RESUSCITATION PLUS 17 (2024) 100561

Available online at www.sciencedirect.com

Resuscitation Plus

journal homepage: www.elsevier.com/locate/resuscitation-plus

Rapid response systems

Access to automated external defibrillators and first responders: Associations with socioeconomic factors and income inequality at small spatial scales

Dokyeong Lee[a,*], *Martin Bender*[b], *Stefan Poloczek*[b], *Christopher Pommerenke*[b], *Eiko Spielmann*[b], *Ulrike Grittner*[c,d], *Christof Prugger*[a]

Abstract

Aim: The 2021 European Resuscitation Council (ERC) guidelines recommend two automated external defibrillators (AEDs)/km^2 and at least 10 first responders/km^2. We examined 1) access to AEDs and volunteer first responders in line with these guidelines and 2) its associations with socioeconomic factors and income inequality, focusing on small spatial scales.

Method: We considered data on 776 AEDs in February 2022 and 1,173 out-of-hospital cardiac arrests (OHCAs) including 713 OHCA with app-alerted volunteer first responders from February to September 2022 in Berlin. We fit multilevel models to analyse AED area coverage and Poisson models to examine first responder availability across 12 districts and 536 neighbourhoods.

Results: Median AED area coverage according to the 2021 ERC guidelines was 43.1% (interquartile range (IQR) 2.3–87.2) at the neighbourhood level and median number of available first responders per OHCA case was one (IQR 0.0–1.0). AED area coverage showed a positive association with average income tax per capita, with better coverage in the highest compared to the lowest quartile neighbourhoods (coefficient: 0.13, 95% confidence interval (CI): 0.01–0.25). First responder availability was not associated with income tax. AED area coverage and first responder availability were positively associated with income inequality, with better coverage (coefficient: 0.13, 95% CI: 0.04–0.23) and availability (rate ratio: 1.31, 95% CI: 1.03–1.67) in quartiles of highest as compared to lowest inequality.

Conclusion: Access to resuscitation resources is neither equitable nor in accordance with the 2021 ERC guidelines. Ensuring better access necessitates understanding of socioeconomic factors and income inequality at small spatial scales.

Keywords: Automated external defibrillator, App-based alert system, Small spatial scale, Socio-economic factors, Income inequality

Introduction

Prompt access to automated external defibrillators (AEDs) and volunteer first responders is of paramount importance for improving the prognosis of out-of-hospital cardiac arrest (OHCA).[1] Nonetheless, access to resuscitation resources is subject to variation associated with socioeconomic factors at small spatial scales.[2]

Previous studies examined AED accessibility in relation to local socioeconomic factors using various metrics such as AED area ratio,[3,4] mean number of AEDs per area,[5] and OHCA risk coverage based on previous incident sites.[6–8] The findings indicate that AED accessibility can vary significantly by area level socioeconomic status; better access was associated with lower social deprivation, higher educational attainment, and greater household income.[3–8] The available evidence on the association of AED access with income inequality is rather limited; we previously showed better AED density with greater inequality at small spatial scales.[7] Bystander cardiopulmonary resuscitation (CPR) has been similarly associated with area-level socioeconomic factors,[9–14] but the relationship of app- or text-based first response with such factors as well as income inequality has not yet been examined.

* Corresponding author at: Institute of Public Health, Charité – Universitätsmedizin Berlin, Chariteplatz 1, 10117 Berlin Germany.
E-mail address: dokyeong.lee@charite.de (D. Lee).

https://doi.org/10.1016/j.resplu.2024.100561
Received 1 September 2023; Received in revised form 10 January 2024; Accepted 14 January 2024

The 2021 ERC guidelines recommend two AEDs and at least 10 volunteer first responders per km^2 for early access to resuscitation resources,[15] given the improved public's capability by app- or text-based alert systems to promptly summon volunteer first responders in the event of suspected OHCAs.[16–18] This interconnected system-level approach strives to ensure equal access to resuscitation resources across entire areas and emphasize the necessity of rectifying disparities in AED and first responder availability. However, no prior study has examined access to AEDs and first responders based on the 2021 ERC guidelines or investigated their associations with socioeconomic factors and income inequality.

Hence, this study aimed to assess the area coverage of AEDs and the availability of volunteer first responders as well as their associations with socioeconomic factors and income inequality at small spatial scales using data from the city of Berlin, Germany.

Methods

This cross-sectional study examines small spatial scales within Berlin, encompassing 542 neighbourhoods (mean population: 6,900 in 2020[19]distributed across 12 districts. We delineated Berlin neighborhoods using 'Planungsräume' (planning areas), the smallest units for managing demographic and social dynamics,[19] which vary in size and population. We excluded six neighbourhoods with a population size of less the 300 inhabitants due to data protection considerations.

In our study, area coverage of AEDs is assessed at the neighbourhood level (i.e., units of analysis are neighbourhoods). Further, first responder availability is assessed at the OHCA case level (i.e., units of analysis are OHCA cases).

Emergency medical system, app-based alert system, and AED registries

The Berlin Fire and Rescue Service is the central authority responsible for Emergency Medical Services (EMS) coordination across the Berlin catchment area, covering 3.7 million residents and 891.7 km^2.[19] The EMS department maintains a comprehensive OHCA registry pursuant to Utstein style[20] that encompasses the protocols of all EMS providers operating within its jurisdiction.

Since 2020, the emergency dispatch centre notifies, via an app-based alert system called KATRETTER, nearby volunteer first responders about patients with suspected OHCA, discerned based on telephone interrogations with the Advanced Medical Priority Dispatch System (AMPDS). Individuals are eligible to register in the KATRETTER system regardless of whether they have completed a CPR and/or AED course. As of October 15, 2022, an enrolment of 10,102 individuals as volunteer first responders was recorded.[21] The KATRETTER alarm activates within a 500-meter radius of the patient's site, which can be extended up to 1,000 meters in the city's outskirts. Each alarm persists for 45 seconds and is iterated up to three times until three responders have accepted the activation; however, more than three responders are possible if the last alarm has more activations than targeted (e.g., 1–1–2) as once accepted activations are not cancelled.

AED installation in Berlin is entirely reliant on private initiatives, with no legal obligation to report publicly accessible AEDs to a regulatory entity. In Berlin, two registries, administered by non-profit organisations "DefiNetz" and "Berlin Schockt", are accessible to volunteer first responders via their respective apps. Of note, the app-based alert system KATRETTER currently lacks connection with AED registry data. Although the dispatch centre holds AED location data from a subset of AEDs in Berlin, the inclusion of AED navigational guidance in standard telephone CPR instructions is uncommon.

Study sample

The study analysed geo data of 776 AEDs retrieved from the "DefiNetz" and "Berlin Schockt" databases on 7 and 10 February 2022, respectively, following the exclusion of 201 duplicate entries, four AEDs located at airports, and two entries with incomplete geospatial data.

For the analysis of AED area coverage, we extracted potential OHCA cases between February 11 and September 30, 2022 from the Berlin Fire and Rescue Service control centre database using Structured Query Language (Supplemental Material). We chose February 11, 2022 to consider OHCA cases after the date of AED retrieval Further, September 30, 2022 was the date of this extraction from the database.

For the analysis of first responder availability, we considered suspected OHCA cases between February 11 and September 30, 2022 identified by systematized caller interrogations with in the AMPDS, which activates the app-based alert system KATRETTER. We distinguished OHCAs according to time of the day (day from 06:00 to 17:59 and night from 18:00 to 05:59).

The ethics committee of Charité – Universitätsmedizin Berlin approved the study (EA4/086/22).

Configuration of geospatial map

We used OHCA zones with a radius of 399.04 m around each OHCA site (corresponding to a 0.5 km^2 area) to calculate AED coverage. After identifying OHCA zones possessing at least one AED, we dissolved areas of overlap between zones and computed the surface of OHCA zones with AEDs and all OHCA zones at the neighbourhood level. Sparsely populated areas under the Federal Nature Conservation Act were identified and subtracted from the areas. Proximity of OHCA cases to commercial and congested areas (<100-meter linear distance) was determined using Google Maps to account for frequentation density. Spatial analyses of AEDs and OHCA sites were conducted using QGIS Version 3.4 (QGIS Development Team, Zurich, Switzerland).

Study endpoints

The primary study endpoint was the area coverage of AEDs at the neighbourhood level, defined as the surface of OHCA zones with at least one AED in relation to the total surface of OHCA zones within the neighbourhood. This endpoint enables the consideration of AED density per 0.5 km^2, in accordance with the 2021 ERC guidelines recommending two AEDs per km^2. The secondary study endpoint was the availability of first responders at the OHCA case level, assessed by the number of responders accepting the alarm (0, 1, 2, 3 or more).

Neighbourhood and district factors

Neighbourhood factors considered were the 2020 unemployment rate and the 2020 proportion of residential areas with substandard living conditions, defined as a high level of structure density, limited availability of green or open spaces, and exposure to noise and odour pollution.[19] District factors considered were: 2017 economic level (average income tax per capita)[22]; 2020 income inequality level (Gini coefficient on a scale ranging from zero (perfect equality) to one (maximum inequality))[23]; 2020 low educational attainment level (percentage of individuals aged $\geq$ 25 years with a low level of education according to the International Standard Classification of Education (levels 0–2)).[18] Regional reports from the Berlin Senate Department for Urban Development[19] and the Berlin-Brandenburg Statistics Office[23] as well as a response from the Berlin Senate Department for Finances[22] were the data sources.

Statistical analyses

We described the study endpoints as means and standard deviations (SDs) or medians and interquartile ranges (IQRs) by quartiles of socioeconomic factors and income inequality. To examine associations of AED area coverage, we used multilevel linear regression (MLR) models, considering the hierarchical data structure with neighbourhoods (level 1, N = 536) nested within districts (level 2, N = 12). We fit separate random-intercept MLR models including the district-level variables income tax per capita (economic model) and Gini coefficient (income inequality model) plus one further district-level variable (low educational attainment) and two neighbourhood-level variables (unemployment rate, substandard living conditions) as explanatory variables. To analyse associations of first responder availability, we used generalized linear regression (GLR) models with Poisson link function accounting for the intra-class correlation (ICC) and the data distribution. We fit separate GLR models for each explanatory variable and additionally included the variables commercial and congested area as well as time of the day. We estimated coefficients (in MLR models) and rate ratios (RRs) (in GLR models) with 95 % confidence intervals (CI) for quartiles of socioeconomic factors and income inequality using quartile 1 as the reference category. As the dependent variables in the MLR models were log-transformed, coefficient estimates can be interpreted as percentage change. Analyses of the secondary endpoint are exploratory. The statistical analysis was performed using R Version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Fig. 1 shows the selection of the analytical samples for both study outcomes. For the analysis of access to AEDs, 5,017 potential OHCA cases were retrieved from the database, with 1,554 OHCA cases confirmed on-site. Excluding 381 cases (due to delayed death declaration, insufficient documentation, unknown address, and locations outside the study area), the analytic sample comprised 1,173 OHCA cases. For the analysis of first responder availability, 2,831 suspected OHCA cases were identified by the AMPDS, of which 2,477 cases triggered the KATRETTER alarm, with 713 confirmed OHCA on-site, including 457 cases from day and 256 cases from night.

Fig. 2 shows OHCA zones based on 1,173 cases and surrounding areas of 0.5 km^2. On average, OHCA zones accounted for 62.1 % (SD 30.3) of neighbourhood surfaces, and 43.1 % (IQR 2.3–87.2) of OHCA zones had access to at least one AED. The median number of available first responders per OHCA case was

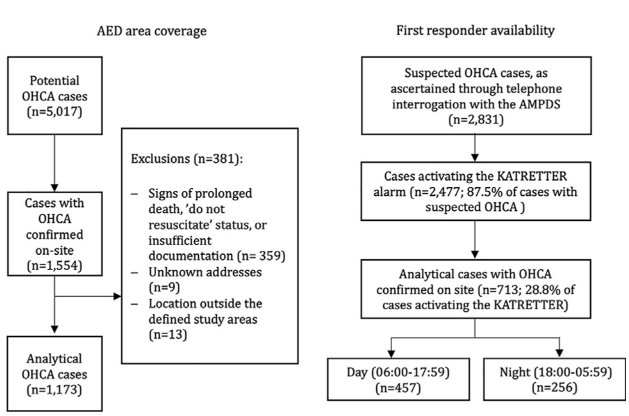

Fig. 1 – Selection of analytical cases for each study endpoint. OHCA; Out-of-Hospital Cardiac Arrest, AMPDS; Advanced Medical Priority Dispatch System.

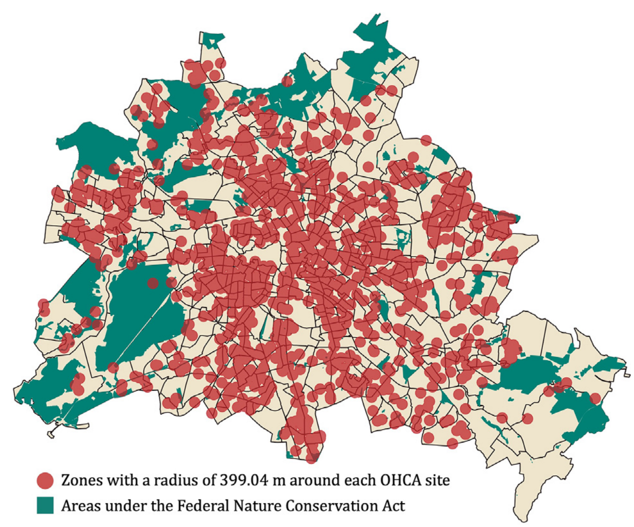

Fig. 2 – OHCA zones in Berlin. OHCA zones defined as areas with a radius of 399.04 m around previous OHCA incident sites.

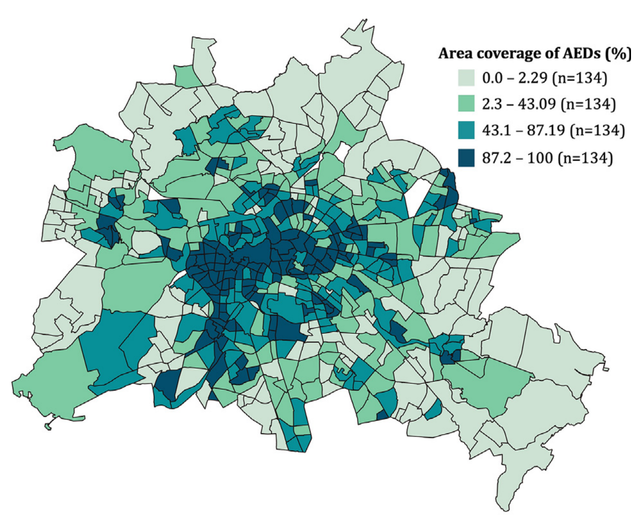

Fig. 3 – Neighbourhoods by quartiles of AED area coverage. Area coverage defined as the surface of OHCA zones with at least one AED in relation to the total surface of OHCA zones within the neighbourhood.

Table 1 – Study metrics by quartiles of socioeconomic factors and income inequality.

	Neighbourhood level (N = 536)				OHCA case level (N = 713)
	OHCA zones[a]		OHCA zones with at least 1 AED		First responders available
	Surface (km^2), median (IQR)	Surface to total neighbourhood surface (%), mean (SD)	Surface (km^2), median (IQR)	Surface to total OHCA zones' surface (%), median (IQR) *(=AED area coverage)*	Number of volunteer first responder, median (IQR) *(=first responder availability)*
Berlin	0.50 (0.33–0.76)	62.1 (30.3)	0.19 (0.08–0.41)	43.1 (2.3–87.2)	1.0 (0.0–1.0)
Neighbourhood level					
Unemployment[b]					
Quartile 1 (low)	0.56 (0.32–0.96)	42.3 (28.1)	0.01 (0.0–0.30)	5.0 (0.0–55.1)	1.0 (0.0–1.0)
Quartile 2	0.50 (0.33–0.68)	65.9 (30.6)	0.26 (0.08–0.43)	58.6 (17.2–96.6)	1.0 (0.0–1.0)
Quartile 3	0.55 (0.34–0.76)	66.1 (27.5)	0.25 (0.04–0.46)	50.5 (14.1–89.1)	1.0 (0.0–1.0)
Quartile 4 (high)	0.42 (0.32–0.66)	74.2 (25.3)	0.21 (0.06–0.40)	53.9 (11.8–90.3)	1.0 (0.0–1.0)
Substandard living conditions[c]					
Quartile 1 (low)	0.49 (0.33–0.71)	63.2 (30.1)	0.21 (0.03–0.42)	54.2 (0.1–93.2)	1.0 (0.0–1.0)
Quartile 2	0.71 (0.50–1.03)	47.9 (26.4)	0.23 (0.0–0.44)	35.5 (0.0–70.6)	1.0 (0.0–1.0)
Quartile 3	0.67 (0.41–0.92)	58.1 (29.9)	0.18 (0.0–0.41)	28.8 (0.0–72.1)	1.0 (0.0–1.0)
Quartile 4 (high)	0.40 (0.27–0.55)	67.1 (30.9)	0.17 (0.01–0.36)	44.5 (0.0–89.5)	1.0 (0.0–1.0)
District level					
Low educational attainment[d]					
Quartile 1 (low)	0.45 (0.31–0.72)	54.3 (52.4)	0.10 (0.0–0.32)	31.4 (0.0–76.3)	1.0 (0.0–1.0)
Quartile 2	0.52 (0.35–0.72)	66.4 (74.0)	0.31 (0.12–0.41)	61.9 (30.5–95.4)	1.0 (0.0–1.0)
Quartile 3	0.51 (0.32–0.81)	69.3 (76.2)	0.25 (0.05–0.49)	63.2 (0.1–92.9)	1.0 (0.0–1.75)
Quartile 4 (high)	0.50 (0.33–0.89)	59.7 (64.2)	0.14 (0.0–0.33)	29.0 (0.0–62.9)	0.0 (0.0–1.0)
Income tax per capita[e]					
Quartile 1 (low)	0.57 (0.37–0.83)	55.2 (30.7)	0.11 (0.0–0.34)	22.9 (0.0–63.9)	1.0 (0.0–1.0)
Quartile 2	0.41 (0.28–0.66)	59.6 (29.5)	0.09 (0.0–0.26)	27.4 (0.0–65.6)	0.0 (0.0–1.0)
Quartile 3	0.51 (0.32–0.74)	69.8 (28.3)	0.33 (0.14–0.48)	73.1 (36.0–97.3)	1.0 (0.0–1.0)

Table 1 (continued)

	Neighbourhood level (N = 536)				OHCA case level (N = 713)
	OHCA zones[a]		OHCA zones with at least 1 AED		First responders available
Quartile 4 (high)	0.50 (0.34–0.70)	63.0 (31.1)	0.20 (0.07–0.42)	55.5 (7.1–95.5)	1.0 (0.0–1.0)
Gini coefficient[f]					
Quartile 1 (low)	0.57 (0.37–0.83)	55.2 (30.7)	0.11 (0.0–0.34)	22.9 (0.0–63.9)	1.0 (0.0–1.0)
Quartile 2	0.52 (0.31–0.83)	59.5 (29.3)	0.18 (0.0–0.39)	36.5 (0.0–72.8)	1.0 (0.0–1.0)
Quartile 3	0.39 (0.32–0.55)	80.5 (19.9)	0.30 (0.17–0.42)	88.4 (37.5–100)	1.0 (0.0–1.0)
Quartile 4 (high)	0.43 (0.31–0.61)	73.1 (29.7)	0.35 (0.14–0.52)	87.7 (43.1–99.8)	1.0 (0.0–2.0)

OHCA: out-of-hospital cardiac arrest, AED: automated external defibrillator.
[a] OHCA zone: OHCA incident sites with a 399.04 m radius.
[b] Unemployment rate: the proportion of unemployed persons of working age (aged above 15 years and below the statutory retirement age) to all persons of working age the neighbourhood level.
[c] Substandard living conditions: the percentage of residential areas with a substandard living condition (according to the rent index; including noise pollution from road traffic) to the total resident area at the neighbourhood level.
[d] Low-level educational attainment: the percentage of persons, aged 25 years and over, with a low level of education (according to the International Standard Classification of Education level 0–2) at the district level.
[e] Income tax per capita: the mean income tax per capita at the district level.
[f] Gini coefficient: measure of income inequality from 0 (expresses perfect equality) to 1 (expresses maximal inequality) at the district level.

one (IQR 0.0–1.0). The number (%) of OHCA with zero, one, two, three, and four first responders was 319 (44.7 %), 261 (36.6 %), 107 (15 %), 24 (3.4 %), and 2 (0.3 %), respectively. Fig. 3 shows Berlin neighbourhoods according to quartiles of AED area coverage. The coverage was highest in the city centre and decreased towards the city's outskirts.

Table 1 presents the study metrics by quartiles of socioeconomic factors and income inequality. The AED area coverage was higher in upper compared to lower income tax quartile neighbourhoods (22.9 % (IQR 0.0–63.9) in quartile 1 vs 55.5 % (IQR 7.1–95.5) in quartile 4). Further, AED area coverage was higher in neighbourhoods with greater inequality according to the Gini coefficient, ranging from 22.9 % (IQR 0.0–63.9) in quartile 1 to 87.7 % (IQR 43.1–99.8) in quartile 4.

Association of AED area coverage

The district level accounted for 18 % of the variance in area coverage at neighbourhood level (ICC = 0.18). Table 2 presents coefficient estimates with 95 % CI from multilevel models for associations of AED area coverage. A positive association was observed with per capita income tax, with quartiles 3 and 4 showing a 15 % and 13 % higher AED area coverage, respectively, as compared to quartile 1 (coefficient [95 % CI]: 0.15 [0.05–0.25] in quartile 3; 0.13 [0.01–0.25] in quartile 4). A positive association with income inequality was also observed; compared to quartile 1, quartiles 2, 3, and 4 exhibited a 6 %, 13 %, and 26 % higher AED area coverage, respectively (coefficient [95 % CI]: 0.06 [0.01–0.11] in quartile 2, 0.13 [0.04–0.23] in quartile 3, and 0.26 [0.19–0.32] in quartile 4). A positive association was observed with unemployment rate in the economic model (coefficient 0.20, 95 % CI 0.13–0.27 in quartile 4) and the income inequality model (coefficient 0.19, 95 % CI 0.12–0.26 in quartile 4). A negative association was found with substandard living conditions in the economic model (coefficient – 0.07, 95 % CI −0.14–−0.00 in quartile 4) and the income inequality model (coefficient – 0.08, 95 % CI −0.14–−0.01 in quartile 4).

Associations of first responder availability

The district level correlation among neighbourhoods regarding the volunteer first responder availability was negligible (ICC = 0.02). Table 3 presents RRs and 95 % CI from Poisson models for associations of first responder availability. No association was found of first responder availability with income tax per capita. A positive association was observed with the highest level of the Gini coefficient, with a 31 % higher responder availability in quartile 4 compared to quartile 1 (RR 1.31, 95 % CI 1.03–1.67). A negative association was found with unemployment rate, with a 22 % lower level in responder availability in quartile 4 compared to quartile 1 (RR 0.78, 95 % CI 0.61–0.98). Similarly, a negative association was found with low educational attainment level, with a 28 % lower availability in quartile 4 compared to quartile 1 (RR 0.72, 95 % CI 0.55–0.92). No association was observed with substandard living conditions.

Discussion

The present study is, to our knowledge, the first to investigate access to AEDs and first responders in accordance with the 2021 ERC guidelines and their associations with socioeconomic factors and income inequality at small spatial scales.

Table 2 – Coefficients with 95% confidence intervals for associations of AED area coverage at the neighbourhood level with socioeconomic factors and income inequality.

	Economic model		Income inequality model	
	Coefficient [95 % CI]	*P*-value	Coefficient [95 % CI]	*P*-value
Neighbourhood level				
Unemployment				
Quartile 1 (low)	Ref.		Ref.	
Quartile 2	0.18 [0.12; 0.23]	<0.001	0.18 [0.12; 0.23]	<0.001
Quartile 3	0.19 [0.13; 0.25]	<0.001	0.19 [0.13; 0.25]	<0.001
Quartile 4 (high)	0.20 [0.13; 0.27]	<0.001	0.19 [0.12; 0.26]	<0.001
Substandard living conditions				
Quartile 1 (low)	Ref.		Ref.	
Quartile 2	– 0.05 [– 0.15; 0.04]	0.269	– 0.05 [– 0.14; 0.04]	0.282
Quartile 3	– 0.08 [– 0.14; – 0.03]	0.004	– 0.07 [– 0.13; – 0.02]	0.011
Quartile 4 (high)	– 0.07 [– 0.14; – 0.00]	0.037	– 0.08 [– 0.14; – 0.01]	0.025
District level				
Low educational attainment				
Quartile 1 (low)	Ref.		Ref.	
Quartile 2	0.08 [– 0.05; 0.22]	0.235	0.17 [0.10; 0.24]	<0.001
Quartile 3	0.05 [– 0.09; 0.18]	0.492	0.09 [0.03; 0.15]	0.002
Quartile 4 (high)	– 0.03 [– 0.12; 0.07]	0.589	0.04 [– 0.02; 0.11]	0.191
Income tax per capita				
Quartile 1 (low)	Ref.			
Quartile 2	0.05 [– 0.07; 0.16]	0.443		
Quartile 3	0.15 [0.05; 0.25]	0.014		
Quartile 4 (high)	0.13 [0.01; 0.25]	0.047		
Gini coefficient				
Quartile 1 (low)			Ref.	
Quartile 2			0.06 [0.01; 0.11]	0.011
Quartile 3			0.13 [0.04; 0.23]	0.008
Quartile 4 (high)			0.26 [0.19; 0.32]	<0.001

Coefficients with 95% confidence intervals from separate multilevel random intercept models for income tax per capita (economic model) and Gini coefficient (income inequality model), with 536 neighbourhoods nested within 12 districts.

Based on registry data from Berlin, our results show that AED area coverage was positively associated with income tax, while first responder availability was not. Both AED area coverage and first responder availability were positively associated with income inequality. AED area coverage was positively associated with unemployment rate and negatively associated with substandard living conditions, whereas first responder availability was negatively associated with unemployment rate and low educational attainment level.

Methodological aspects of AED area coverage assessment

Previous studies included entire neighbourhoods and total numbers of AEDs in assessing AED area ratio and AED density.[2–4] This approach may result in biased estimation due to sparsely populated areas and large numbers of AEDs in certain locations. To overcome this issue, we excluded green and terrain-protected areas and established 0.5 km^2 zones based on OHCA incidence sites, aligning with the recommendation of two AEDs per km^2. This approach is applicable to other settings.

Socioeconomic factors at small spatial scales

Prior studies showed a pronounced positive association of AED accessibility with the economic level at spatial scales.[3,6,7] Our results indicate this association persists under the 2021 ERC guidelines, emphasizing the pivotal role of financial resources in ensuring equitable spatial distribution of AEDs.[24,25] Further, prior studies showed positive associations of bystander CPR with the economic level,[9,11,12] but we observed no association of first responder availability with income tax per capita. This finding suggests use of an app-based alert system flattens disparities according to area income and supports prior studies indicating the efficacy of such a system in improving bystander CPR rates.[26,27] The finding further suggests volunteer first responders who bring AEDs to the scene may represent a future strategy for equitable access. Our analysis shows inconsistent associations of resuscitation resources with neighbourhood unemployment rate in line with previous research: a positive association of AED accessibility[3] and a negative association of first responder availability with unemployment rate.[13,28] Such incongruity may impede the optimal resource utilization and disrupt the continuity in the chain of survival.[29]

Education level is considered a crucial factor in bystander CPR engagement.[11,12] We extrapolate previous finding in this regard to app-based first responder availability showing a negative association with low educational attainment, but only at the highest level. This may be due to educated individuals being involved in the app-based first responder system[28] and their engagement remaining unaffected by local educational attainment level until a certain threshold is surpassed.

Table 3 – Rate ratios and 95% confidence intervals for associations of first responder availability at the OHCA case level with socioeconomic factors and income inequality.

	Rate Ratio [95 % CI]	*P*-value
Neighbourhood level		
Unemployment		
Quartile 1 (low)	Ref.	
Quartile 2	0.93 [0.74; 1.16]	0.504
Quartile 3	0.76 [0.60; 0.97]	0.025
Quartile 4 (high)	0.78 [0.61; 0.98]	0.035
Substandard living conditions		
Quartile 1 (low)	Ref.	
Quartile 2	0.88 [0.71; 1.08]	0.232
Quartile 3	0.88 [0.70; 1.08]	0.223
Quartile 4 (high)	1.02 [0.69; 1.45]	0.932
District level		
Low educational attainment		
Quartile 1 (low)	Ref.	
Quartile 2	1.04 [0.84; 1.29]	0.737
Quartile 3	1.08 [0.84; 1.37]	0.550
Quartile 4 (high)	0.72 [0.55; 0.92]	0.011
Income tax per capita		
Quartile 1 (low)	Ref.	
Quartile 2	0.88 [0.70; 1.10]	0.266
Quartile 3	1.12 [0.88; 1.41]	0.356
Quartile 4 (high)	1.12 [0.88; 1.43]	0.359
Gini coefficient		
Quartile 1 (low)	Ref.	
Quartile 2	0.95 [0.77; 1.17]	0.628
Quartile 3	1.07 [0.72; 1.56]	0.718
Quartile 4 (high)	1.31 [1.03; 1.67]	0.026

Rate ratios and 95% CI from separate generalized linear regression models with Poisson link function adjusted for commercial and congested area and time of the day, with 713 OHCA cases with app-based alert.

CI: confidence interval.

Income inequality at small spatial scales

Prior social epidemiology research has established a negative association between income inequality at spatial levels and population health.[30–32] Our findings, however, indicate a positive association between inequality and access to resuscitation resources. This deviance from previous research may relate to the small-scale spatial level of our study. In contrast to macro- or meso-level spatial contexts, micro-level spatial contexts such as neighbourhoods or districts are everyday living spaces. When analysing such small spatial context, the Gini coefficient may be seen as an indicator of income diversity rather than inequality. Aligned with Wilson's social mix theory,[33] individuals who are considerably wealthier than the general residents in a given area may more likely receive political attention, leading to the allocation of premium resources. This could foster a sense of collective efficacy within the community[34] and encourage community engagement in public health initiatives related to the chain of survival.

In the model development, we found a collinearity between the highest quartile of average per capita income tax and the highest quartile of the Gini coefficient. This was due to the influence of extreme values on the mean income tax. Further research should investigate the underlying mechanism linking economic level and income inequality and explore their potential impact on the resuscitation strategies and OHCA outcomes at small spatial scales.

Policy implications

Our study results, showing alert system activation in 87.5 % and 60.8 % of suspected and confirmed OHCA cases, respectively, AED area coverage according to the 2021 ERC guidelines of 43.1 %, and availability of only one volunteer first responder per OHCA case, emphasise the combined assessment of these indicators can reveal imbalances and imply priorities in guideline implementation.

Our study findings further underline the importance of considering potential associations of AED area coverage and first responder availability with socioeconomic factors and income inequality at small spatial scales: policy makers should focus on mitigating any disparities in resource accessibility that may relate to such contextual factors.

The 2021 ERC guidelines are based on a study conducted by Stieglis et al. in the Netherlands.[17] Lower OHCA survival rates in Germany than the Netherlands suggest shortcomings in guideline implementation.[35] Dutch AED dissemination has been enhanced by a synergy of public and private initiatives, coupled with a campaign for 24/7 AED accessibility, whereas Berlin's AED installation is solely dependent on private efforts without a similar campaign. The Dutch alert system activates up to 30 first responders,[17] while the KATRETTER system currently targets a smaller group of just three. Furthermore, the Dutch system operates AED dispatch within its alert mechanism, a feature not yet implemented in Berlin. Notably, from October 2020 to October 2022, 34 % of KATRETTER first responders in Berlin terminated their activation without initiating CPR, due to prior arrival of the rescue service,[21] indicating an area for potential system improvement. The Dutch regions investigated by Stieglis et al. and our study region Berlin are similarly urbanized according to the EUROSTAT classification.[36] However, considering degree of urbanisation may be relevant for guideline implementation.

Strengths and limitations

This study has several strengths. Firstly, the study provides first data on access to AEDs and volunteer first responders based on the 2021 ERC guidelines, using a stepped-up methodological approach, which accounts for sparsely populated areas and concentrated AED distribution. Secondly, the study provides novel insights into associations between accessibility of resuscitation resources and income inequality at small spatial scales. Thirdly, the analysis of responder availability considers OHCA occurrence time and congested areas as possible confounding factors. Of note, frequentation density may differ between day and night and urban areas considered (residential, tourist, and industrial).

This study is also subject to several limitations. First, as a cross-sectional study, the analysis does not account for temporal sequence. Second, the study was limited to OHCA cases that occurred over a period of approximately seven months, resulting in a selected sample of OHCA areas and a restricted sample of OHCA events with alert system activation. Third, we used socioeconomic data from 2017 and 2020, alongside outcome data from 2022. Thus, we could not consider potential recent changes in socioeconomic factors. Fourth, the AED registry data might be incomplete due to lack of mandatory registration, and we are unable to estimate the extent of AED registration. However, unregistered AEDs lack connection to the resuscitation system. Fifth, our study results, derived from a complex EMS in a high-income country, may lack generalizability to low- or middle-income countries.

Conclusion

This study substantiated inadequate accessibility of AEDs and first responders in relation to the 2021 ERC guidelines, with disparities related to socioeconomic factors and income inequality at small spatial scales. Ensuring public access to resuscitate resources necessitates a thorough understanding of social patterns underpinning the implementation. In particular, income inequality along with socioeconomic factors at small spatial scales should be considered to ensure equitable access to AEDs and volunteer first responders.

CRediT authorship contribution statement

Dokyeong Lee: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Martin Bender:** Writing – review & editing, Investigation, Data curation. **Stefan Poloczek:** Writing – review & editing, Investigation, Data curation. **Christopher Pommerenke:** Writing – review & editing, Investigation, Data curation. **Eiko Spielmann:** Writing – review & editing, Investigation, Data curation. **Ulrike Grittner:** Writing – review & editing, Methodology, Data curation. **Christof Prugger:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

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

Acknowledgment

The authors thank "DefiNetz" and "Berlin Schockt" for providing the geo data of publicly accessible AEDs. Furthermore, we are grateful to the volunteer first responders who engage in KATRETTER.

Declaration of generative AI and AI-assisted technologies in scientific writing

The authors have nothing to declare.

Funding/Support

Nothing to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100561.

Author details

[a]Institute of Public Health, Charité – Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Charitéplatz 1, 10117 Berlin, Germany [b]Emergency Medical Services Department, Berlin Fire and Rescue Service, Voltairestraße 2, 10179 Berlin, Germany[c]Institute of Biometry and Clinical Epidemiology, Charité – Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Charitéplatz 1, 10117 Berlin, Germany [d]Berlin Institute of Health, Charité – Universitätsmedizin Berlin, Charitéplatz 1, 10117 Berlin, Germany

REFERENCES

1. Nolan JP, Maconochie I, Soar J, Olasveengen TM, Greif R, Wyckoff MH, et al. Executive summary: 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendation. Circulation 2020;142:2–27.
2. Sasson C, Keirns CC, Smith D, et al. Small Area Variations in Out-of-Hospital Cardiac Arrest: Does the Neighborhood Matter? Ann Intern Med 2010;153:19–22.
3. Griffis HM, Band RA, Ruther M, Harhay M, Asch DA, Hershey JC, et al. Employment and residential characteristics in relation to automated external defibrillator location. Am Heart J 2016;172:185–91.
4. Brown TP, Perkins GD, Smith CM, Deakin CD, Fothergill R. Are there disparities in the location of automated external defibrillator in England? Resuscitation 2022;170:28–35.
5. Dicker B, Garrett N, Wong S, McKenzie H, McCarthy J, Jenkin G, et al. Relationship between socioeconomic factors, distribution of public access defibrillators and incidence of out-of-hospital cardiac arrest. Resuscitation 2019;138:53–8.
6. Heidet M, Freyssenge J, Claustre C, Deakin J, Helmer J, Thomas-Lamotte B, et al. Association between location of out-of-hospital cardiac arrest, on-scene socioeconomic status, and accessibility to public automated defibrillators in two large metropolitan area in Canada and France. Resuscitation 2022;181:97–109.
7. Lee D, Stiepak JK, Pommerenke C, Poloczek S, Grittner U, Prugger C. Public access defibrillators and socioeconomic factors on the small-scale spatial level in Berlin - a cross-sectional analysis. Dtsch Arztebl Int 2022;119:393–9.
8. Leung KHB, Brooks SC, Clegg CR, Chan TCY. Socioeconomically equitable public defibrillator placement using mathematical optimization. Resuscitation 2021;166:14–20.
9. Sasson C, Magid DJ, Chan P, Root ED, McNally BF, Kellermann AL, et al. Association of neighborhood characteristics with bystander-initiated CPR. N Engl J Med 2012;367:1607–15.
10. Root ED, Gonzales L, Persse DE, Hinchey PR, McNally B, Sasson C. A tale of two cities: the role of neighborhood socioeconomic status in spatial clustering of bystander CPR in Austin and Houston. Resuscitation 2013;84:752–79.
11. Andersen LW, Holmberg MJ, Granfeldt A, Løfgren B, Vellano K, McNally BF, et al. Neighborhood characteristics, bystander automated external defibrillator use, and patient outcomes in public out-of-hospital cardiac arrest. Resuscitation 2018;126:72–9.
12. Brown TP, Booth S, Hawkes CA, Soar J, Mark J, Mapstone J, et al. Characteristics of neighbourhoods with high incidence of out-of-hospital cardiac arrest and low bystander cardiopulmonary resuscitation rates in England. Eur Heart J Qual Care Clin Outcomes 2019;5:51–62.
13. Huebinger R, Vithalani V, Osborn L, Decker C, Jarvis J, Dickson R, et al. Community disparities in out of hospital cardiac arrest care and outcomes in Texas. Resuscitation 2021;163:101–7.
14. Reuter PG, Baert V, Colineaux H, Escutnaire J, Javaud N, Delpierre C, et al. A national population-based study of patients, bystanders and contextual factors associated with resuscitation in witnessed cardiac arrest: insight from the French RéAC registry. BMC Public Health 2021;21:2202.
15. Semero F, Greif R, Böttiger BW, Burkart R, Cimpoesu D, Georgiou M, et al. European Resuscitation Council Guidelines 2021: systems saving lives. Resuscitation 2021;161:80–97.

16. Stroop R, Lerner T, Strickmann B, Hensel M. Mobile phone-based alerting of CPR-trained volunteers simultaneously with the ambulance can reduce the resuscitation-free interval and improve outcome after out-of-hospital cardiac arrest: A German, population-based cohort study. Resuscitation 2020;147:57–64.
17. Stieglis R, Zijlstra J, Riedijk F, Smeekes M, Van der Worp WE, Koster RW. AED and text message responders density in residential areas for rapid response in out-of-hospital cardiac arrest. Resuscitation 2020;150:170–7.
18. Smith CM, Lall R, Spaight R, Fothergill RT, Brown T, Perkins GD. Calculating real-world travel routes instead of straight-line distance in the community response to out-of-hospital cardiac arrest. Resuscitation Plus 2021;8 100176.
19. Senatsverwaltung für Stadtentwicklung und Wohnen Berlin (ed.): Monitoring Soziale Stadtentwicklung 2021. Berlin. https://www.berlin.de/sen/sbw/stadtdaten/stadtwissen/monitoring-soziale-stadtentwicklung/bericht-2021/tabellen/ (last accessed on 08 November 2023).
20. Jacobs I, Nadkarni V, Bahr J, Berg RA, Billi JE, Bossaert L, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries: a statement for healthcare professionals from a task force of the International Liaison Committee on Resuscitation (American Heart Association, European Resuscitation Council, Australian Resuscitation Council, New Zealand Resuscitation Council, Heart and Stroke Foundation of Canada, InterAmerican Heart Foundation, Resuscitation Councils of Southern Africa). Circulation 2004;110:338597.
21. Pommerenke C, Poloczek S, Breuer F, Wolff J, Dahmen J. Automated and app-based activation of first responders for prehospital cardiac arrest: an analysis of 16.500 activation of the KATRETTER system in Berlin. Scand J Trauma Resusc. Emerg Med 2023;31:105.
22. Perdoni S: Überraschende Zahlen: So viel Steuern zahlen die Berliner. Berliner Zeitung (21.08.2018). www.berliner-zeitung.de/berlin/ueberraschende-zahlen-soviel-steuern-zahlen-die-berliner-31139632 (last accessed on 16 October 2019).
23. Amt für Statistik Berlin-Brandenburg (ed.): Regionaler Sozialbericht Berlin und Brandenburg 2021. Potsdam 2022. https://www.statistik-berlin-brandenburg.de/publikationen (last accessed on 08 November 2023).
24. Kuisma M, Castren M, Nurminen K. Public access defibrillation in Helsinki-costs and potential benefits from a community-based pilot study. Resuscitation 2003;56:149–52.
25. Neumann PJ, Cohen JT, Weinstein MC. Updating cost-effectiveness-the curious resilience of the $50,000-per-QALY threshold. N Engl J Med 2014;371:796–7.
26. Ringh M, Rosenqvis M, Hollenberg J, Jonsson M, Fredman D, Nordberg P, et al. Mobile-phone dispatch of layperson of CPR in out-of-hospital cardiac arrest. N Engl J Med 2015;372:2316–25.
27. Andelius L, Hansen CM, Lippert FK, Karlsson L, Trop-Pedersen C, Ersbøll AK, et al. Smartphone activation of citizen responders to facilitate defibrillation in out-of-hospital cardiac arrest. J Am Coll Cardiol 2020;76:43–53.
28. Uny I, Angus K, Duncan E, Dobbie F. Barriers and facilitators to delivering bystander cardiopulmonary resuscitation in deprived communities: a systematic review. Perspect Public Health 2023;143:43–53.
29. Stieglis R, Zijlstra JA, Riedijk F, Smeekes M, van der Worp WE, Tijssen JGP, et al. Alert system-supported lay defibrillation and basic life-support for cardiac arrest at home. Eur Heart J 2022;43:1465–74.
30. Liao T, De Maio F. Association of Social Economic Inequality with Coronavirus Disease 2019 Incidence and Mortality Across US Counties. JAMA Netw Open 2021;4:e2034578.
31. Pickett KE, Wilkinson RG. Income inequality and health: A causal review. Social Sci Medicine 2015;128:316–26.
32. Paskov M, Dewilde C. Income inequality and solidarity in Europe. Res Soc Stratif Mobil 2012;30:415–32.
33. Wilson WJ. The truly disadvantaged. Chicago: University of Chicago Press; 1987.
34. Steinmetz-Wood M, Wasfi R, Parker G, Bornstein L, Caron J, Kestens Y. Is gentrification all bad? Positive association between gentrification and individual's perceived neighborhood collective efficacy in Montreal. Canada Int J Health Geogr 2017;16:24.
35. Gräsner JT, Wnent J, Herlitz J, Perkins GD, Lefering R, Tjelmeland I, et al. Survival after out-of-hospital cardiac arrest in Europe—results of the EuReCa TWO study. Resuscitation 2020;148:218–26.
36. Degree of Urbanisation (DEGURBA). 2018. European Statistical Commission. Available at https://ec.europa.eu/eurostat/documents/7116161/7188982/DEGURBA-LAU-2018-Population-Grid-2011.pdf.