as well as its explicit consideration of the notification lag, which has not received much attention in the literature.

Methods

Data sources

Crime data

All murders and attempted murders recorded by the Metropolitan Police and the City of London Police in the Greater London area between April 1, 2002, and March 31, 2007, were initially considered.[1] This amounted to

[1] Because offence classifications can change as time passes and the case progresses, a decision was made to base our offence selection on the Home Office current main classification as recorded in the police forces' crime reporting information systems. Any offences where only the original main classification—but not the current main classification—met the selection criteria were excluded (e.g., an attempted murder that was later reclassified as a lesser violent offence).

1559 unique crime events and 1819 victims, of whom 997 (54.8%) sustained lethal injuries.[2]

For each of these offences, data were available for the date and time of the report (i.e., when the emergency call took place), the date and time of the crime event (i.e., when the incident actually occurred, as established by victims/witnesses or estimated by the medical examiners and case investigators for lethal incidents where no witnesses were available), its location in the form of geographical coordinates, the type of place where the incident occurred (e.g., street, residence), the type of weapon used (if any), the age, gender, and race of the victim, and the level of injury the victim sustained measured on an ordinal scale from no injury to fatal. Unfortunately, it was not possible to determine from the data available which of the fatal incidents involved a victim who was dead by the time help was summoned or by the time emergency services arrived on the scene. It was also not possible to determine who made the call to emergency services, which would have helped establish the health status of the victim in some cases (e.g., if the victim him/herself called for assistance). These limitations are considered in the "Discussion" section.

About 17% of the records had missing or inaccurate data pertaining to the location and/or weapon variables and had to be removed from the sample.[3] This resulted in a final sample of 1289 crime events and 1512 victims. Of these victims, 778 (51.5%) sustained lethal injuries. No data were missing for the victim characteristics, the level of injury, or the timing of the crime event, although about 13% of the offences had fairly wide time windows during which the crime could have occurred (e.g., 167 of the 1289 offences had time windows greater than 1 h, based on the recorded "from" and "to" dates/times).

Emergency care facilities data

Data were also gathered for ambulance stations and accident and emergency (A&E) departments in the Greater London area. These data were collected from various sources, namely National Health Service (NHS) Choices, 2007 Ordnance Survey Point of Interest data, UK government data sharing portal data.gov.uk, and the London Ambulance Service. These sources were cross-referenced and manually checked for location accuracy and dates of operation. There were 70 ambulance stations and 30 emergency departments active during the time period the crime data covered. Specialist emergency departments (e.g., for eye injuries), which are not normally used by paramedics when faced with life-threatening injuries, were excluded.

Analytical strategy

For each crime event, "reporting times" were calculated as the difference between the timing of the crime event and that of the report (i.e., when emergency services were requested). Because the data were highly skewed, this variable was dichotomised into notification lags longer than 1 h (1) or shorter or equal to 1 h (0). This cut-off point was chosen based on the "golden hour" tenet of trauma emergency care (see Cowley 1976; for a recent review of relevant empirical studies, see Harmsen et al. 2015).[4]

Manhattan distances from the nearest ambulance station and to the nearest emergency department (in miles) were then calculated.[5] For simplicity, the "Location type" variable was recoded into three categories: (1) outdoors (e.g., street, park, open parking lot); (2) indoor public premises (e.g., bar, restaurant, office, retail store); and (3) indoor private premises (i.e., residential property, hotel/hostel, residential home). The "Weapon type" variable was also reclassified, with six mutually exclusive and exhaustive categories: (1) firearm; (2) sharp instrument; (3) blunt instrument; (4) other weapon (e.g., poison, explosives); (5) more than one weapon type; and 6) no weapon (e.g., punching, kicking, strangulating). The "Victim's race" variable was coded as either: (1) white; (2) black; or (3) other. The location, weapon type, and victim race variables were dummy-coded in the multivariate analysis, using "outdoors," "no weapon," and "white" as the reference categories, respectively. Additional binary predictors were derived to indicate whether the crime

[2] There was an additional incident relating to the bus explosion in Tavistock Square on July 7, 2005, where 13 people were killed and almost a hundred injured. This event was part of a larger coordinated terrorist attack which resulted in 52 deaths overall. Three other explosions took place within the London Underground (subway) system, but these did not appear in our dataset because they fell under the jurisdiction of British Transport Police. A decision was made to remove this incident from the analysis, as it was deemed to be too qualitatively different from the rest.

[3] Records had to be removed when the location type was recorded as "Not known" or left blank (63 offences; 4.0%). In an additional 76 cases (4.9%), the type of location was known but not the exact location, so geographical coordinates were not available; most of these offences (47) occurred on streets or other outdoor location types. Finally, a further 131 offences (8.4%) had no data entered in the weapon field, which we regarded as missing data, rather than no weapon being used, as a category for "No weapon used" was available in the system.

[4] Quality checks were conducted using shorter cut-off points (i.e., 15, 30, and 45 min) and after applying a log transformation to the original reporting time. The results remained consistent in each case, so these are discussed no further.

[5] Euclidean distances were also calculated, and the analyses repeated using these. Consistent results were obtained so these are discussed no further.

event occurred at night (i.e., 8.00 p.m.–7.59 a.m.)[6] or if it involved a male victim.

After performing descriptive analyses, a binary logistic regression analysis was conducted to determine the joint influence of all predictors on the odds of a victim sustaining a lethal injury. Most but not all crime events (1140 or 88.4% of all 1289 events) involved a single victim. This did not provide enough distinction between level 1 (victim) and level 2 (offence) observations, so multilevel regression models or even clustered standard errors were deemed unnecessary. Instead, to control for any differences that may exist between single-victim and multi-victim events, a dummy-coded variable (indicating whether the victim was associated with a single-victim crime event) was incorporated into the model.[7] Post-estimation diagnostic tests were conducted, and these confirmed the model was appropriately specified, with no assumptions being violated. No multicollinearity was detected.

Results

About 17% of all offences were reported as soon as they occurred (i.e., zero reporting time window), both for fatal (16.8%) and non-fatal incidents (17.4%). As the reporting times increased, however, differences were observed between the two groups of offences. While as many as 74% of all non-fatal incidents were reported within 15 min, this was the case for just 56% of fatal events (see Fig. 1, panels a and b).

In contrast, our data showed no differences between fatal and non-fatal offences in relation to the distance to either the nearest ambulance station or the nearest emergency department (see Fig. 1, panels c and d, respectively; also see Table 2). Most offences occurred within two miles of the nearest ambulance station; this was the case for 84.2% of fatal and 88.3% of non-fatal incidents. Minimum distances to the nearest emergency department tended to be slightly greater, with 85.4% of fatal and 87.2% of non-fatal incidents having an emergency department within *three* miles.

Other factors

Most fatal incidents (92%) involved a single victim, while the percentage of non-fatal incidents involving a single victim was just 57.8%. When percentages are calculated the other way, these showed as many as 62.8% of single-victim offences resulted in a fatal outcome, in contrast to just 16.7% of multiple-victim offences (see Fig. 2). Additional associations were apparent for the location type variable, with indoor private locations being more likely to be associated with fatal outcomes (while outdoor and indoor public venues were more likely to be associated with non-fatal incidents), and also for the weapon variable. In the latter case, unexpected patterns emerged. Contrary to expectations, no-weapon offences were associated with *fatal* outcomes, while those involving a firearm were associated with *non-fatal* outcomes; it is possible these patterns are a direct consequence of attempted murders being used as the non-fatal incidents, and this is discussed in detail in the "Discussion" section. All other weapon categories were associated with fatal outcomes, in line with expectations (see Fig. 2). Regarding victim characteristics, fatal outcomes were more likely for white and older victims; there was no apparent bivariate effect for the victim's gender.

Multivariate analysis

A binary logistic regression analysis confirmed most of the results from the bivariate preliminary analyses. When it took longer than 1 h for emergency services to be called, this increased the odds of lethality by 132% (see Table 3). In contrast, the distances from the nearest ambulance station and to the nearest emergency department were not significant predictors of lethality.

The odds of a fatal outcome were higher for single-victim incidents and those occurring in indoor private locations. The latter consisted mostly of residential settings (93.5%), with a minority of cases occurring in hotel/hostel rooms or residential homes. As for the dummy-coded weapon type variable, the "no weapon" category was used as a reference category, which led to some unexpected results: except for the "other weapon" category, which was non-significant, all other categories associated with the use of a weapon were associated with a significant *decrease* in the odds of an offence having a fatal outcome. A possible explanation for these patterns is offered in the next section.

The model also revealed black victims to have lethality odds that were 66% higher than white victims, but no significant coefficients were detected for the "other race" category or for the victim age variable. Despite bivariate analyses indicating there was no relationship between gender and lethality, the regression model estimated male victims to have significantly higher lethality odds than females. Follow-up tests indicated the "Victim's gender" variable may be acting as a suppressor in the model. In other words, despite the victim's gender not being significantly associated with lethality, including this variable in the model improved its fit due to it being correlated

[6] The timing of the event could only be accurately determined for those 1122 incidents (87%) where the time window was no more than 1 h. To prevent further attrition in the sample, incidents with time windows longer than one hour were also coded as zeros for this variable, which may have underestimated the impact of the night timing on the outcome.

[7] For completeness, the model was rerun using robust standard errors clustered on the crime event, and also excluding multiple-victim cases. Consistent results were obtained so these are discussed no further.

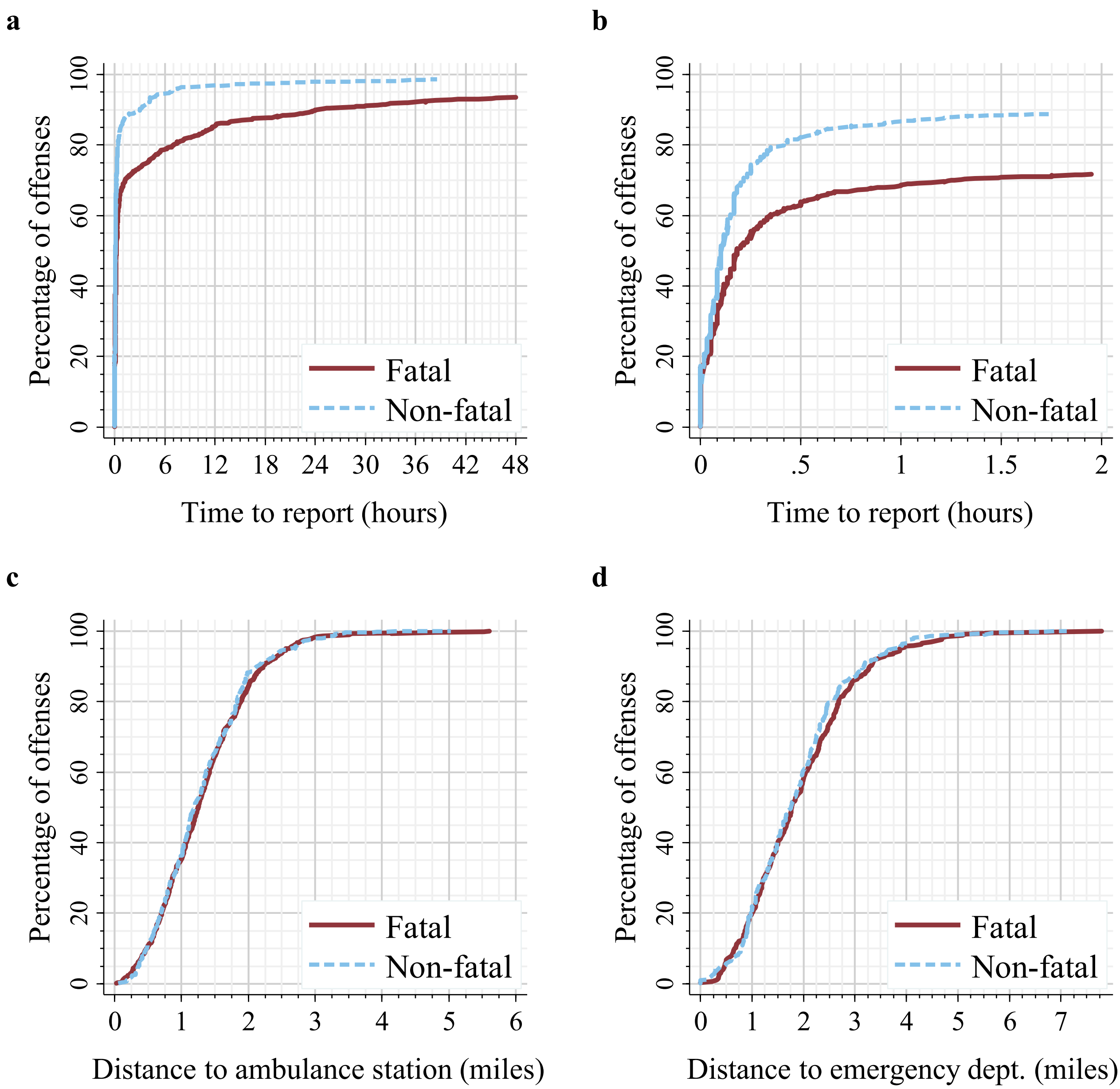

Fig. 1 Empirical cumulative distribution functions for the time taken to report the assault (**a**, **b** for detail), and Manhattan distances to the nearest ambulance station (**c**) and Emergency Department (**d**), separated by offence outcome

Table 2 Descriptive statistics for comparisons between fatal and non-fatal incidents in relation to the three access to emergency medical care proxy variables

Variable	Fatal (N = 778)			Non-fatal (N = 734)		
	Median	Mean	SD	Median	Mean	SD
Time taken to report (h)	0.2	205.3	3093.1	0.1	138.7	2899.2
Distance to ambulance station (miles)	1.2	1.3	0.7	1.2	1.3	0.7
Distance to emergency department (miles)	1.8	2.0	1.1	1.8	1.9	1.1

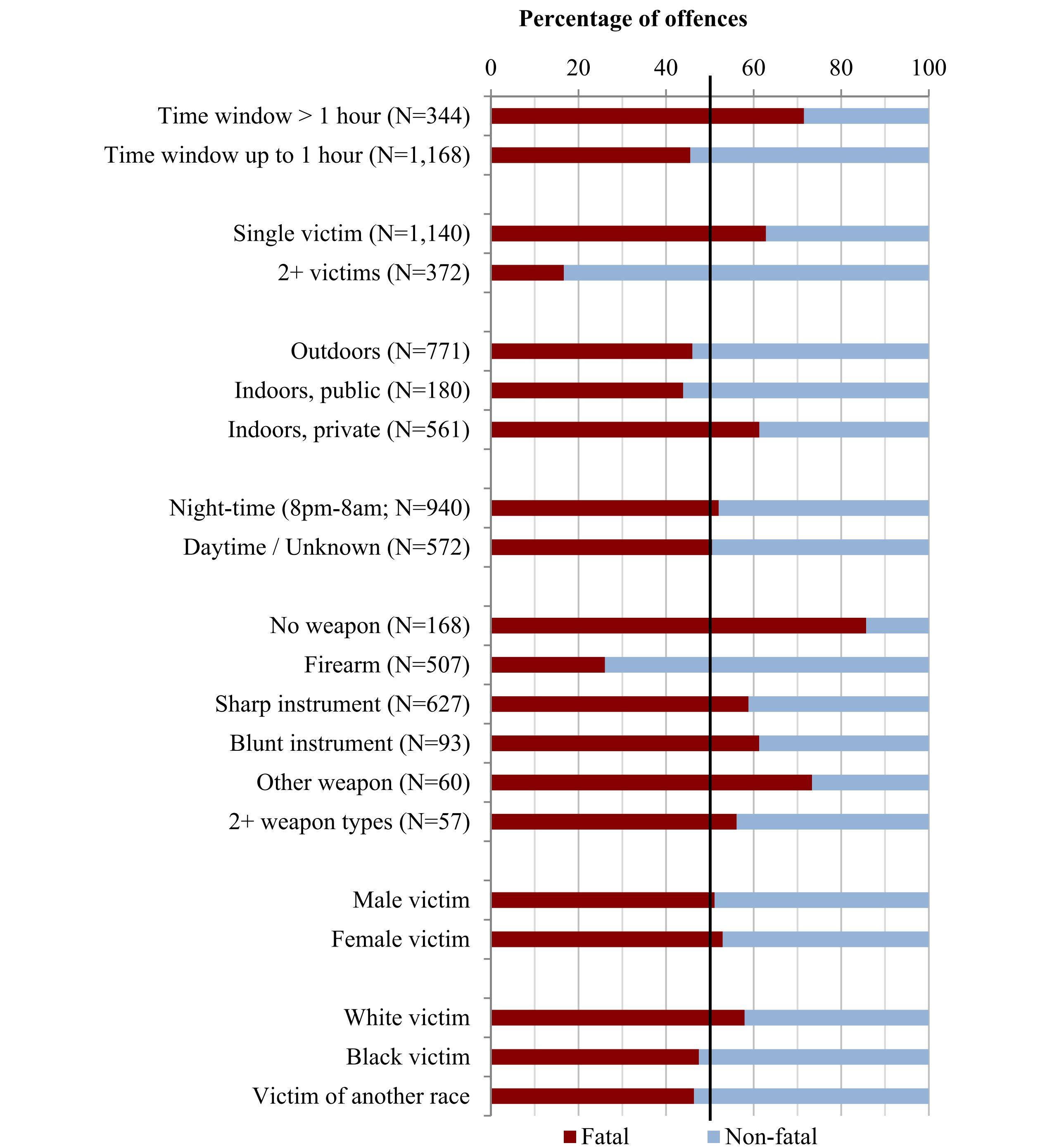

Fig. 2 Percentage of offences associated with fatal and non-fatal outcomes, for specific situational characteristics

with other predictors, most notably weapon use (see Tzelgov and Henik 1991). The VIF values for the regression model were all below 4. A similar scenario emerged for the "Victim's race" variable, where different findings were obtained in the bivariate and multivariate analyses. The analyses were repeated excluding each of these two predictors and these quality checks confirmed the significance patterns of all other variables remained stable.

Sensitivity analyses were performed whereby only those incidents where the victim sustained either fatal or serious injuries (N = 1243) were considered, but no changes in the significance patterns were detected. An

Table 3 Logistic regression of access to emergency medical care and other situational factors on offence outcome (i.e., fatal vs. non-fatal; N = 1512 victims)

Variable	OR	Z
Reporting time window greater than 1 h	2.325	5.34***
Distance to ambulance station (miles)	0.982	− 0.20
Distance to emergency dept. (miles)	0.948	− 0.88
Single-victim event	5.596	10.36***
Location of assault[a]		
Indoors, public	1.140	0.65
Indoors, private	1.407	2.40*
Night-time (8.00 p.m.–7.59 a.m.)	1.239	1.69
Weapon used[a]		
Firearm	0.082	− 9.11***
Sharp instrument	0.297	− 4.92***
Blunt instrument	0.409	− 2.72**
Other weapon	0.505	− 1.67
More than one weapon type	0.315	− 3.03**
Age (years)	1.009	1.87
Male	1.617	2.96**
Race[a]		
Black	1.655	3.14**
Other	1.006	0.04
(df) Likelihood-ratio χ^2	(16)	463.67***
McFadden pseudo-ρ^2	0.221	
McFadden adjusted pseudo-ρ^2	0.205	

OR odds ratio

[a] Reference categories were "outdoors" for "Location type" variable, "no weapon" for "Weapon used" variable, and "white" for "Race" variable. Constant terms have been omitted from this display

*p < .05, **p < .01, ***p < .001

argument may be made that the distance from the ambulance station and the distance to the emergency department would be inconsequential if the notification lag was long enough. For this reason, the three binary logistic regression models were repeated using only incidents reported either immediately (N = 259), within five (N = 539), 10 (N = 796), or 15 min (N = 956) of the attack occurring (i.e., 12 additional models), but the parameters for the distance variables still failed to achieve statistical significance.

Discussion

This study expands the evidence base on the relationship between the accessibility of emergency medical care and lethality following a violent attack. Attempted and completed murders in Greater London were compared regarding the notification lag (i.e., how long it took to request emergency assistance), the distance from the nearest ambulance station, and the distance to the nearest emergency department, after controlling for other offence and victim characteristics. In line with expectations, incidents where it took longer than 1 h to seek emergency assistance were significantly more likely to result in a fatal outcome. In contrast, the distances from the nearest ambulance station and to the nearest emergency department did not seem to be associated with lethality. These patterns remained consistent after only fatally or severely injured victims were considered, and also when restricting the analyses to incidents with short notification lags.

It is likely the null findings for the distance variables are due to most of the offences in our sample having occurred within two miles of the nearest ambulance station (with no offences being further than six miles), and/or within three miles of the nearest emergency department (the maximum recorded distance in this case was less than eight miles). As suggested by Gonzalez et al. (2006, 2009), it is possible that such distances, and their corresponding travelling times, are not an issue in urban settings, where the high population density drives a greater density of emergency medical care facilities. Distances to emergency care in rural settings have been shown to be longer and subject to greater variation. For instance, the Royal College of Surgeons in England (2006) recommends acute hospitals should serve no fewer than 300,000 residents. This calls for similar research to be conducted in future using data from suburban and rural settings.

Some may regard our use of physical distances to the nearest emergency care facilities, in lieu of actual travelling times, as a further limitation. Although it is true we cannot guarantee a perfect correlation between distance and actual travelling times, we believe our approach to be useful in that the findings may more directly inform decisions about where emergency care facilities should be located.

Among the other variables considered yielding significant parameters in the multivariate models, at least two deserve special attention. First is the single-victim indicator. Although this variable was used mostly to control for the small clustering in the data, other researchers have used it as a proxy for bystander presence and reported higher mortality rates for single-victim violent offences (e.g., Nielsen et al. 2005). In this case, it is worth noting multiple-victim events had shorter notification lags overall (median was 6 min for multiple- and 10 min for single-victim offences), which suggests notification lags may be moderating the relationship between the number of victims and lethality.

The other variable of interest was weapon use. Our analyses showed most weapons to be associated with a reduction in the odds of an incident having a fatal outcome, which contradicts expectations and prior research (e.g., Felson and Messner 1996; Ganpat et al. 2013; Libby and Corzine, 2007; Nielsen et al. 2005; Weaver et al. 2004). These odds were estimated with no-weapon offences as the reference category, with this subgroup having a lethality rate of 86% (the highest of all weapon categories). This counterintuitive finding is likely an artefact of crime classification, by which no-weapon offences would have to be extremely serious to be considered an attempted murder. In contrast, the mere use of a weapon may trigger such a classification, regardless of whether substantial injuries were inflicted.

To investigate this possibility, we calculated the distribution of injury severity for firearm offences, which was the only weapon category where a majority of offences turned out to be non-lethal. In almost 17% of all cases, the victim sustained no injuries (i.e., the shooter missed), and in a further 18% cases, victims sustained only minor or moderate injuries. In any case, restricting the analysis to fatally and seriously injured victims did not solve the problem (i.e., the calculated odds ratios for the various weapon categories remained below 1 and significant), due to the artificially extreme lethality rate in the no-weapon reference category.

As discussed earlier, our approach of comparing solely murder and attempted murder was an attempt to keep lethal intent consistent. However, it appears it is not only researchers, but also the police, who are using weapon use as a proxy for such intent. Removing the weapon variable from our main analyses did not affect our results regarding the emergency medical care access variables. In any case, the apparent circularity observed leads us to suggest lower-level violent offences are considered in future lethality studies if the focus is on weapon use as a predictor.

A shortcoming of the present study was our inability to determine which murders involved a victim that was dead by the time help was summoned or by the time emergency services arrived on the scene. This is a potential confounding variable as the fatal cases will most likely include victims who would have died regardless of how accessible emergency medical assistance was. At the other end of the spectrum there would be cases that would have a *non-fatal* outcome also regardless of those variables, if the victim sustained no injuries or non-life-threatening injuries. It is possible the inclusion of both sets of cases may have diluted any small differences that may exist in the distances to emergency medical facilities. Having said that, the distances observed were perhaps too similar across fatal and non-fatal offenses for this to be considered a viable conclusion (see Crandall et al. 2013). While we were unable to identify DOA cases and exclude those from the analyses, excluding those cases where the victims sustained no injuries (N = 109, 7.2% of all cases) and even those with less serious injuries (N = 66 cases involving minor injuries; N = 94 moderate injuries) did not change the results. In any case, future researchers should exclude DOA cases whenever possible.

Data to estimate mobilisation times and the time spent at the scene were also unavailable, and this could have potentially affected our findings. However, the fact both tend to be extremely short (Harmsen et al. 2015; Stratmann and Thomas 2016) would likely minimise this bias.

Finally, some authors have expressed concerns regarding racial disparities in emergency medical care provision, and the effect these may have on fatality rates (e.g., Hanke and Gundlach 1995; also see Nielsen et al. 2005), despite there being some evidence emergency response times are not significantly different across racial subgroups (e.g., David and Harrington 2010). We had only limited information about the victims' racial profiles, and this led to conflicting results. While the bivariate analysis indicated white victims had higher lethality rates, it was black victims who seemed more likely to sustain fatal injuries after other variables were considered. It is possible the findings are confounded by the socio-economic status of the victims and the neighbourhoods in which they resided. Unfortunately, we had no relevant information at the victim level to test this hypothesis. Although UK Census data could have been collated at the neighbourhood level, this would have involved the use of multi-level models, which was beyond the scope of this study. Future researchers should explore these issues.

Conclusions

This research contributes to the extant literature by demonstrating a relationship between how long it takes to seek emergency medical assistance and the lethality of a violent attack, using the victim as the unit of analysis and controlling for various offence and victim variables. Prior to this research, hardly any studies had considered the impact of such a notification lag, although situational variables that can presumably affect such a lag (e.g., type of location) have been shown to be predictive of lethality. While the distance to emergency medical care facilities was not found to predict lethality, the null results may be attributed to the specific characteristics of our study area.

Our research complements emergency medicine studies that have also used the individual event as the unit of analysis but considered various forms of trauma in the aggregate. These studies tend to measure emergency medical care access in actual traveling time units, rather than average traveling time or distance units. While this might provide a more accurate measurement of the relationship between these two variables, the results are not as easily translated into real world planning. The fact our distance variables were not statistically significant predictors of lethality appears to indicate the geographic distribution of emergency care facilities in the study area can be deemed satisfactory. Future studies should further explore the impact of these variables in varied settings, while controlling for the notification lag and other relevant variables.

Expanding this evidence base could improve our ability to minimise the harm of violent assaults by exploiting the influence situational variables, and more specifically access to emergency medical assistance, can have on the lethality of such events.

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Authors' contributions
LS was the lead for this research, including the original idea and the manuscript write-up. The crime data used in the research were the same data used for her Ph.D. research. TGR was a Ph.D. student who assisted LS with the study as part of an independent studies course. The main objective of this course was to mentor TGR through the development of a manuscript and its submission for publication. TGR compiled the health services data and drafted the Methods section. She also helped identify bibliographical sources and provided summaries of such sources. LS performed these same data collation and literature searching tasks, to ensure nothing was missed, and co-wrote the Background and Methods sections with TGR. LS took the lead for the analysis and discussion, but TGR was very actively involved in these too. Together, LS and TGR created a poster with the preliminary findings that was presented at the American Society of Criminology conference. Both authors read and approved the final manuscript.

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Availability of data and materials
The crime data used in this research were obtained from the Metropolitan Police Service in London and cannot be shared. The health services data were compiled from various sources and we would be happy to share these with any researchers wanting to use it for their own research. Neither data set has been uploaded to any repositories, but the health services data can be requested by sending an email to the corresponding author.

Competing interests
No financial or non-financial competing interests apply.

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