Population Movement and Sudden Cardiac Arrest Location

Running title: Marijon et al.; High-Risk Public Areas for Sudden Cardiac Arrest

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Abstract

Background—Although the benefits of Automatic External Defibrillators (AEDs) are undeniable, their effectiveness could be dramatically improved. One of the key issues is the disparity between the location of AEDs and Sudden Cardiac Arrest (SCA).

Methods and Results—From Emergency Medical Services and other Parisian agencies, data on all SCAs occurring in public places in Paris, France were prospectively collected between 2000 and 2010, and recorded using 2,020 grid areas. For each area, population density, population movements, and landmarks were analyzed. Of the 4,176 SCA, 1,255 (30%) occurred in public areas, with a highly clustered distribution of SCA, especially in areas containing major train stations (12% of SCAs in 0.75% of the Paris area). The association with population density was poor, with a non-significant increase of SCA with population density (P=0.4). Occurrence of public SCAs was, by contrast, highly associated with population movements (P<0.001). In multivariate analysis, including other landmarks in each grid-cell in the model and demographic characteristics, population movement remained significantly associated with occurrence of SCA (OR 1.48, 95%CI 1.34–1.63, P < 0.0001), as well as grid-cells containing train stations (OR 3.80, 95%CI 2.66–5.36, P<0.0001).

Conclusions—Using a systematic analysis of determinants of SCA in public places, we demonstrated the extent to which population movements influence SCA distribution. Our findings also suggested that beyond this key risk factor, some areas are dramatically associated with a higher risk of SCA.

Key words: sudden cardiac arrest, automated external defibrillator, cardiopulmonary resuscitation, Survival, Sudden death, Incidence
Introduction

Sudden cardiac arrest (SCA) remains a leading mode of death in the industrialized world, representing approximately 20% of overall mortality.\textsuperscript{1} Except for a few recent encouraging reports,\textsuperscript{2-4} survival after SCA remains poor and relatively stable over time, between 7 to 8%, despite decades of research and major financial investments in resuscitation.\textsuperscript{5-7}

SCA most often presents with an initial ventricular fibrillation,\textsuperscript{8} external defibrillation has therefore been incorporated as a key factor in the chain of survival since the early 1990’s.\textsuperscript{9,10}

Public access defibrillation programs have thus been developed, in order to make automatic external defibrillators (AED) publicly available, allowing rapid early defibrillation.\textsuperscript{11,12, 13,14,15-17}

Although the benefits of AED are undeniable, public utilization rates remain very low,\textsuperscript{4,15,18} and thus the effectiveness of such programs could be dramatically improved. One of the key issues is the disparity between the location of AEDs and SCAs. In Paris, although AED deployment in the community –which started in 1993 with first the progressive equipping of EMS ambulances– has been particularly active the last decade, the choice of where to install AEDs in public places has been mainly driven by empirical considerations (local unguided initiatives). Recent studies have already pointed out the limitations of such an approach, calling for evidence-based strategy.\textsuperscript{19}

Although previous studies have identified sites with a higher risk of SCAs,\textsuperscript{18-22} especially raising the association with train stations and airports, the reliability as well as the determinants of such high-risk places have only been partially explored. In this study, we collected data on SCA locations in Paris. We hypothesized that population movement was a key factor for SCA distribution, but could not explain by itself the overall heterogeneity of SCA distribution.
Methods

Population Study

From January 1, 2000 to July 31, 2010, and using the two Emergency Medical Services systems existing in Paris, we prospectively collected all out-of-hospital SCA cases using a specific case report form.\textsuperscript{23} The Paris Emergency Medical System is a 2-tiered response system, coordinated via a unique dispatcher center: (i) a Basic Life Support tier provided by firefighters of the Brigade de Sapeurs Pompiers de Paris (BSPP), who can apply AED, and (ii) an Advanced Cardiac Life Support function provided by ambulance teams with an emergency physician, a nurse, and a paramedic (Service d’Aide Médicale Urgente–SAMU). Although, the Brigade de Sapeurs Pompiers de Paris usually (>85% of cases) arrive the first on scene, SAMU coordinating local operational units in some public places, may be the first in the remaining cases.

SCA was defined, according to Utstein’s guidelines, as a sudden cardiac death case in which specific resuscitation records were available (deceased or successfully resuscitated), after exclusion of cases with obvious extra-cardiac causes (eg. sudden infant death syndrome, drug overdose, suicide, drowning, hypoxia, exsanguination, cerebrovascular accident, subarachnoid hemorrhage, and trauma).\textsuperscript{24-26}

In the present analysis, we considered SCA occurring in public (non-residential) areas. We defined public areas as all areas accessible to the general public, including all outdoor locations, public transportation sites, schools, commercial and civic establishments.

Geolocalisation of SCA

We used a two-step approach to localize SCA. First, the exact locations of SCAs were geographically coded and marked on the digital city map. Automated geolocalization was first performed, and all addresses were then verified manually (Google Maps API Web Services v3,
HTML 5 and JavaScript). Second, we merged geolocalized data with a Parisian grid system established with the Geographic Information System from the Atelier Parisien de l’Urbanisme (APUR, http://www.apur.org), including a defined and grid net with a standardized size of 2,020 cells of 200 meters squared each (200*200-m grid cells) over 101 km². Of note, the two large public parks located along Paris (Bois de Vincennes and Bois de Boulogne) were not considered in this study, which aimed to evaluate an urban setting.

**Population and Landmarks Data**

We obtained information for each of the grid cells on (i) the density of the population, (ii) population movements and (iii) landmarks in each grid. This involved data collection from different agencies, and coordinated by APUR. National and Parisian agencies enrolled in the evaluation of population densities and population movements of Paris City were: the Syndicat des transports d’Île-de-France (STIF), the Direction Régionale et Interdépartementale de l’Équipement et de l’Aménagement (DRIEA), the Observatoire de la Mobilité en Île-de-France (OMNIL), the Institut National de la Statistique et des Études Économiques (INSEE), the Institut d’Aménagement et d’Urbanisme Ile de France (IAU), the Paris City Hall, the French Ministry of Transports as well as the French Ministry of Education.

First, the density of the population was defined as the number people living in the area (hundred inhabitants per hectare).

Second, regarding population movements, the flow of persons moving through the grid-cell was determined by estimating the daily number of population movements in Paris for each grid-cell. Those data were based from the 2001 Enquête Global des Transports (2001 EGT). This survey was carried out from October 2001 to April 2002, under the auspices of the French Ministry of Public Works, Transportation and Housing. This survey, initiated in 1976, has been
carried out by the Institut National de la Statistique et des Études Économiques (INSEE) every 7 to 10 years in Paris (last survey in 2010). Methodology of the survey followed a standardized approach established by the Centre d’Études sur les Réseaux, les Transports, l’Urbanisme et les Constructions Publiques (CERTU). Briefly, a representative sample of 10,500 families was randomly selected in Paris. Non-permanent residents and/or people living in hotels and/or other community locations were not enrolled in this evaluation. Each member of the family was interviewed face-to-face by one investigator, at their home, regarding all trips he/she had done the previous day, through a specific questionnaire (including 106 variables). Children under of 6 year-old were not considered since they were considered as always being escorted by older people. Individual movement was defined as the mean of individual trips taken by living/local population per day, between one origin and one destination, associated with a specific intention/goal. Information on timing, specific itinerary and mode of transportation (walking, cycling, car, public transportations) was also collected. ‘Intentions’ were classified as being related to work, shopping, sports/exercise, education, tourism, health, administrative issues or other activities (such as other leisure time activities). For one given grid-cell, the population movement (thousand per grid-cell) were the sum of individual movements of persons entering into this specific grid-cell, per day, with either the intention of participating in a specific activity, or when commuting home. The mean accumulated number of trips taken was estimated to 8,259,134 per day in Paris. The results of the 2010 EGT survey was very similar to 2001 EGT survey.

Finally, we obtained information on the evaluation of different city landmarks in each cell. Train stations (large train stations were defined as having more than an average of 20,000 passengers daily), exhibition centers, shows and convention centers, museums, public swimming
pools or other sport facilities (public or private, outdoor or indoor), place of worship, primary to high schools, large shopping malls (more than 300 m²), hospitals, and tourist attractions (monuments) were considered.

In Paris, the major airports are outside the limit of the city district and could not be studied with the same methodology. To address this issue, we focused on Charles de Gaulle Airport, which is France’s most crowded airport and also has a centralized systematic collection of all cases of SCA by EMS. We collected all cases of SCA in this airport from 2000 and 2010. Regarding population movement, no detailed data comparable to EGT used in urban Paris was available. By consequence, we used the annual frequency of person visits of this airport (60.5 million passengers in 2010) as the reference value for the flow of population.

Statistical Analysis

The subject characteristics were described as mean±standard deviation, proportions, median and interquartile ranges, as appropriate.

We first provided descriptive data on population density, population movements and local landmarks in each of the 2,020 grid cells. The association between the number of SCAs and population density and population movements were assessed using a general linear model over classes.

Secondly, to assess if SCA incidence differed between two typical places with same population movement, we paired each grid-cell containing the six major train stations (Austerlitz Station, Lyon Station, Nord Station, Est Station, Montparnasse Station, Saint Lazare Station) with the most populated grid-cells containing a touristic place (The Eiffel Tower, Georges Pompidou Beaubourg Center, Basilica of the Sacré Cœur–Montmartre, Louvre Museum, Notre-Dame of Paris, Paris Porte de Versailles Exhibition Center), on the closer population movement.
We calculated for each pair the difference of number of ACR between the two cells and tested the global difference to zero using the Wilcoxon signed rank test, to assess if SCA incidence differed between two typical places with same population movement.

Then we estimated the risk of having SCA in one of the 2,020 grid-cells containing specific city landmark (listed above). We used a count model, the negative binomial regression. This model allowed better consideration of the over-dispersion compared to the Poisson regression in our sample data. The dependent variable was the number of public SCA in each grid-cell; the independent variable was the presence or absence of the landmarks in the grid-cell. We normalized each cell by using the logarithm of population movements (per each unity i.e. the grid-cell) as an offset. We provided first a univariate model and then a multivariate model considering adjustment on other landmarks in the grid-cell. The relative risk (RR) of the cell containing the landmark was the exponential of the regression coefficient, using SAS PROC GENMOD with negative binomial probability distribution and log link function.\textsuperscript{19, 31} We performed a multinomial logistic regression explaining the number of SCA in three categories – no SCA, one SCA, two or more SCA - within a grid-cell by landmarks in the grid-cell as well as population movement and population density (considered as adjustment variables). We considered population movement and density in six categories, as already described. No SCA was chosen as the reference category. We established univariate and multivariate regressions with logistic distribution and general logit link.

All tests were two-tailed, and $P$ values of less than 0.05 were considered to indicate statistical significance. All data were analyzed at INSERM, Unit 970, Cardiovascular Epidemiology and Sudden Death, Paris, using SAS version 9.3 (SAS Institute Inc, Cary, NC). The authors had full access to data and designed the statistical analysis, had final responsibility
for the decision to submit the manuscript for publication, and vouch for the accuracy and completeness of the data and the analyses. This prospective study was conducted according to the Declaration of Helsinki, after IRB (Committee for the Protection of Human Subjects in Biomedical Research and French data protection committee) approval.

Results

Characteristics and Clustered Distribution of SCA in Paris

Overall, out of the 8,234 out-of-hospital cardiac arrests in Paris, 5,296 received EMS-resuscitation attempt (Figure 1), and 4,176 were presumed to have a cardiac aetiology (eventually considered as SCA): 2,921 (69.9%) occurring in a residential location and 1,255 (30.1%) in a public location. Baseline characteristics of public SCA are described in Table 1. Of note, among the 5,296 SCA (64.3%) with EMS-resuscitation attempt, those occurring in public places had more attempts compared to those occurring at home (85.7% vs. 55.4%, P<0.0001). Among those SCAs which occurred in public places, the proportion considered for resuscitation was very similar across different public locations: 83.7% in train stations compared to 86.5% in others areas (P=0.41). The proportion of SCA was observed to be higher in the morning and afternoons (representing 56% of the overall SCAs occurring in 30% of the day).

Figure 2 shows the locations of all 1,255 SCA in public places over the 2,020 Parisian grid-cells. The mean number of SCA occurring in one grid-cell was 0.62, varying from 0.56 in grid-cell including a school to 9.93 for grid-cell including a large train station. Among public SCA, 478 cases (38.1%) occurred in public facilities, such as train stations, malls or museums, whereas 777 (61.9%) took place outside of such facilities, mostly on the “sidewalk”. The SCAs were scattered around the city with a highly heterogeneous frequency distribution, with many
SCAs clustered in areas: 50% of SCA occurred in 9% of the Paris total area. We noted a particularly high-density of SCAs near the six major train stations where 12% of SCAs occurred (less than 0.75% of the total Paris area). This distribution was stable over 3 sequential periods of 40 months.

**Population Density and Population Movement**

The incidence of SCA was evaluated across the classes of population density and population movements (Figure 3). The mean number of public SCA by grid-cell was not significantly associated with population density, varying from 0.33 to 0.78 SCA per grid-cell for the first and the sixth class respectively (P for trend = 0.4). By contrast, when considering population movements, we observed a highly significant association between the number of public SCA and the different classes of population movements, with a 6-fold difference: the mean number of public SCA by grid-cell varying from 0.22 to 1.43 SCA per grid-cell respectively for the lowest and the highest class of population movement (P for trend <0.001).

**Population Movement and Specific Locations**

We analyzed the six most visited places in Paris, which accounted for a very similar population movements number compared to the six major train stations (median 26930.0 vs. 24591.5 per day and grid-cell, P=0.06). The median number of SCA per grid-cell was almost 5-fold lower for the tourist sites (4.5 vs. 22.5, P=0.03) (Figure 4).

Using a multinomial logistic regression model (Table 2), we explored the extent to which SCA occurrence was influenced by landmarks in cells after adjustment for the population movement and the population density of each grid-cell. In univariate modeling, we observed that the OR for having 2 or more SCA in grid-cells containing a train station was 5.76 (95%CI 4.14-8.01, P<0.0001) higher than in grid-cells without this landmark. Grid-cells containing large
shopping mall or exhibitions were also significantly associated with the occurrence of 2 or more SCA, compared to grid-cells without those landmarks. Regarding demographic characteristics, in univariate analysis, categories of population density and categories of population movement were associated with occurrence of 2 or more SCA.

In multivariate analysis, including in the model other landmarks in each grid-cell and demographic characteristics, categories of population movement remained significantly associated with occurrence of 2 or more SCA (OR 1.48, 95%IC 1.34 - 1.63, P < 0.0001), whereas categories of population density was no longer associated. Grid-cells containing train stations remained significantly associated with occurrence of 2 or more SCA (OR 3.80, 95%CI 2.66–5.36, P<0.0001), whereas shopping mall or exhibitions were no longer significantly associated with occurrence of 2 or more SCA. By contrast, in multivariate analysis, grid-cells containing primary to high schools were negatively associated with occurrence of 2 or more SCA (OR 0.65, 95%IC 0.48-0.89, P=0.006).

As a sensitivity analysis, we also performed a negative binomial regression model (Supplemental Table), to explore the extent to which SCA occurrence was influenced by landmarks in cells normalized by the population movement of each grid-cell (population movement used as an offset). In a multivariate model accounting for landmarks and population movements, large train stations were significantly associated with occurrence of SCA (RR 2.60, 95%CI 1.69–4.01, P<0.0001).

Overall, 67 SCA occurred in Paris Charles de Gaulle Airport during the same period (2000-2010), giving a frequency of occurrence of 0.12 per million in Charles de Gaulle airport.
Discussion

Our findings offer better understanding of the extent to which SCAs occurring in public places may be clustered in a large city, with 12% of SCAs occurring in less than 0.75% of the total Paris area – emphasizing why population movement matter is crucial to consider, with very few events occurring in empty areas. To the best of our knowledge, our study is the first to provide information on population movements, in addition to population density. We demonstrated that the number of population movements was a major determining factor of such heterogeneity, much more than variations in population density. Finally, our results strongly suggest that beyond simply population movements, some areas (major train stations) remain at particularly high risk for SCA occurrence. These data should help optimize AED placement in the community, by concentrating AEDs in high-risk areas for SCA, such as train stations.

Stability in the incidence of SCA within geographic areas has been demonstrated. Accordingly, identifying high-risk places for SCA should be considered as a reliable method to guide optimal AED location in order to eventually increase the cost-effectiveness of such programs. For this, a better understanding of high-density SCA areas is needed to provide evidence to the medical community and policy makers to guide strategies for optimal AED deployment, especially in concentrating AEDs in high-risk areas for SCA, and acknowledging that some large areas do not need to be so well equipped. The hypothesis that population movement was a highly influential factor, driving “hot spots” for SCA, was strong, although this has not yet been formally tested, mainly due to the lack of reliable data on population movements. Data from different urban Parisian agencies gave us the unique opportunity to explore this question; we demonstrate the extent to which SCA density was associated with population movements, and that this association remained significant after adjustment for
different landmarks in each grid-cell (including train stations) and demographic characteristics. Further attention should be given in the future to those locations with the highest population movement. Stability in the incidence of SCA within geographic areas has been recently demonstrated.\textsuperscript{32}

As a result of our main finding – that population movement is a major determinant of SCA distribution– we observed that large train stations are particularly high-risk areas for SCAs, and confirm that in the setting of a large urban European area, clustered distribution is observed. These data are highly consistent with publications which previously demonstrated an association between major train stations and SCA.\textsuperscript{18, 19, 33-35 36,37} A differential proportion in resuscitation attempted by EMS (according to the location of SCA) may have led to a significant reporting bias. This has not been observed, however, with a very similar proportion of SCA with resuscitation attempted being observed in different public places (train station vs. non-train stations). Accordingly, in public places, population movement appears unlikely to be a surrogate for an increased likelihood of having a SCA that is witnessed and thus more likely to undergo resuscitation.

Our data add to this prior literature, in providing the extent to which those associations were driven by population movements. Consequently, our results are in line with prior literature regarding location of SCA. Associations between SCA incidence and population density have been tested in the setting of residential (non-public) areas, demonstrating the poor predictive relevance of this factor.\textsuperscript{38} In quantifying the association between SCA occurrence and the level of population movements, our findings may be particularly useful to provide a strong rationale for AED deployment in the community, targeting high-risk areas.

In 2005, North-American guidelines recommended implantation of AEDs in sites “where
the probability of cardiac arrest occurring is at least once in every 5 years”. European guidelines considered areas with at least one SCA every 2 years as being candidate sites for AED placement. However, these guidelines were based on limited evidence. Recent data, available since 2009, also elegantly demonstrated the limitation of using such an approach, and these recommendations were finally deleted in the recent updated guidelines. When we look at the history of AED deployment in Paris, it is interesting to observe that this has been carried out, independently of any evidence-based approach. For example, the 20 City Halls of the different districts were the first public places equipped with AEDs; during our study period, no SCA at all occurred in these locations. Overall a relatively consistent pattern of deployment of almost one thousand of AEDs in public places during the 2000-2010 period has been observed. Taking the example of major train stations, the first AEDs were installed in 2005, eventually providing a very similar level of coverage compared to well-known tourist sites in Paris, such as the Eiffel Tower and the Musée du Louvre. This contrasts with the actual pattern of SCA distribution seen in our study. This emphasizes the point that AED placement may be substantially improved, emphasizing the importance for policy makers and the medical community to consider that AED distribution should followed the SCA distribution, based on evidence such as that provided in this study.

Our study also reports additional and interesting findings, suggested by our descriptive approach and also confirmed by our modeling. Population movements cannot be the only explanation for the high rate of SCA in some public areas: when compared to the most tourist-visited sites in Paris, large train stations (with, however, very similar population movements) had a much higher frequency of SCA. Our approach, based on a count modeling (negative binomial regression), showed a highly significant association between SCA and major train stations,
which is only attenuated when considering population movements in the model. Possible explanations include particular physical activity, most often acute, at train stations, which is known to favor ventricular arrhythmias, especially among untrained middle-age men.\textsuperscript{41} Another hypothesis may be postulated concerning the associated psychological stress associated with public transportation areas (train stations or airports), mainly related to timing departure issues.\textsuperscript{42} Third, particulate pollution in these areas may possibly play a role.\textsuperscript{43} Finally, populations in train stations are relatively “unselected” in contrast with users of sport facilities who are likely to be younger, in better physical shape, and have been sometimes screened by physicians. This may contribute to this higher frequency of events. Of interest, when we look at the number of SCA in Paris Charles de Gaulle Airport (60.5 millions of passengers in 2010), during the same period (2000-2010), we observed a very similar frequency of SCA compared to the train stations: 0.12 per million in Charles de Gaulle airport compared to the 0.08 per million observed in the six major train stations in Paris. The very similar findings observed in major train stations as well as airports reinforce the idea that physical and psychological stress may be a trigger of SCA in those “high-risk” areas; other socio-economic factors might also account for higher rates at those areas and need further investigations. Considering that “exposure time” (waiting time) may be higher in airports compared to those expected in train stations, this could explain (at least in part) the absolute lower rate of SCA observed in train stations versus the airport.

Our study contributes to the existing literature regarding localization of SCA,\textsuperscript{19,32,44} with an innovative approach based on population movement. However, we must acknowledge some limitations. First, we studied only SCA with presumed cardiac cause, which could represent a selection bias. However, this population is the likeliest to benefit from AED and represents the main target of public access to defibrillation programs. Second, the low density of SCA in the
majority of grid-cells could distort (to a minor extent) the binomial negative model utilized, but with an unlikely overall impact on the results and model fit. Second, according to Utstein’s guidelines, we did not collect information on out-of-hospital cardiac arrests not related to a primary cardiac cause.8,25,26 The extent to which those data (additional 20% of cases, in agreement with prior literature) would change our findings seems limited, since those non-cardiac cases are known to present a very small proportion with shockable rhythm, and thus would be less likely to benefit from public AEDs. Third, although the classification status of SCA cases (tourists or permanent resident) was not collected during the study, the extent to which movements related to tourism may influence the distribution of SCA in Paris was of particular interest. It could be possible that population movement may have been underestimated in train stations based on a survey of Paris residents alone. However, the 2005 evaluation carried out by the Institut National de la Statistique et des Études Économiques (INSEE) emphasized that tourism frequency was equivalent to 224,400 permanent residents (~11% of the total population of Paris), and that the number of those additional subjects was similar to the number of permanent residents from outside the city (mainly commuting for business purposes).45 Overall, even in one of the most tourist-visited cities worldwide, the influence of tourism on SCA distribution appears limited. Fourth, although interesting existing data have demonstrated the influence of neighborhood socioeconomic status on incidence and management of SCA.46 However, regarding SCA occurring in public places, this "time of exposition" (influence of neighborhood socioeconomic status) to neighborhood appears of limited value, especially in a city like Paris, with very high population movement and consequently considerable heterogeneity in socio economic status. The extent to which the association between SCA and major train station may be driven by different (lower) socioeconomic status need to be examined in further studies. Fifth, spatial autocorrelation is an important issue, that may be
considered through a variety of complex analytic approaches, guided by novel specific softwares (such as SaTScan).47 Although crucial to consider in the field of infectious diseases, pollution effects etc…, in the setting of SCA, this approach remains more debatable. Finally, our study is limited to Paris city, and high-risk areas may differ according to the preferred public transportation system of the city/country (mainly major train stations and airports). Although our descriptive results fit extremely well with data from Folke and colleagues (in Copenhagen: 19.5% of SCA occurred in 1.2% of the city area, compared to 1.4% in Paris),19 the extent to which the present results may be generalized to other non-European cities requires further study. The urban and demographic data available for Paris, as well as the population density and the large number of tourists was a unique opportunity to assess the relationship between SCA and population movements. This model may not be easy to replicate in other cities.

**Conclusion**

In providing a systematic analysis of determinants of SCA within a public urban setting, we demonstrated the extent to which population movements may account for the “hot spots” of SCA observed. Our results also suggested that beyond this key risk factor, some areas show a dramatically higher risk of SCA. This should provide evidence to the medical community and policy makers to guide strategies for optimal AED deployment.

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**Conflict of Interest Disclosures:** None.

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**Table 1.** Characteristics of Subjects and Selected Features of the 1,255 SCA Occurring in Public Areas in Paris.

<table>
<thead>
<tr>
<th>Demographic data</th>
<th>N=1,255</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs, mean±SD</td>
<td>62.5±16</td>
</tr>
<tr>
<td>Male sex, N (%)</td>
<td>1036 (82.5)</td>
</tr>
<tr>
<td>History of cardiovascular disease, N (%)</td>
<td>441 (38.4)</td>
</tr>
</tbody>
</table>

**Management of SCA, N (%)**

<table>
<thead>
<tr>
<th>Time of occurrence (hour)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6-9</td>
<td>188 (15.0%)</td>
</tr>
<tr>
<td>10-13</td>
<td>351 (28.0%)</td>
</tr>
<tr>
<td>14-17</td>
<td>350 (27.9%)</td>
</tr>
<tr>
<td>18-21</td>
<td>238 (19.0%)</td>
</tr>
<tr>
<td>22-5</td>
<td>128 (10.1%)</td>
</tr>
<tr>
<td>Witnessed SCA</td>
<td>996 (85.4)</td>
</tr>
<tr>
<td>Bystander CPR</td>
<td>389 (35.4)</td>
</tr>
<tr>
<td>Initial ventricular fibrillation</td>
<td>446 (37.3)</td>
</tr>
<tr>
<td>Shock by external defibrillator</td>
<td>658 (53.9)</td>
</tr>
<tr>
<td>Call—to–AED placement, min</td>
<td>10.9±4.9</td>
</tr>
</tbody>
</table>

**Alive at hospital admission, %**

|                  | 625 (50.6) |

AED denotes automatic external defibrillator, CPR cardiopulmonary resuscitation, SCA sudden cardiac arrest. Percentages were calculated on the basis of the total number of known events.
Table 2. Relative Risk for SCA of Grid-Cells Containing Specific Landmark. Univariate and Multivariate Analyses (Multinomial Logistic Regression Model).

<table>
<thead>
<tr>
<th>Features</th>
<th>SCA category</th>
<th>Univariate</th>
<th>Multivariate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>P Value</td>
<td>OR</td>
</tr>
<tr>
<td>Population density</td>
<td>1</td>
<td>1.30 (1.20-1.41)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(per 1-category)</td>
<td>2</td>
<td>1.20 (1.08-1.34)</td>
<td>0.95 (0.84-1.08)</td>
</tr>
<tr>
<td>Population movement</td>
<td>1</td>
<td>1.32 (1.24-1.39)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>(per 1-category)</td>
<td>2</td>
<td>1.55 (1.43-1.68)</td>
<td>1.48 (1.34-1.63)</td>
</tr>
<tr>
<td>Primary to high schools</td>
<td>1</td>
<td>1.41 (1.14-1.73)</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.91 (0.70-1.20)</td>
<td>0.65 (0.48-0.89)</td>
</tr>
<tr>
<td>Large shopping mall</td>
<td>1</td>
<td>2.15 (1.73-2.68)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.30 (1.75-3.03)</td>
<td>1.21 (0.88-1.65)</td>
</tr>
<tr>
<td>Exhibitions and shows</td>
<td>1</td>
<td>1.70 (1.31-2.21)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.12 (1.56-2.90)</td>
<td>1.29 (0.91-1.82)</td>
</tr>
<tr>
<td>Place of worship</td>
<td>1</td>
<td>1.34 (1.01-1.78)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.38 (0.97-1.96)</td>
<td>1.11 (0.76-1.62)</td>
</tr>
<tr>
<td>Sports facilities</td>
<td>1</td>
<td>0.98 (0.72-1.35)</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.92 (0.61-1.39)</td>
<td>1.07 (0.68-1.67)</td>
</tr>
<tr>
<td>Museum</td>
<td>1</td>
<td>1.02 (0.66-1.56)</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.17 (0.69-1.96)</td>
<td>0.87 (0.49-1.54)</td>
</tr>
<tr>
<td>Hospital</td>
<td>1</td>
<td>1.42 (0.90-2.24)</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.85 (0.43-1.69)</td>
<td>0.72 (0.35-1.48)</td>
</tr>
<tr>
<td>Monument, tourist setting</td>
<td>1</td>
<td>1.52 (0.69-3.29)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.25 (0.97-5.24)</td>
<td>1.35 (0.53-3.44)</td>
</tr>
<tr>
<td>Station</td>
<td>1</td>
<td>2.08 (1.51-2.88)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5.76 (4.14-8.01)</td>
<td>3.80 (2.66-5.36)</td>
</tr>
</tbody>
</table>

SCA categories: 1=1 SCA in the grid cell, 2 = 2 or more SCA in the grid cell (cells without SCA used as reference)
Figure Legends:

**Figure 1.** Flow Chart.

**Figure 2.** Location of SCA Occurring in Public Places in Paris City (2000–2010).

**Figure 3.** Association Between Classes of Population Density and Population Movements in Regards to SCA Occurrence.

**Figure 4.** Descriptive Approach Aiming to Compare the Population Movements and Occurrence of SCA in the Six Major Train Stations (Red) Versus in the Six Most Touristic Sites (Green) in Paris.
Out-of-Hospital Cardiac Arrests Considered for Resuscitation
*From 01/2000 to 07/2010*
*Paris City*
N=5,296

Evidence of Extra-Cardiac Etiology
N=1,120

Sudden Cardiac Arrests
N=4,176

Home Location
N=2,921

Public Location
N=1,255

Admitted to Hospital
N=615 (NA=52)
### Population Density (per hectare)

<table>
<thead>
<tr>
<th>Population Density</th>
<th>0</th>
<th>&lt;100</th>
<th>100-200</th>
<th>200-300</th>
<th>300-400</th>
<th>≥400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Grid-Cell</td>
<td>93</td>
<td>506</td>
<td>495</td>
<td>526</td>
<td>284</td>
<td>116</td>
</tr>
<tr>
<td>Number of SCA</td>
<td>31</td>
<td>335</td>
<td>302</td>
<td>324</td>
<td>173</td>
<td>90</td>
</tr>
<tr>
<td>Mean SCA per Grid-Cell</td>
<td>0.333</td>
<td>0.662</td>
<td>0.61</td>
<td>0.616</td>
<td>0.609</td>
<td>0.776</td>
</tr>
</tbody>
</table>

### Population Movements (thousand per day)

<table>
<thead>
<tr>
<th>Population Movement</th>
<th>&lt;2</th>
<th>2-3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-6</th>
<th>≥6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Grid-Cells</td>
<td>424</td>
<td>223</td>
<td>291</td>
<td>265</td>
<td>241</td>
<td>576</td>
</tr>
<tr>
<td>Number of SCA</td>
<td>89</td>
<td>83</td>
<td>125</td>
<td>143</td>
<td>176</td>
<td>639</td>
</tr>
<tr>
<td>Mean SCA per Grid-Cell</td>
<td>0.21</td>
<td>0.37</td>
<td>0.43</td>
<td>0.54</td>
<td>0.73</td>
<td>1.11</td>
</tr>
</tbody>
</table>

**Figure 3**
Figure 4

Mean movement per day (thousand) vs Total cases of SCA

- Lyon Station
- Parc des expositions
- Montparnasse Station
- Notre-Dame
- Saint Lazare Station
- Beaubour Center
- Nord Station
- Louvre Museum
- Est Station
- Montmartre
- Austerlitz Station
- Eiffel Tower
Population Movement and Sudden Cardiac Arrest Location
Eloi Marijon, Wulfran Bougouin, Muriel Tafflet, Nicole Karam, Daniel Jost, Lionel Lamhaut, Frankie Beganton, Patricia Pelloux, Hervé Degrange, Guillaume Beal, Jean-Pierre Tourtier, Albert Alain Hagege, Jean-Yves Le Heuzey, Michel Desnos, Florence Dumas, Christian Spaulding, David S. Celermajer, Alain Cariou and Xavier Jouven

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Supplemental Material

Methods

We estimated the risk of having SCA in one of the 2,020 grid-cells containing specific city landmark. We used a count model, the negative binomial regression. This model allowed better consideration of the over-dispersion compared to the Poisson regression in our sample data. The dependent variable was the number of public SCA in each grid-cell; the independent variable was the presence or absence of the landmarks in the grid-cell. We normalized each cell by using the logarithm of population movements (per each unity i.e. the grid-cell) as an offset. We provided first a univariate model and then a multivariate model considering adjustment on other landmarks in the grid-cell. The relative risk (RR) of the cell containing the landmark was the exponential of the regression coefficient, using SAS PROC GENMOD with negative binomial probability distribution and log link function.\textsuperscript{19, 31}

Table Legend

Relative Risk for SCA of Grid-Cells Containing Specific Landmark. Univariate and Multivariate Analyses (Negative Binomial Regression Model). The RR represents the risk of SCA in a grid-cell with specific landmark compared to grid-cell without the considered landmark.

Table

<table>
<thead>
<tr>
<th>Grid-Cell Characteristics†</th>
<th>Grid-Cell, N</th>
<th>SCA, N\textsuperscript{‡}</th>
<th>Univariable RR (95%CI)</th>
<th>P Value</th>
<th>Multivariable RR (95%CI) *</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary to high schools</td>
<td>893</td>
<td>496</td>
<td>0.69 (0.6 - 0.8)</td>
<td>&lt;0.0001</td>
<td>0.73 (0.63 - 0.84)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Large shopping mall</td>
<td>646</td>
<td>531</td>
<td>0.95 (0.82 - 1.1)</td>
<td>0.49</td>
<td>0.93 (0.8 - 1.07)</td>
<td>0.49</td>
</tr>
<tr>
<td>Exhibitions and shows</td>
<td>383</td>
<td>309</td>
<td>0.93 (0.79 - 1.1)</td>
<td>0.41</td>
<td>0.95 (0.8 - 1.12)</td>
<td>0.29</td>
</tr>
<tr>
<td>Place of worship</td>
<td>311</td>
<td>222</td>
<td>0.89 (0.74 - 1.08)</td>
<td>0.23</td>
<td>0.94 (0.78 - 1.13)</td>
<td>0.52</td>
</tr>
<tr>
<td>Train station</td>
<td>258</td>
<td>418</td>
<td>1.82 (1.54 - 2.15)</td>
<td>&lt;0.0001</td>
<td>1.77 (1.5 - 2.09)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sports facilities</td>
<td>250</td>
<td>161</td>
<td>1.12 (0.9 - 1.39)</td>
<td>0.32</td>
<td>1.16 (0.93 - 1.43)</td>
<td>0.19</td>
</tr>
<tr>
<td>Museum</td>
<td>132</td>
<td>115</td>
<td>0.97 (0.74 - 1.28)</td>
<td>0.84</td>
<td>0.91 (0.69 - 1.19)</td>
<td>0.49</td>
</tr>
<tr>
<td>Hospital</td>
<td>98</td>
<td>57</td>
<td>0.86 (0.62 - 1.19)</td>
<td>0.37</td>
<td>0.93 (0.68 - 1.28)</td>
<td>0.66</td>
</tr>
<tr>
<td>Touristic sites</td>
<td>36</td>
<td>37</td>
<td>1.05 (0.65 - 1.69)</td>
<td>0.84</td>
<td>0.98 (0.63 - 1.55)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

CI denotes confidence interval, RR, relative risk, SCA, sudden cardiac arrest.
†Grid cells are defined as 200*200-m areas.
‡ Denotes the total number of SCA within a grid cell containing a given landmark. The number of SCA can overlap between the different grid-cell characteristics because one grid-cell can contain several landmarks. Overall, 1,255 SCA occur over 2,020 grid-cells, including 1,555 grid-cells with at least one characteristics/landmark (1,132 SCA) and 465 grid-cells with none of the characteristics mentioned on the table (123 SCA).

* Multivariable model considering adjustment on other landmarks of the grid-cell.