

ORIGINAL RESEARCH

Citizen Responder Activation in Out-of-Hospital Cardiac Arrest by Time of Day and Day of Week

Katarina Høgh Mottlau , MD; Linn Charlotte Andelius , MD; Rasmus Gregersen , MD; Carolina Malta Hansen, MD, PhD; Fredrik Folke , MD, PhD

BACKGROUND: We aim to examine diurnal and weekday variations in citizen responder availability and intervention at out-of-hospital cardiac arrest (OHCA) resuscitation.

METHODS AND RESULTS: We included confirmed OHCA where citizen responders were activated by a smartphone application in the Capital Region of Denmark between September 1, 2017 and August 31, 2018. OHCA were analyzed by time of day (daytime: 07:00 AM–03:59 PM, evening: 4:00–11:59 PM, and nighttime: 12:00–06:59 AM) and day of week (Monday–Friday or Saturday–Sunday/public holidays). We included 438 OHCA where 6836 citizen responders were activated. More citizen responders accepted alarms in the evening (mean 4.8 [95% CI, 4.4–5.3]) compared with daytime (3.7 [95% CI, 3.4–4.4]) and nighttime (1.8 [95% CI, 1.5–2.2]) ($P<0.001$), and more accepted alarms during weekends (4.3 [95% CI, 3.8–4.9]) compared with weekdays (3.4 [95% CI, 3.2–3.7]) ($P<0.001$). Proportion of OHCA where at least 1 citizen responder arrived before Emergency Medical Services were significantly different between day (42.9%), evening (50.3%), and night (26.1%) ($P<0.001$), and between weekdays (37.2%) and weekends (53.5%) ($P=0.002$). When responders arrived before Emergency Medical Services, there was no difference of bystander cardiopulmonary resuscitation or defibrillation between daytime, evening, and nighttime ($P=0.75$ and $P=0.22$, respectively) or between weekend and weekdays ($P=0.29$ and $P=0.12$, respectively).

CONCLUSIONS: Citizen responders were more likely to accept OHCA alarms during evening and weekends, with the highest proportion of responders arriving before Emergency Medical Services in the evening. However, there was no significant difference in delivering cardiopulmonary resuscitation or early defibrillation among cases where citizen responders arrived before Emergency Medical Services.

REGISTRATION: URL: <https://www.clinicaltrials.gov>; Unique identifier: NCT03835403.

Key Words: defibrillation ■ emergency medical services ■ out-of-hospital cardiac arrest ■ resuscitation

See Editorial by Stieglis and Koster.

Early cardiopulmonary resuscitation (CPR) and bystander defibrillation are associated with increased survival after out-of-hospital cardiac arrest (OHCA).^{1–4} Defibrillation within the first 3 to 5 minutes can increase survival up to 50% to 70%, but the majority of all OHCA occur in private homes where the use of automated external defibrillators (AEDs) and early defibrillation is low.^{5,6}

In Denmark, ~5400 OHCA occur each year with a 30-day survival rate of about 16%.⁷ Survival has increased over the last decades in Denmark, which might be partly explained by national focus on early CPR, use of AEDs, and an increasing availability of AEDs for public access defibrillation.⁸ However, approximately half of all publicly available AEDs are placed in location

Correspondence to: Katarina Høgh Mottlau, MD, Copenhagen Emergency Medical Services, University of Copenhagen, Telegrafvej 5, opgang 2, 1. sal, 2750 Ballerup, Denmark. E-mail: katomottlau@hotmail.com

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CLINICAL PERSPECTIVE

What Is New?

- Voluntary, smartphone-app-activated citizen responders can be activated for out-of-hospital cardiac arrest at night and during weekends.
- Fewer citizen responders accepted alarms at night, but this was mainly limited by fewer noticing alarms.

What Are the Clinical Implications?

- Citizen responder systems should consider activating citizen responders during all times and days of weeks.
- Updates to overrule do-not-disturb and silent mobile functions might improve nighttime activation.

Nonstandard Abbreviations and Acronyms

OHCA out-of-hospital cardiac arrest

without 24-hour service (schools, shops, etc) with low accessibility during off-hours.⁹

Activating volunteer citizens through mobile technology has been associated with an increase in bystander CPR and defibrillation.^{10–16} The American Heart Association 2020 guidelines recommend implementation of volunteer citizen activation, and accordingly, citizen responder programs are increasingly implemented in many countries worldwide.^{17,18} Although OHCA at nighttime are generally associated with decreased survival,¹⁹ several citizen responder systems only activate citizen responders during daytime and evening, leading to limited knowledge on activation during nighttime.^{11,12,19,20} In contrary, citizen responders in Denmark are activated during daytime, evening, and nighttime with no exceptions on weekends and holidays.

The aim of this study was to investigate citizen responder availability when activated to OHCA by a smartphone app according to time of day and day of week. Furthermore, we assessed differences in arriving before emergency medical services (EMS), AED retrieval according to time of day, and their involvement in OHCA resuscitation. Such information is pivotal for designing and optimizing citizen responder systems to use volunteer resources in the most meaningful manner.

METHODS

Data and Analysis Transparency

The data supporting our findings are available from the corresponding author upon reasonable request. The

coding used for data management, analyses, and graphical presentation can likewise be shared upon request.

Study Setting and Design

This study was part of a pilot project for the HeartRunner Trial (www.clinicaltrials.gov NCT03835403).²¹ We performed a retrospective cross-sectional study including OHCA with activated citizen responders in the Capital Region of Denmark. Approximately 1500 people experience an OHCA each year in the region which holds 1.8 million inhabitants and covers almost 2600 km² comprising rural and urban areas.²²

EMS and the Citizen Responder System

One emergency dispatch center covers the entire study area. In cases of suspected OHCA, the emergency dispatch center activates a 2-tiered EMS system consisting of basic life support provided by ambulance personnel and advanced life support by a physician-manned car. The dispatcher instructs the caller to start CPR, and if there are additional available bystanders, they are instructed to retrieve the nearest publicly accessible AED. The Danish AED Network is a nationwide registry of publicly available AEDs which holds information on placement and accessibility.⁹ Approximately 5000 AEDs were registered in the region (108 AEDs/100 000 inhabitants) of which 32% was accessible at all times.¹⁶ The AED network is linked directly to the emergency dispatch center as well as the citizen responder system. The citizen responder system is based on a smartphone app technology (Heartrunner App) and activated by the emergency dispatch center in case of suspected OHCA.²³ It was implemented in the Capital Region of Denmark in September 2017 and became nationwide in 2020. Citizen responders within 1.8 km from all suspected cardiac arrest locations are alerted and receive an alarm on their app with directions to the nearest publicly available AED and OHCA location. The system has been described in detail previously.²⁴ Recruitment of citizen responders started July 2017. CPR and/or AED training is strongly recommended, but not mandatory before registration. The citizen responder system is not activated to traumatic cardiac arrests, in children <8 years, in suicide or overdose, in unsafe situations, and in situations like nursing homes where professional personnel are present.

During the first 3 months of the study period, the nearest 10 available citizen responders were automatically alerted. To increase acceptance rates, the algorithm was adjusted to activate a maximum of 20 available citizen responders from December 2018.

Data Collection

An electronic survey was sent to all activated citizen responders 90 minutes after an alarm. Through the survey, we identified OHCA where citizen responders

had arrived before EMS, performed CPR, applied an AED, and performed defibrillation. Through the app server, we collected citizen responders' information (sex and age), location, and how they responded to the alarm (either accepted, declined, or no-response). Distances from the citizen responders to OHCA and the assigned AED were calculated as straight-line distances. Information about patient identification number, age, time of cardiac arrest, first recorded rhythm, location, witnessed status, bystander CPR, bystander defibrillation, and return of spontaneous circulation was collected from the Danish Cardiac Arrest Registry. Bystander interventions included CPR and defibrillation from both random bystanders and activated citizen responders. In case of discrepancy between citizen responder survey and the Danish Cardiac Arrest Registry, the latter was considered to be correct. From the emergency dispatch center, we obtained data on EMS response time, defined as time from dispatch of EMS to arrival at the OHCA location. The Danish Civil Registration System provided data on time of death.

Study Population

OHCAs with activated citizen responders from September 1, 2017 to August 31, 2018 were included. As defined by the Danish Cardiac Arrest registry, we excluded cardiac arrests with obvious signs of death, cases where resuscitation attempt was not continued by the EMS, those with a do-not-resuscitate order, and cardiac arrests witnessed by EMS. We also excluded cardiac arrests because of trauma, suicide, or overdose, and cases where no citizen responders were nearby or where no citizen responder answered the survey. Further, cases with missing EMS response times were excluded.

Outcomes

The following were defined as outcomes: proportion of citizen responders who were activated and accepted an alarm, proportion of patients who had an AED applied and received bystander defibrillation by citizen responders before EMS arrival. All outcomes were analyzed according to the exposures time of day and day of week. Time of day was divided into daytime (07:00 AM–03:59 PM), evening (4:00–11:59 PM), and nighttime (12:00–06:59 AM). Day of week was divided as weekdays (Monday–Friday) and weekends (Saturday and Sunday, including public holidays).

Statistical Analysis

The number of responses per OHCA (alerted, accepted, and assigned to AED) were defined as count-data. Number of citizen responders who accepted the alarm, including those who initially accepted the alarm and then

declined after >5 minutes. Because of over-dispersion in the analyses of count-data, we used a negative binomial regression for all analyses on responses.²⁵ To assess AED accessibility, we calculated how many cases had at least 1 citizen responder assigned to an AED, since the algorithm assigns the first 4 citizen responders to an AED, if there is 1 accessible at the time of the alarm. When normally distributed, continuous outcomes were analyzed by unpaired t test (binary exposures) and 1-way ANOVA (non-binary exposures), and otherwise Mann-Whitney *U* test (binary exposures) and Kruskal-Wallis test (non-binary exposures). Categorical outcomes were analyzed by Chi-square test or Fisher Exact Test. A $P < 0.05$ were defined as statistically significant. No measures to adjust for multiple testing were used. Analyses were done using SAS Enterprise Guide (Version 7.15 SAS Institute Inc, NC, USA).

Ethics

The project was registered with the Danish Patient Safety Authority (3-3013-2721/1) and approved by the Data Protection Agency (Journal nr.: 2012-58-0004, VD-2018-28, I-Suite nr.: 6222 and Journal nr.: P-2021-82). Citizen responders accept that the data are used for research at registration. According to Danish law approval from the Ethics Committee is not needed for retrospective, observational studies.

RESULTS

Demography of the Cohort

During the study period, the citizen responder system was activated in 819 suspected OHCAs, of which 438 (53.5%) were confirmed OHCAs and included for further analyses (Figure 1). Median age of the patients was 71.4 years, most were men (66.7%), and most (81.3%) of the OHCAs occurred in residential locations (Table). Of the included OHCAs, 27.2% occurred in the first 3 months of the study period where up to 10 citizen responders were alerted and 72.8% occurred when up to 20 citizen responders were activated. A total of 6836 citizen responders were alerted: the number of alerted responders per alarm was 15.6 (95% CI, 15.0–16.1), of which 7.9 (95% CI, 7.6–8.3) responded to the alarm (mean values). Most OHCAs occurred during daytime (46.3%), followed by evening (33.6%), and nighttime (20.1%). About one third (29.5%) occurred on weekends including public holidays (Figure 1).

Citizen Responders' Participation by Time of Day and Day of Week

Among all citizen responders who accepted the alarm, 1401 (86.3%) completed the online survey. No significant difference in number of alerted citizen responders per

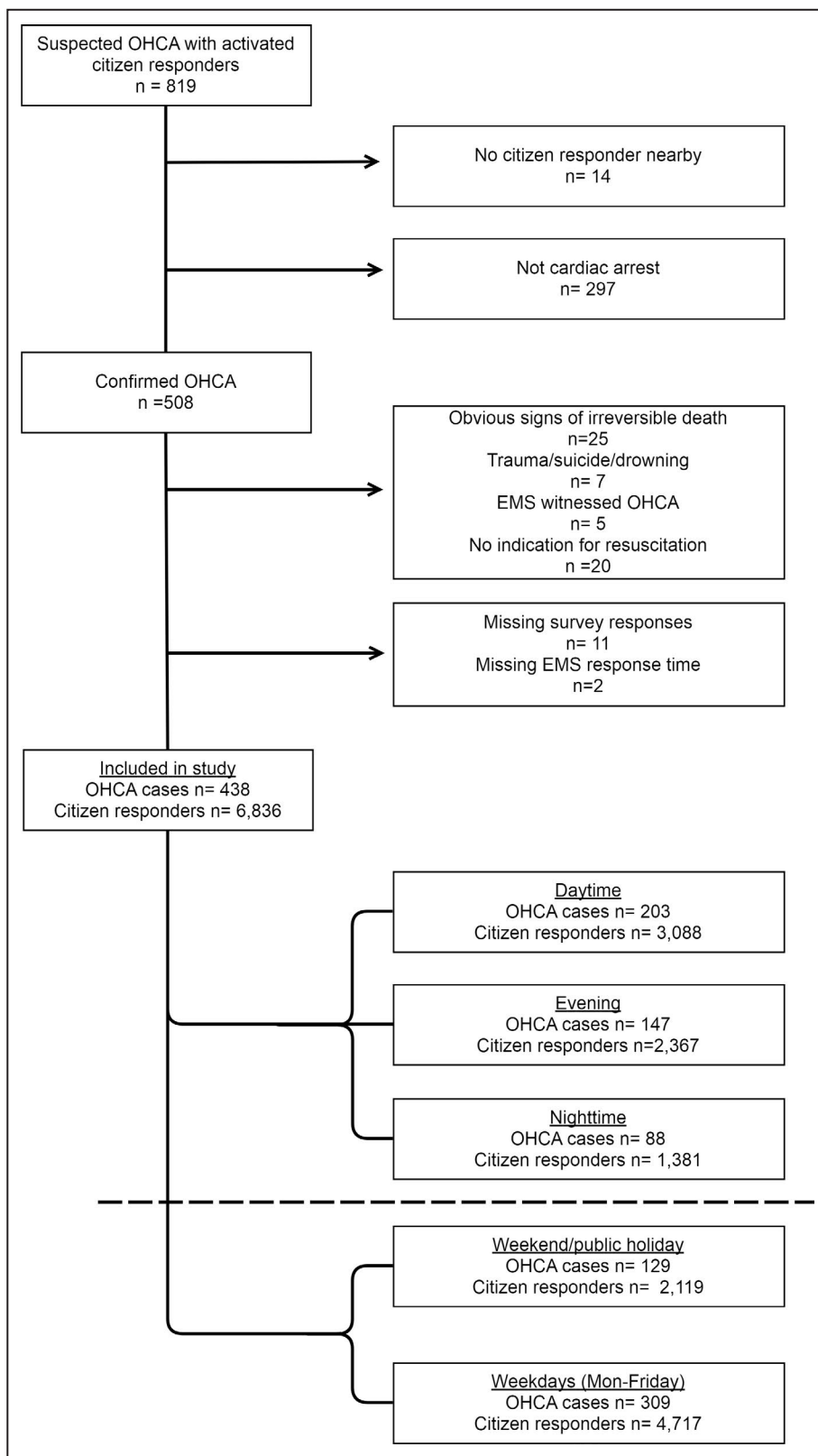


Figure 1. Flowchart of cardiac arrest cases in the study period. EMS indicates emergency medical services; and OHCA, out-of-hospital cardiac arrest.

Table Characteristics of Out-of-Hospital Cardiac Arrests Patients According to Time of Day and Day of Week

	Total (n=438)	Time of day				Day of week				Missing
		Daytime (n=203)	Evening (n=147)	Nighttime (n=88)	P value	Weekday (n=309)	Weekend/public holiday (n=129)	P value		
		Age, y, median (Q ₁ , Q ₃)	70.6 (60.0–77.5)	71.0 (62.0–81.4)	0.13	71.3 (62.6–80.4)	72.0 (62.7–80.6)	0.62		
Men, n (%)	292 (66.7)	91 (61.9)	57 (64.7)	0.49	205 (66.3)	87 (67.4)	0.32			
Residential OHCA location, n (%)	356 (81.3)	124 (84.4)	84 (95.5)	<0.0001	246 (79.6)	110 (85.3)	0.17			
Witnessed by bystander, n (%)	241 (55.2)	77 (52.7)	45 (51.1)	0.39	168 (54.5)	73 (56.6)	0.70			
Shockable rhythm (VF/pVT), n (%)	129 (29.9)	42 (28.6)	21 (24.4)	0.31	91 (29.8)	38 (29.9)	0.99			
EMS response time, min:s, median (Q ₁ , Q ₃)	5:46 (4:22–8:11)	5:00 (4:09–8:24)	6:45 (4:46–8:11)	0.54	5:39 (4:24–8:25)	6:02 (4:08–7:56)	0.68			
Citizen responders before EMS, n (%)	184 (42.0)	74 (50.3)	23 (26.1)	0.0013	115 (37.2)	69 (53.5)	0.002			
Citizen responders assigned to available AED, mean (95% CI)	2.0 (1.8–2.2)	1.9 (1.7–2.2)	1.0 (0.8–1.2)	<0.0001	1.9 (1.7–2.1)	2.4 (2.0–2.8)	0.01			
Distance between accepted citizen responder and OHCA, m, median (Q ₁ , Q ₃)	520 (291–798)	502 (275–793)	471 (326–742)	0.13	508 (295–794)	548 (285–813)	0.38			
Distance between accepted citizen responder, AED and OHCA, m, median (Q ₁ , Q ₃)	748 (492–1048)	750 (508–1082)	750 (496–1008)	0.30	746 (475–1032)	752 (532–1091)	0.18			
Bystander CPR, n (%)	352 (80.4)	120 (81.6)	62 (70.5)	0.03	253 (81.9)	99 (76.7)	0.22			
Bystander defibrillation, n (%)	56 (12.8)	19 (13.0)	10 (11.4)	0.90	45 (14.6)	11 (8.5)	0.08			
ROSC, n (%)	160 (36.6)	49 (33.6)	29 (33.0)	0.31	110 (35.7)	50 (38.8)	0.55			
30-day survival, n (%)	61 (14.4)	22 (15.5)	7 (8.1)	0.18	42 (14.1)	19 (15.0)	0.83			

Bystanders included both citizen responders and random bystanders. CPR indicates cardiopulmonary resuscitation; daytime, 07:00 AM to 03:59 PM; EMS, emergency medical services; evening, 4:00 to 11:59 PM; nighttime, 12:00 to 06:59 AM; OHCA, out-of-hospital cardiac arrest; Q₁, Q₃, interquartile boundaries; ROSC, return of spontaneous circulation; and VF/pVT, ventricular fibrillation/pulseless ventricular tachycardia.

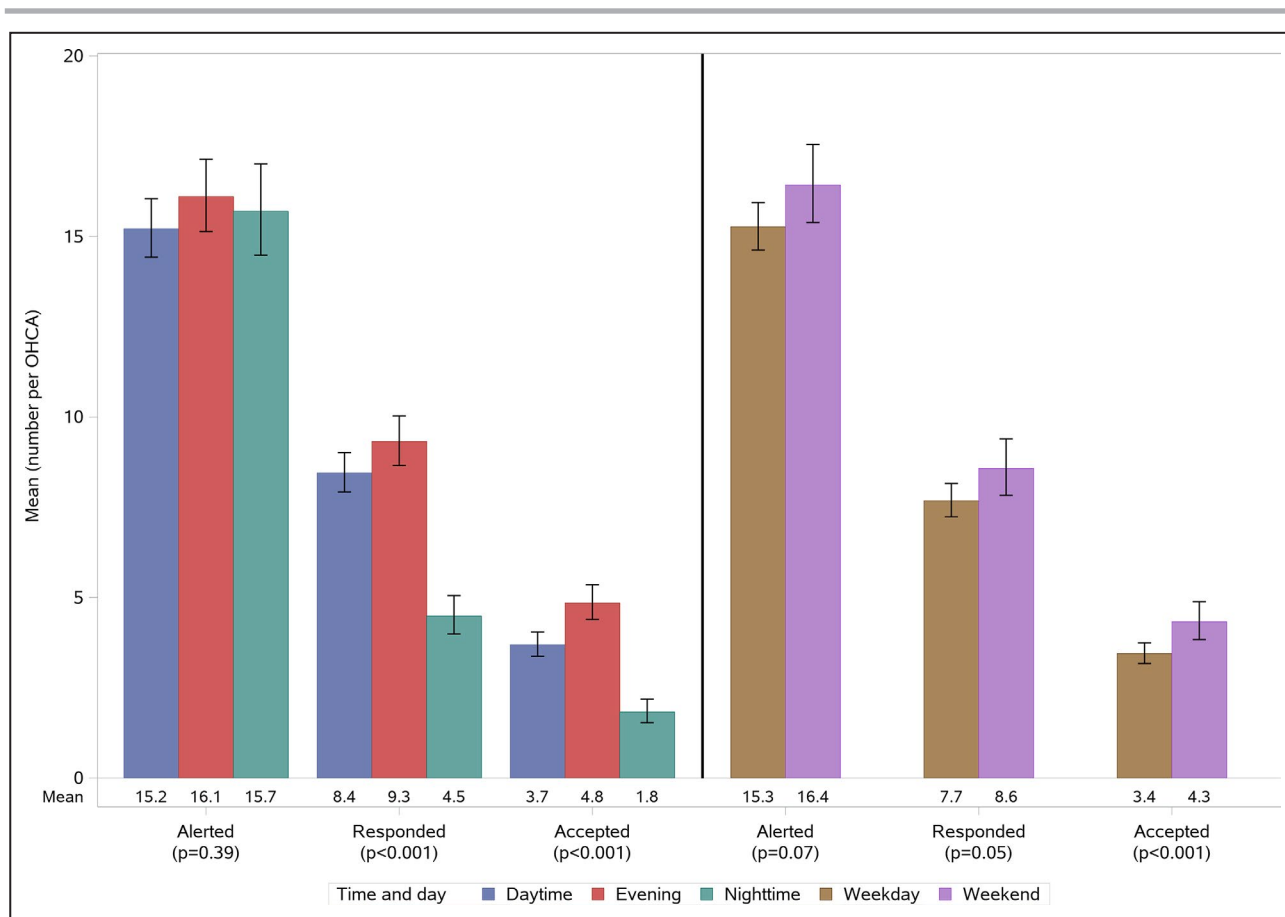


Figure 2. Mean number of citizen responders' interaction with alarms according to time of day and day of week.

Black markers indicate 95% CIs. Alerted: number of citizen responders who were located within 1800 m from the OHCA location. Responded: number of citizen responders who have accepted, declined, or rejected the alert. Accepted: number of citizen responders who accepted the alarm. Daytime: 07:00 AM to 03:59 PM. Evening: 4:00 to 11:59 PM. Nighttime: 12:00 to 06:59 AM. Weekday: Monday to Friday. Weekend: Saturday and Sunday incl. public holidays. CPR, cardiopulmonary resuscitation; and OHCA, out-of-hospital cardiac arrest.

OHCA was observed according to time of day ($P=0.39$) and day of week ($P=0.07$) (Figure 2). A higher number of citizen responders accepted an alarm in the evening, compared with daytime and nighttime ($P<0.001$) and a higher number of citizen responders accepted the alarm on weekends compared with weekdays ($P<0.001$). Among those who responded to the alarm, the proportion of acceptance was highest in the evening (52.0%, $n=712$) compared with daytime (43.7%, $n=750$) and nighttime (40.8%, $n=161$) ($P<0.001$), and higher on the weekend (50.5%, $n=558$) compared with the weekday (44.9%, $n=1065$), ($P=0.002$).

AED accessibility was 91.2% (95% CI, 87.6%–94.0%) unstratified, and stratified 88.8% (95% CI, 84.0%–93.7%, $n=143$) at daytime, 95.4% (95% CI, 91.8%–99.0%, $n=125$) in the evening, and 86.8% (95% CI, 76.1%–97.6%, $n=33$) at night ($P=0.08$). There was no difference in number of OHCA where a citizen responder was dispatched to an accessible AED on weekdays (91.1%, $n=225$) and on weekends (91.4%, $n=105$) ($P=0.92$).

Citizen Responders Arriving Before EMS

In 184 (42.0%) of all OHCA at least 1 citizen responder arrived before EMS, with highest proportion observed during the evening and the lowest during nighttime (Table). Although significantly fewer citizen responders arrived before EMS during nighttime, there were no statistically significant differences in CPR performed ($P=0.75$), AED attached ($P=0.52$), or defibrillation performed by citizen responders ($P=0.22$) according to time of day when the citizen responders arrived before EMS (Figure 3).

For OHCA occurring in weekends, at least one citizen responder arrived before EMS more frequently compared with weekdays ($P=0.002$) (Table). In OHCA where at least one citizen responder arrived before EMS, were more frequent in weekends compared with weekdays ($P=0.002$) (Table). Among cases where a citizen responder arrived before EMS, there were no differences in performing CPR ($P=0.29$), AED attachment ($P=0.21$), and defibrillation by citizen

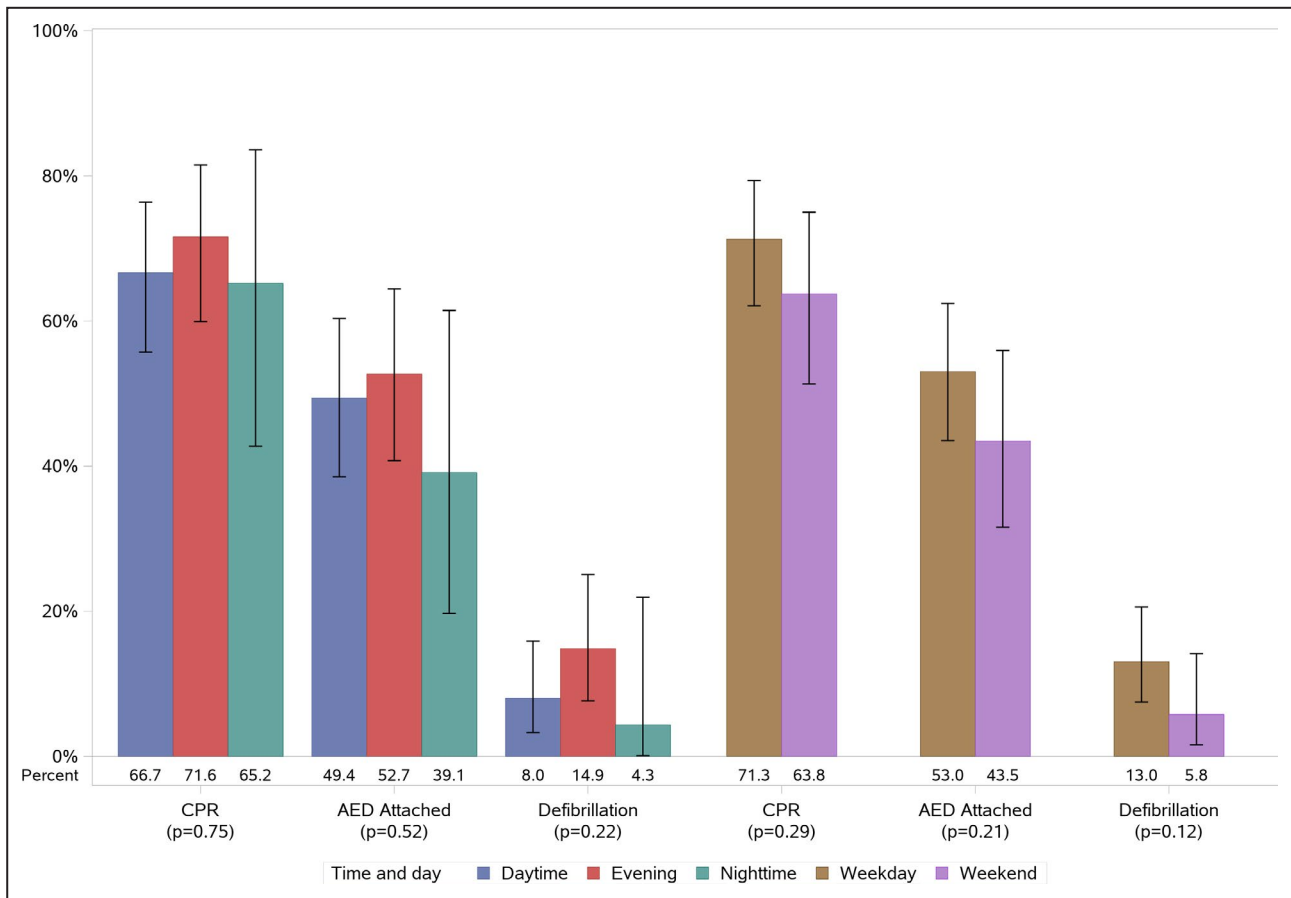


Figure 3. Proportion of performed cardiopulmonary resuscitation, automated external defibrillator attachment, and performed defibrillation in out-of-hospital cardiac arrest where at least 1 citizen responders arrived before EMS according to time of day and day of week.

AED indicates automated external defibrillators; and CPR, cardiopulmonary resuscitation. Black markers indicate 95% CIs. Daytime: 07:00 AM to 03:59 PM. Evening: 4:00 to 11:59 PM. Nighttime: 12:00 to 06:59 AM. Weekday: Monday to Friday. Weekend: Saturday and Sunday including public holidays. AED indicates automated external defibrillators; and CPR, cardiopulmonary resuscitation.

responder according to weekdays and weekends ($P=0.12$) (Figure 3).

DISCUSSION

In this observational study we examined citizen responders' willingness to assist in OHCA resuscitation according to time of day and day of week, and how that correlated to reaching the OHCA location before EMS to perform CPR and defibrillation. We found that more citizen responders responded and accepted the alarm during the evening and in weekends, and that at least one citizen responder arrived before EMS more often in the evening and weekends. Even though fewer citizen responders accepted alarms and arrived before EMS at night, we found that a considerable number of citizen responders were willing to participate in OHCA resuscitation at night indicating that activation of citizen responder at night remains useful in our setting.

Citizen responder programs are currently being implemented in many communities but not all systems are active during nighttime.¹⁸ Out of 6 identified citizen responder systems^{11–15,20} 2 systems dispatched citizen responders at night^{13,15,26} with only the study by Pijls et al evaluating the effect of nighttime involvement.²⁶ Pijls et al found a higher probability of survival in the evening/night when the system was activated compared with when the system was not activated. In comparison, we found a higher number of responding citizen responders in the evening and weekends, which could be explained by citizen responders being more available to attend in OHCA resuscitation outside working hours. Generally, the findings were as expected: a higher number of accepting citizen responders per OHCA is observed in the periods where people are awake, off work, and are available in the areas where OHCA occur. While the number of alerted citizen responders were uniform according to time of day, the number of alerted responders who accepted the alarm at night

compared with evenings was reduced by more than 50%. The lower number of accepting citizen responders at night could be explained by citizen responders not hearing the alarm because of mobiles turned off or on silent mode and therefore not responding to the alarm. To increase the chance of noticing an alarm the application has recently been updated to allow interruption of silent and do-not-disturb mode in case of an OHCA alarm. The proportion of alarms accepted during nighttime (40.8%) did not differ greatly from day (43.7%) or evening (52.0%) and indicates a willingness by citizen responders to attend OHCA resuscitation even at nighttime. If the recent application changes do not sufficiently increase the number of accepting citizen responders at night, it might be necessary to increase the number of alarmed citizen responders during nighttime. An option for citizen responders to indicate whether they wish to receive nighttime alarms might also increase the accept proportion. Although fewer citizen responders arrived before EMS at night, we found no significant differences in how involved these citizen responders were in the resuscitation attempt according to time of day or weekend/weekdays.

A low AED accessibility at nighttime has been described in Denmark with only 10% of all AEDs being accessible at night compared with 30% in the evening and about 95% during daytime in weekdays.²⁷ Equally many public OHCA occurred within 100 m from an AED in daytime compared with evening, nighttime, and weekends (30.5% and 27.8%, respectively) but the AED coverage (defined as an accessible AED within 100 m) of OHCA were 29.5% during daytime but only 12.9% during evening, nighttime, or weekends.²⁷ In our study, it was possible to refer citizen responders to an accessible AED with a mean of 1.0 to 2.8 citizen responders per OHCA over time of day and day of week, and there was no significant difference over time and type of day. However, it is important to note that the maximum distance for AED retrieval was 1800 m which might explain the high proportion of OHCA with at least 1 citizen responder referred to an available AED. A higher number of accepting citizen responders and accessible AEDs would increase the chance of a citizen responder being close to an AED and the OHCA and thus increase the chance of early defibrillation. Importantly, these results further underline the importance of unhindered AED accessibility for the public at all times. This has already been shown in a study by Karlsson et al,⁹ where they found a doubled chance of 30-day survival when the nearest AED was accessible compared with similar cases with nearest AED inaccessible at the time of OHCA.

Comparable systems are being implemented in many countries and evaluation is ongoing.¹⁸ While citizen responder systems can be effective everywhere, they have

the highest potential in areas with longer ambulance travel distances, such as rural areas. For these systems to be successful, it is necessary to have available voluntary citizens with basic life support competences, a working alarming system, required approvals, and publicly available AEDs. A survey of the opinion on the North American system PulsePoint showed high support towards implementation of the system and receiving basic life support both in public and private.²⁸ This study provides additional information, as it shows that a considerable proportion of citizen responders noticing alarms at night are willing to participate in nighttime resuscitation.

Limitations

The study was limited by design, since the observational design only reveals associations of the time of day and day of week and the citizen responders' interaction with the app. The citizen responder app only includes AEDs that are registered in the Danish AED registry and we could not account for potential available AEDs not included in the app. Information about the performed action of activated citizen responder was collected from the online questionnaire and a limitation to this study was a non-complete survey response rate which could underestimate the performance of the citizen responders. Further, the survey was self-reported and unvalidated. The distance from the citizen responders to the OHCA and AED was calculated by a straight-line and not true route distance for the citizen responders. Lastly, the limited sample size might comprise a risk of type II errors.

CONCLUSIONS

Citizen responders were more likely to respond to alarms in the evening and weekends with fewest responders at night. Fewer citizen responders arrived before EMS at nighttime and during weekdays. However, the proportion who accepted the alarm was comparable with other times of day, indicating that citizen responders could be a useful addition to EMS even at nighttime. We recommend, that citizen responder systems are also used during nighttime to investigate potential benefits and initiatives to increase nighttime activation, such as overriding silent and do not disturb functions, are implemented simultaneously.

ARTICLE INFORMATION

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Affiliations

Copenhagen University Hospital – Copenhagen Emergency Medical Services, Copenhagen, Denmark (K.H.M., L.C.A., C.M.H., F.F.); Department of Clinical Medicine, University of Copenhagen, Denmark (L.C.A., F.F.); Department of Emergency Medicine, Copenhagen University Hospital – Bispebjerg and Frederiksberg, Copenhagen, Denmark (R.G.); and Department of Cardiology, Copenhagen University Hospital – Herlev and Gentofte, Copenhagen, Denmark (F.F.).

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Author contribution: FF was responsible for funding acquisition. LCA, CMH, and FF were responsible for initial conceptualization and acquisition of data. KHM was main investigator and responsible for writing initial draft. RG carried out formal analysis and visualizations. All authors critically revised the manuscript, approved the final version, and agreed upon submission.

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Disclosures

None.

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