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ORIGINAL SCIENTIFIC PAPER

Smartphone-activated volunteer responders and bystander defibrillation for out-of-hospital cardiac arrest in private homes and public locations

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Aims To investigate the association between the arrival of smartphone-activated volunteer responders before the Emergency Medical Services (EMS) and bystander defibrillation in out-of-hospital cardiac arrest (OHCA) at home and public locations.

Methods and results This is a retrospective study (1 September 2017–14 May 2019) from the Stockholm Region of Sweden and the Capital Region of Denmark. We included 1271 OHCAs, of which 1029 (81.0%) occurred in private homes and 242 (19.0%) in public locations. The main outcome was bystander defibrillation. At least one volunteer responder arrived before EMS in 381 (37.0%) of OHCAs at home and 84 (34.7%) in public. More patients received bystander defibrillation when a volunteer responder arrived before EMS at home (15.5 vs. 2.2%, $P < 0.001$) and in public locations (32.1 vs. 19.6%, $P = 0.030$). Similar results were found among the 361 patients with an initial shockable heart rhythm (52.7 vs. 11.5%, $P < 0.001$ at home and 60.0 vs. 37.8%, $P = 0.025$ in public). The standardized probability of receiving bystander defibrillation increased with longer EMS response times in private homes. The 30-day survival was not significantly higher when volunteer responders arrived before EMS (9.2 vs. 7.7% in private homes, $P = 0.41$; and 40.5 vs. 35.4% in public locations, $P = 0.44$).

Conclusion Bystander defibrillation was significantly more common in private homes and public locations when a volunteer responder arrived before the EMS. The standardized probability of bystander defibrillation increased with longer EMS response times in private homes. Our findings support the activation of volunteer responders and suggest that volunteer responders could increase bystander defibrillation, particularly in private homes.

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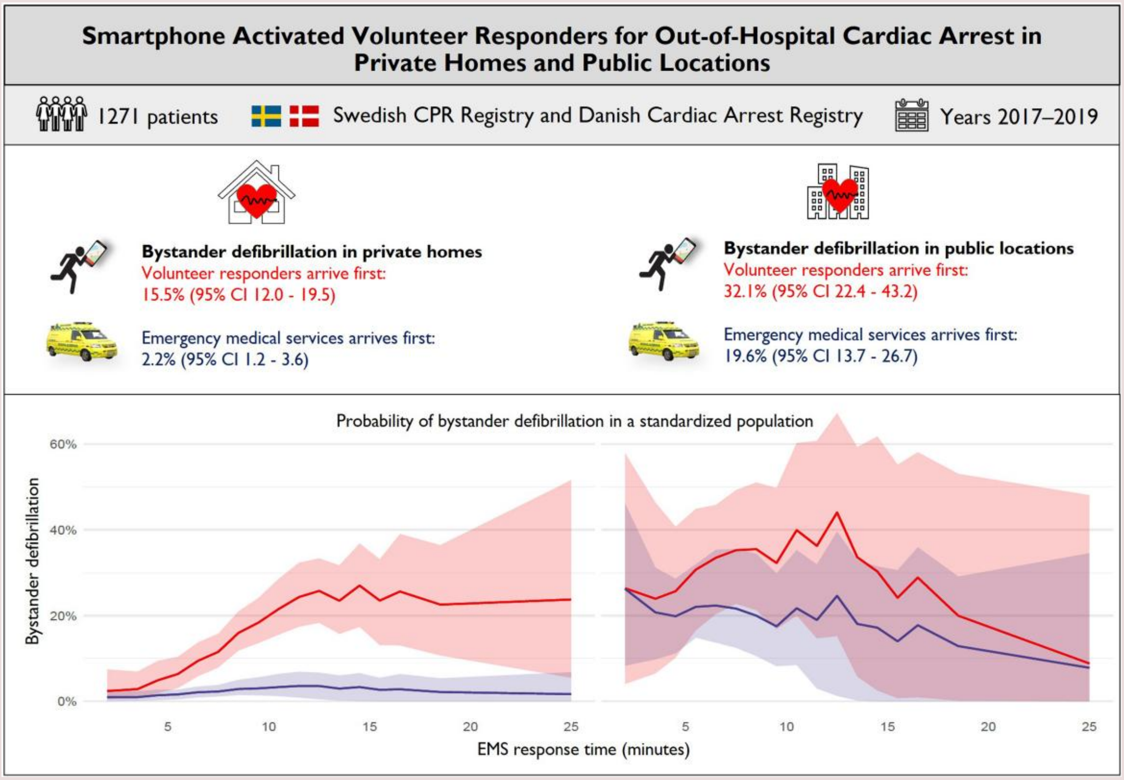
Graphical Abstract



Keywords OHCA • CPR • AED • dispatch • responder app

Introduction

Most out-of-hospital cardiac arrests (OHCAs) occur in private homes.[1–3] Patients with OHCA at home are more likely to have unwitnessed arrest, non-shockable heart rhythm, and a lower chance of bystander-initiated resuscitation, all factors associated with a low chance of survival.[4–7] Given the high proportion of OHCAs that occur in private homes, even a small increase in survival rates would yield many lives saved in absolute numbers. Therefore, strategies to increase bystander-initiated resuscitation at home are warranted.

Bystander defibrillation in private homes remains substantially lower than in public locations despite the increased deployment of publicly accessible automated external defibrillators (AEDs).[2,8] Strategic placement of AEDs has not been well-defined for residential areas, and AEDs are rarely available for OHCAs in these settings.[2,9] Often, only one bystander is present in private homes,[10] and the opportunity for a bystander to collect an AED before the Emergency Medical Services (EMS) arrival is limited.[9] Activating nearby volunteers through smartphone applications (apps) to collect an AED is a promising strategy to increase bystander defibrillation and survival for patients with OHCA at home.[11–13] Accordingly, volunteer responder activation to improve community response and bystander resuscitation is recommended by the American Heart Association[14] and the European Resuscitation Council[15] 2020/2021 guidelines, although more evidence for the effect on patient outcome is needed.[16]

Volunteer responder programmes using the same responder app were implemented in the Stockholm Region of Sweden in 2015 and the Capital Region of Denmark in 2017. We aimed to describe the association between the arrival of volunteer responders before EMS and bystander defibrillation in private homes and public locations. To impact patient outcomes, volunteer responders must arrive before EMS. Therefore, we assessed the standardized probability of bystander defibrillation according to EMS response time. We hypothesized that the arrival of volunteer responders before EMS would be associated with higher proportions of bystander defibrillation in private homes and public locations, and the standardized probability of bystander defibrillation would increase with longer EMS response time.

Methods

Study design and setting

We conducted a retrospective, observational study using prospectively collected data from two European regions: the Stockholm Region of Sweden and the Capital Region of Denmark. The Stockholm Region comprised 2.39 million inhabitants and covered 6519 km^2[17] and the Capital Region of Denmark comprised 1.85 million inhabitants and covered 2559 km^2 in 2020.[18] Approximately, 2700 EMS-treated OHCAs are reported yearly in these two regions, corresponding to 66 OHCAs/100 000 inhabitants.[19,20] Both regions are served by one emergency dispatch centre and by a two-tiered EMS system including a basic life support ambulance and a physician-staffed critical care unit, simultaneously activated for OHCA. In addition, Stockholm Region has 16 fire department units and 140 police cars equipped with AEDs, which are dispatched as professional first responders. The Capital Region of Denmark only occasionally activated firefighters as professional first responders during the study period and did not activate police. The emergency dispatch centres have protocols for dispatch-assisted cardiopulmonary resuscitation (CPR), and additional bystanders are referred to nearby publicly accessible AEDs. When feasible, the contact person for the nearest AED is encouraged to deliver the AED to the OHCA location. Sweden and Denmark have nationwide AED registries.[21–24] The registries are linked to the emergency dispatch centres and included approximately 2800 AEDs (122 AEDs/100 000 inhabitants/1000 km^2) in the Stockholm Region and 5000 AEDs (278 AEDs/100 000 inhabitants/1000 km^2) in the Capital Region of Denmark at the beginning of the study.

The volunteer responder programmes

A smartphone app-based volunteer responder programme was implemented in the Stockholm Region in 2015.[12] It was preceded by a Short Message Service (SMS)-based volunteer responder programme implemented in 2011.[25] Based on experiences from Stockholm, the same volunteer responder app (Heartrunner[26]) was implemented in the Capital Region of Denmark in September 2017. By September 2017, 12 625 volunteer responders were registered in the Stockholm Region (549 responders/100 000 inhabitants) and 3665 in the Capital Region of Denmark (204 responders/100 000 inhabitants) which increased to 46 647 in the Stockholm Region (2028 responders/100 000 inhabitants) and 29 279 in the Capital Region of Denmark (1627 responders/100 000 inhabitants) at the end of the study period. A volunteer responder is a person (≥18 years) who voluntarily registers to be dispatched if located nearby an OHCA. A course in CPR is requested in Sweden and highly recommended, but not mandatory, in Denmark. Volunteer responders are activated by the emergency dispatch centre, and up to 20 responders in Denmark and 30 responders in Sweden are notified via the app. They are directed to either start CPR or retrieve an AED. The app is connected to the respective AED networks and can direct responders to an available AED at the time of the alarm. Between September 2017 and May 2018, Sweden used a radius of 1200 m for responders assigned to CPR and 2400 m for responders assigned to AEDs. After May 2018, a radius of 1800 m was used for both assignments, as was the case in Denmark throughout the study period. Dispatchers in both regions are instructed not to activate volunteer responders to traumatic OHCA, OHCA in unsafe surroundings or where an AED is not indicated (e.g. nursing homes where trained personnel and AEDs are present), and not to children <8 years. In the Stockholm Region, volunteer responders are only activated between 07:00 a.m. and 11:00 p.m., whereas in Denmark the programme is active 24 h a day. All dispatched volunteer responders receive a text message with a link to an electronic survey approximately 90 min after each alarm. The Swedish and Danish surveys are presented in Supplementary material online, *eMethods*. Through the survey, they can report their actions at resuscitation and if they arrived before or after the EMS (including before police and firefighters in Sweden). A reminder is sent the following day in case of no response in Denmark and after three days in Sweden. Both volunteer responder programmes have been described in detail previously.[11,12]

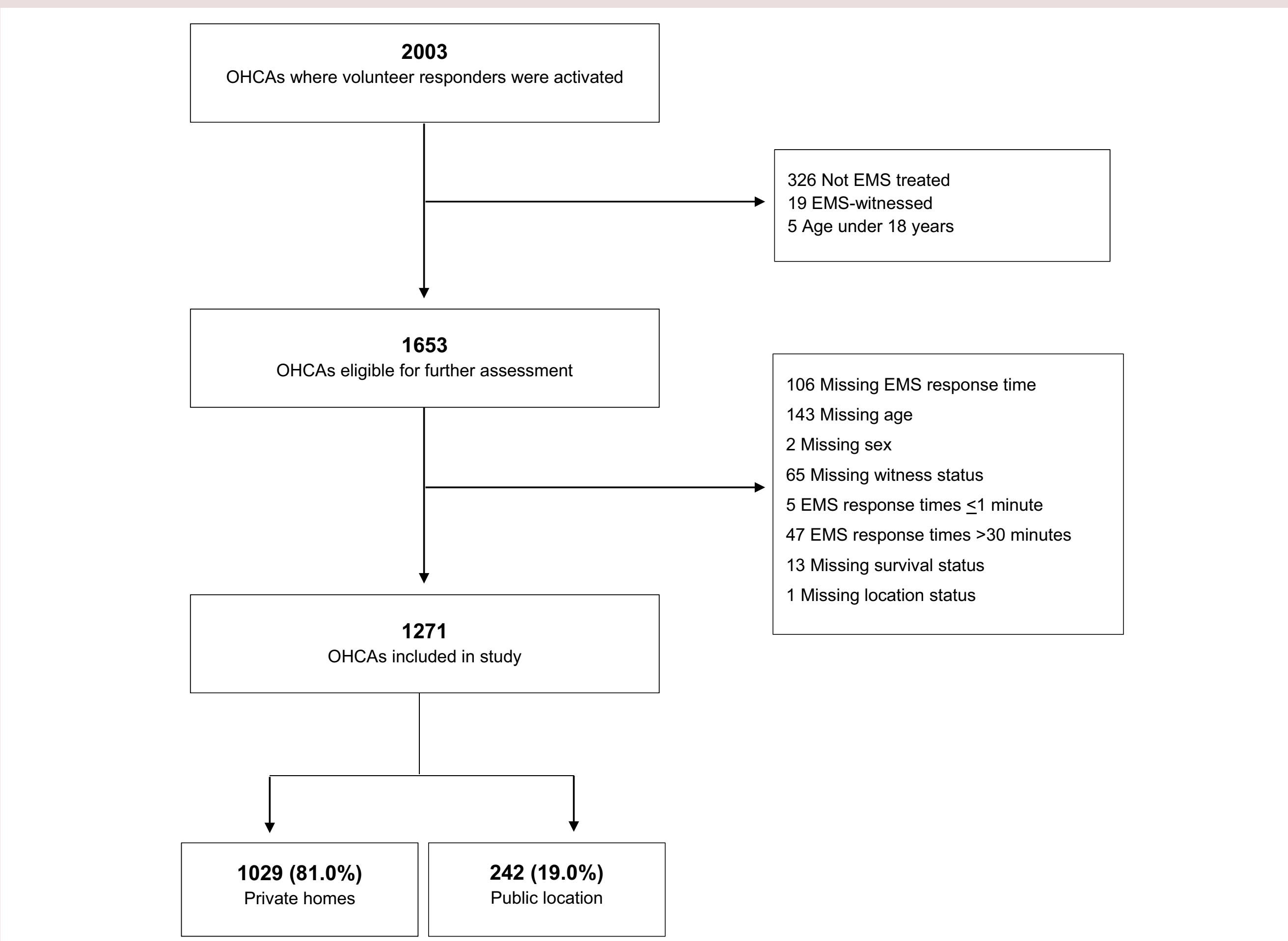


Figure 1 Flowchart illustrating patient selection. EMS, Emergency Medical Services; OHCA, out-of-hospital cardiac arrest.

Data sources

Patient characteristics were collected from the Swedish Registry of Cardiopulmonary Resuscitation[20] and the Danish Cardiac Arrest Registry.[19] We included age, sex, initial heart rhythm (defined as shockable if pulseless ventricular tachycardia/ventricular fibrillation was recorded as the first rhythm by the EMS, or if the patient was defibrillated by an AED), witnessed status, location (private home or public location defined as sports facilities, airports, work/office buildings, outdoor, public transportation, or other locations), EMS response time (time from emergency call to the vehicle at the scene), time of OHCA, bystander CPR, bystander defibrillation, and return of spontaneous circulation (ROSC). Thirty-day survival was obtained from the Swedish national board of health and welfare and from the Danish Civil Registration System.[27] The survey was used to identify cases where at least one volunteer responder arrived at the patient before EMS. If no volunteer responder was reported to have arrived before EMS, the case was classified as EMS arrived first.

Table 1 Characteristics for patients with out-of-hospital cardiac arrest at home and in public locations

	Total (*N* = 1271)	Missing	OHCA at home (*N* = 1029)		OHCA in public locations (*N* = 242)	
			Volunteer responders arrived first (*n* = 381)	EMS arrived first (*n* = 648)	Volunteer responders arrived first (*n* = 84)	EMS arrived first (*n* = 158)
Age, years, median (Q_1, Q_3)	73 (62, 81)	—	74 (64, 82)	74 (63, 82)	70 (61, 76)	68 (57, 77)
Age groups, years						
18–50	123 (9.7)		34 (8.9)	61 (9.4)	5 (6.0)	23 (14.6)
50–65	277 (21.8)		73 (19.2)	129 (19.9)	26 (31.0)	49 (31.0)
65–75	340 (26.8)		104 (27.3)	166 (25.6)	31 (36.9)	39 (24.7)
75–85	353 (27.8)		112 (29.4)	188 (29.0)	16 (19.0)	37 (23.4)
>85	178 (14.0)		58 (15.2)	104 (16.0)	6 (7.1)	10 (6.3)
Sex, male	865 (68.1)	—	267 (70.1)	408 (63.0)	69 (82.1)	121 (76.6)
Bystander witnessed arrests	706 (55.5)	—	188 (49.3)	346 (53.4)	63 (75.0)	109 (69.0)
Initial shockable rhythm	361 (28.8)	19	112 (29.8)	122 (19.0)	45 (55.6)	82 (53.6)
EMS defibrillation	383 (30.3)	5	98 (25.7)	172 (26.6)	39 (47.0)	74 (47.4)
EMS response time, min, median (Q_1, Q_3)	7.5 (5.6, 10.0)	—	8.7 (6.5, 11.0)	7.0 (5.3, 9.7)	7.9 (5.8, 9.9)	6.3 (5.0, 10.0)
EMS response times, groups, min						
<3	24 (1.9)		3 (0.8)	14 (2.2)	1 (1.2)	6 (3.8)
3–4	81 (6.4)		5 (1.3)	50 (7.7)	3 (3.6)	23 (14.6)
4–5	144 (11.3)		26 (6.8)	88 (13.6)	9 (10.7)	21 (13.3)
5–6	172 (13.5)		44 (11.5)	91 (14.0)	12 (14.3)	25 (15.8)
6–7	165 (13.0)		44 (11.5)	99 (15.3)	11 (13.1)	11 (7.0)
7–8	147 (11.6)		47 (12.3)	79 (12.2)	8 (9.5)	13 (8.2)
8–9	117 (9.2)		46 (12.1)	48 (7.4)	11 (13.1)	12 (7.6)
9–10	112 (8.8)		44 (11.5)	45 (6.9)	9 (10.7)	14 (8.9)
10–11	82 (6.5)		32 (8.4)	38 (5.9)	6 (7.1)	6 (3.8)
11–12	51 (4.0)		22 (5.8)	22 (3.4)	3 (3.6)	4 (2.5)
12–13	38 (3.0)		19 (5.0)	15 (2.3)	2 (2.4)	2 (1.3)
13–14	22 (1.7)		11 (2.9)	9 (1.4)	0 (0.0)	2 (1.3)
14–15	23 (1.8)		9 (2.4)	10 (1.5)	0 (0.0)	4 (2.5)
15–16	18 (1.4)		9 (2.4)	6 (0.9)	1 (1.2)	2 (1.3)
16–17	14 (1.1)		2 (0.5)	7 (1.1)	2 (2.4)	3 (1.9)
17–20	26 (2.0)		9 (2.4)	10 (1.5)	2 (2.4)	5 (3.2)
20–30	35 (2.8)		9 (2.4)	17 (2.6)	4 (4.8)	5 (3.2)
Time of day						
Day (8:00 a.m. to 3:59 p.m.)	648 (51.0)		180 (47.2)	310 (47.8)	51 (60.7)	107 (67.7)
Evening (4:00 p.m. to 11:59 p.m.)	436 (34.3)		157 (41.2)	207 (31.9)	30 (35.7)	42 (26.6)
Night (12:00 a.m. to 7:59 a.m.)	187 (14.7)		44 (11.5)	131 (20.2)	3 (3.6)	9 (5.7)

All results are *n* (%) unless otherwise specified.
AED, automated external defibrillator; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.

Non-dispatch bystanders could be present in both situations, and bystander CPR and bystander defibrillation included interventions from both volunteer responders and non-dispatched bystanders.

Study population

We included all patients aged 18 years and older with EMS-treated OHCA where volunteer responders were activated between 1 September 2017, and 14 May 2019. EMS-witnessed OHCAs were excluded. To model standardized probabilities of bystander defibrillation, we excluded patients with missing data on location, bystander defibrillation, age, sex, witnessed status, survival status, and EMS response time. We further excluded patients with EMS response times of <1 and >30 min since they were assumed to represent outliers.

Ethics

Ethical approval for Swedish data was granted from the Swedish ethics review authority (DNR: 2016/1531-31/4, amendment 2018/497-32). Patient data collection for Danish patients was approved by the Danish Patient Safety Authority (3-3013-2721/1). The Data Protection Agency approved the storage of patient data (Journal nr.: 2012-58-0004, VD-2018-28, I-Suite nr.: 6222) and volunteer responder data (Journal nr.: P-2021-82) for Danish data. Volunteer responders sign the terms of the agreement at registration which includes consent to be contacted by the research team, agreement to share location when logged on to the app, and agreement not to disclose any information about resuscitation attempts. Volunteer responders can delete the app and withdraw from the volunteer responder programme at any time.

Statistical analysis

Categorical variables were summarized using frequencies and percentages and differences were analysed with Fisher's Exact Test. Medians and interquartile ranges were calculated for continuous variables and differences were analysed with Kruskal–Wallis tests. All analyses were carried out separately for private homes and public locations. The main outcome was bystander defibrillation. The analysis was based on a multiple logistic regression model. The model included an interaction between volunteer responders' arrival before EMS and EMS response time (using cubic splines with three knots). Cubic splines were used since we did not expect the effect of decreasing the response time by 1 min on bystander defibrillation to be independent of where in the range of the response time the decrease happened (i.e. decreasing from 6 to 5 min has a larger effect than decreasing from 19 to 18 min). The model was further adjusted for additive effects of sex and age groups (18–50, 50–65, 65–75, 75–85, >85). To analyse if the chance of bystander defibrillation was higher due to volunteer responders, we used the multiple logistic regression model to calculate standardized probabilities of bystander defibrillation according to EMS response time with and without volunteer responders arriving before EMS. We standardized with respect to the observed distribution of age and sex for given EMS response times. Confidence intervals (95%) for the standardized probabilities were calculated using 1000 bootstrap samples. Multiple logistic regression was also used to associate 30-day survival probabilities with additive effects of bystander defibrillation, age groups, sex, witnessed status, and EMS response times (restricted cubic spline). Average 30-day survival chances with and without bystander defibrillation standardized to the observed distribution of the other variables were reported. The level of statistical significance was set at 5%. Statistical analyses were performed in SAS 9.4 (SAS Institute Inc., Cary, NC, USA) and R version 4.1.0.[28]

Results

Study population

Volunteer responders were activated in 43.3% (1130/2609) of all OHCAs in the Stockholm Region and 37.0% (873/2357) in the Capital Region of Denmark. In total, volunteer responders were activated in 2003 OHCAs, of which 1271 (63.5%) were EMS-treated and eligible for analyses (*Figure 1*). Characteristics for patients excluded due to missing data are presented in Supplementary material online, *eTable S1*. Of the included OHCAs, 1029 (81.0%) occurred at home and 242 (19.0%) in public (*Table 1*). In 36.7% of the OHCAs, at least one responder answered that they arrived before the EMS. In 37.3%, at least one responder answered that they arrived after EMS, and in 26.0% no one answered the question in the survey. At least one volunteer responder arrived before EMS in 381 (37.0%) of OHCAs at home and 84 (34.7%) in public. EMS response time was similar in private homes and public locations [7.6 (5.8; 10.0) vs. 7.0 (5.0; 10.0) min]; however, longer when volunteer responders arrived before EMS.

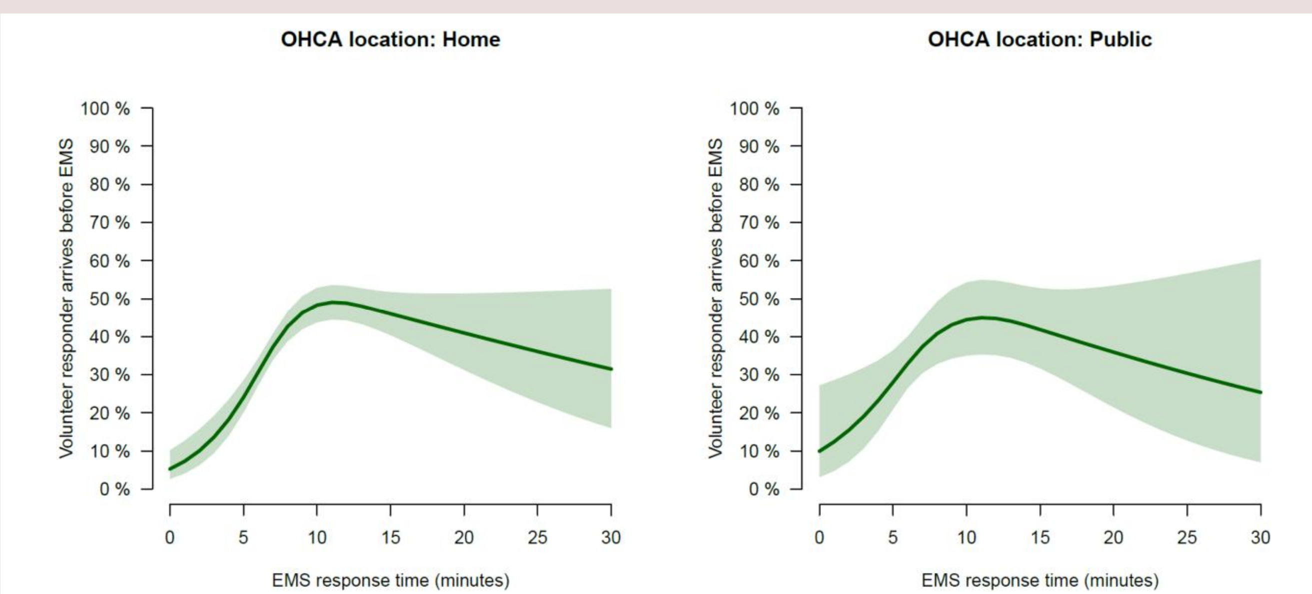


Figure 2 Chances of at least one volunteer responder arriving before EMS according to the location of out-of-hospital cardiac arrest. EMS, Emergency Medical Services; OHCA, out-of-hospital cardiac arrest.

Patient characteristics for the Swedish and Danish population are presented in Supplementary material online, *eTable S2*. *eTable S3* (Supplementary material online) shows characteristics for patients where the volunteer responders were activated and not activated.

Bystander interventions according to OHCA location

The probability of at least one volunteer responder arriving before EMS increased with increasing EMS response times in both locations (*Figure 2*). The increase peaked around 12 min, where approximately 50% of OHCAs at home and 49% in public had at least one volunteer responder arriving first. Bystander defibrillation was 7 times higher when a volunteer responder arrived before EMS in private homes compared with cases where EMS arrived first [15.5% (95% CI, 12.0–19.5%) vs. 2.2% (95% CI, 1.2–3.6%), $P < 0.001$] and a 1.5 times higher in public locations [32.1% (95% CI, 22.4–43.2%) vs. 19.6% (95% CI, 13.7–26.7%), $P = 0.030$] (*Table 2*). More patients also received bystander CPR when volunteer responders arrived first; 87.6% (95% CI, 83.9–90.0%) vs. 71.4% (67.8–74.98%) in private homes ($P < 0.001$) and 94.0% (95% CI, 86.7–98.0%) vs. 84.1% (95% CI, 77.4–89.4%) in public locations ($P = 0.026$). However, 30-day survival was not significantly higher when volunteer responders arrived before EMS; 9.2% (95% CI, 6.5–12.5%) vs. 7.7% (95% CI, 5.8–10.1%) in private homes ($P = 0.41$) and 40.5% (95% CI, 29.9–51.8%) vs. 35.4% (95% CI, 28.0–43.4) in public locations ($P = 0.44$).

The standardized probability of bystander defibrillation increased with longer EMS response times in private homes when volunteer responders arrived before EMS, whereas no increase was found when EMS arrived first (*Figure 3*). A similar difference was not found in public locations. Observed probabilities of bystander defibrillation are presented in Supplementary material online, *eFigure S1*. The 30-day survival chance was higher in the standardized population when a patient received bystander defibrillation compared with not receiving bystander defibrillation at home [6.5% (95% CI, 0.2–12.9%), $P = 0.04$] and in public [14.4% (95% CI, 1.2–27.6%), $P = 0.03$].

Patients with an initial shockable heart rhythm

In private homes, 234 (23.0%) patients had an initial shockable rhythm compared with 127 (54.3%) in public locations. Significantly more patients had a shockable rhythm when volunteer responders arrived first in private homes whereas no difference was found in public locations (*Table 1*). Among patients with a shockable rhythm at home, more patients received bystander CPR and defibrillation when volunteer responders arrived before EMS (93.7 vs. 75.4%, $P < 0.001$ for CPR, and 52.7 vs. 11.5%, $P < 0.001$ for defibrillation). A non-statistically significant difference was found for survival where fewer patients were likely to survive for 30 days in private homes when volunteer responders arrived first (20.5 vs. 31.2%, $P = 0.074$). In public locations, bystander defibrillation was higher for patients where volunteer responders arrived before the EMS (60.0 vs. 37.8%, $P = 0.025$), whereas no differences were found in bystander CPR (93.3 vs. 89.0%, $P = 0.54$) and 30-day survival (55.6 vs. 52.4%, $P = 0.85$).

Discussion

This study assessed volunteer responder activation for OHCAs in private homes and public locations. We included patients from two European regions with similar, well-developed, OHCA response systems and mature volunteer responder programmes based on the same responder app. We found that bystander defibrillation was 7 times higher in private homes when volunteer responders arrived

Table 2 Outcomes for patients with out-of-hospital cardiac arrest at home and in public locations

	Total ($n = 1271$)		Missing	OHCA at home ($n = 1029$)					OHCA in public locations ($n = 242$)				
				Volunteer responders arrived first ($n = 381$)		EMS arrived first ($n = 648$)		P-value	Volunteer responders arrived first ($n = 84$)		EMS arrived first ($n = 158$)		P-value
	No./Total of patients	% (95% CI)	No. (%)	No./Total of patients	% (95% CI)	No./Total of patients	% (95% CI)		No./Total of patients	% (95% CI)	No./Total of patients	% (95% CI)	
Bystander CPR	1006/1268	79.3 (77.0–81.5)	3 (0.2)	333/380	87.6 (83.9–90.8)	462/647	71.4 (67.8–74.9)	<0.001	79/84	94.0 (86.7–98.0)	132/157	84.1 (77.4–89.4)	0.026
Bystander defibrillation	131/1271	10.3 (8.7–12.1)	—	59/381	15.5 (12.0–19.5)	14/648	2.2 (1.2–3.6)	<0.001	27/84	32.1 (22.4–43.2)	31/158	19.6 (13.7–26.7)	0.030
ROSC	452/1248	36.2 (33.6–39.0)	23 (1.8)	111/375	29.6 (25.0–34.5)	208/637	32.7 (29.0–36.5)	0.31	48/83	57.8 (46.5–68.6)	85/153	55.6 (47.3–63.6)	0.74
30-day survival	175/1271	13.8 (11.9–15.8)	—	35/381	9.2 (6.5–12.5)	50/648	7.7 (5.8–10.1)	0.41	34/84	40.5 (29.9–51.8)	56/158	35.4 (28.0–43.4)	0.44

CPR, cardiopulmonary resuscitation; EMS, emergency medical services; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.

before EMS compared with cases where the EMS arrived first. The standardized probability of receiving bystander defibrillation increased with longer EMS response times. In public locations, more patients received bystander defibrillation when a volunteer responder arrived first, although the relative difference was not as large as in private homes.

While bystander CPR has increased in many communities, bystander defibrillation remains rare, particularly in private homes.[2,3,7] Placing AEDs in the homes of patients at risk of OHCA has shown no effect on survival,[29] probably because high-risk patients only account for a small proportion of all OHCA patients.[30] Therefore, strategies to cover unselected larger populations with AEDs in residential areas are needed to improve bystander defibrillation and survival in private homes.

Sweden and Denmark have high densities of publicly accessible AEDs and nationwide AED registries available to the public via websites and apps.[21,24] On-site or nearby AEDs increase the chance of bystander defibrillation, and the availability of AEDs is higher in public locations than in private homes.[31,32] Furthermore, more bystanders are often present in public locations. For these reasons, there is a higher chance of a non-dispatched bystander using an on-site AED in public locations.[2,8,13] Engagement from non-dispatched bystanders might explain why we only observed a small difference in standardized probability of bystander defibrillation in public locations when volunteer responders arrived first. This is in alignment with a randomized trial from Sweden which did not find a significant increase in AED attachment when volunteer responders were activated.[33]

In private homes, only one bystander (often a family member) is usually present, and retrieving an AED is often not feasible.[9] If the family member is not in a physical or psychological state to perform CPR,[34,35] volunteer responders can start CPR, bring an AED, and provide early defibrillation. Having a volunteer responder entering private homes is described as a barrier because of liability and safety concerns in the USA.[36,37] However, a survey from North America described that >80% of included persons would accept a layperson to enter their home in case of OHCA.[38] By activating volunteer responders to private homes, the majority of OHCAs would be covered by a volunteer responder programme and the impact on absolute numbers of patients receiving early defibrillation could be large. Activating off-duty professional responders to private homes could be the first step towards volunteer responder activation.[3,39] However, only activating this selected group led to a low density of available responders and low chance for a responder to start resuscitation before EMS arrival in the USA.[39]

The benefit of a volunteer responder program for overall survival will be limited by the fact that volunteer responders are not activated for all OHCAs. First, the dispatcher must recognize the OHCA to activate volunteer responders. A previous study from Copenhagen showed that this is done in about 70% of all OHCAs.[40] Second, in our setting, the dispatchers have guidelines on when to activate responders (e.g. not too traumatic OHCAs, unsafe surroundings, etc.) leaving only a selected proportion of all OHCA eligible for volunteer responder activation. Finally, even when the responders are activated, they must arrive before the EMS. In fact, the responder must arrive several minutes before the EMS to have a real impact on survival. We had no timestamp on volunteer responder arrival and could therefore not assess how many minutes before the EMS arrived, but the EMS response time was significantly longer when volunteer responders arrived first. A long EMS response time gives volunteer responders time to arrive before the EMS and provide bystander interventions. However, when competing with early advanced life support provided by the EMS, volunteer responders' impact on survival might be limited. This could explain why we did not find a significant increase in survival when volunteer responders arrived first.

Strength and limitations

This study included patients from two countries using the same responder app which strengthens our findings. Both countries have access to detailed data from the volunteer responder programmes, and data are comparable between sites. However, the included regions have a culture of high bystander engagement for OHCA resuscitation even without volunteer responder activation. Our results might therefore not be generalizable to other communities with lower bystander rates and lower AED density. Additionally, a case where a responder arrived before EMS but did not complete the survey might be misclassified as 'EMS arrived first' and hereby weakened the observed impact of volunteer responders in our results. Also, if a volunteer responder arrived before EMS and applied an AED, but the patient had a non-

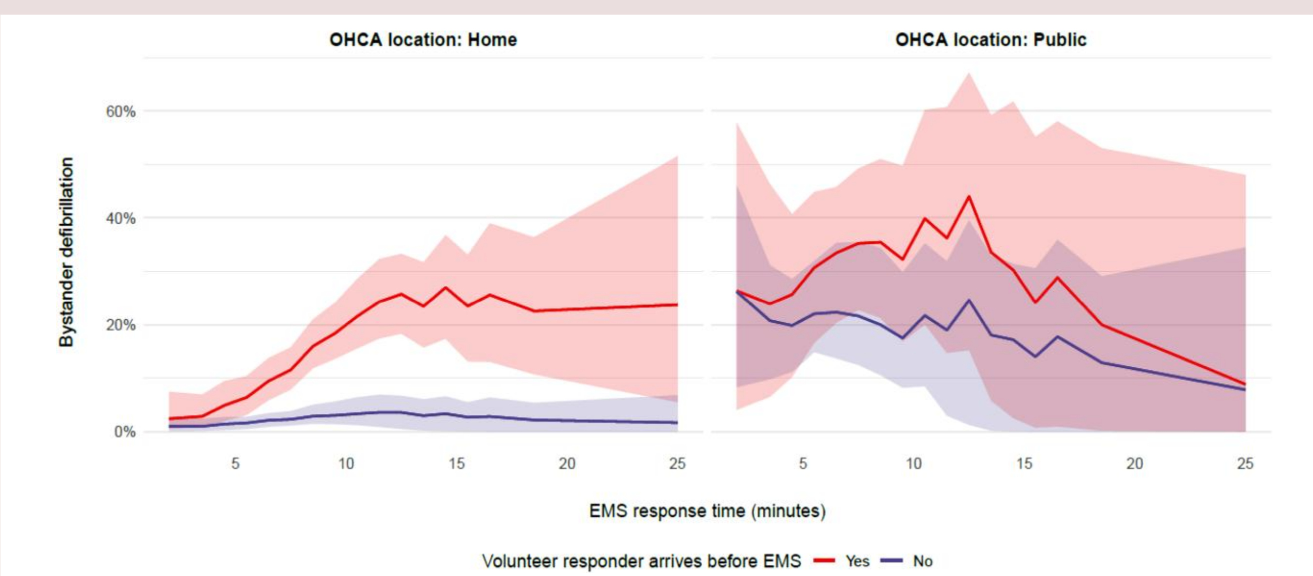


Figure 3 Standardized chances of bystander defibrillation according to the location of out-of-hospital cardiac arrest. EMS, Emergency Medical Services; OHCA, out-of-hospital cardiac arrest.

shockable rhythm, we could not account for this situation. However, applying an AED before EMS arrival should be considered a successful scenario for a volunteer responder programme.

Our results are observational and only represent associations. However, our analysis mimics a randomized trial and tries to estimate a causal effect based on the observed data by estimating standardized probabilities of bystander defibrillation.[41] Activating volunteers through apps or text messages has been associated with increased bystander-initiated resuscitation, but no causal effect on survival has yet been described.[13,25,36,42] When the emergency dispatch centre suspects an OHCA, they can activate volunteer responders. Accordingly, OHCAs with activated volunteer responders are recognized by the dispatcher, and protocols for OHCA can be effectuated, such as dispatch-assisted CPR, the highest level of EMS response, and the direction of bystanders to nearby AEDs. Consequently, OHCAs with activated volunteer responders will have a more favourable response at baseline than OHCAs without volunteer responder activation (like an Utstein population[43]). Identifying the optimal comparison group when evaluating the impact of volunteer responder activation in an observational setting is limited by the risk of bias. We chose to compare OHCAs where the volunteer responders arrived before EMS (had the possibility to impact the outcome) and OHCAs where EMS arrived first (no impact from volunteer responders). In this way, we eliminated the selection bias from the dispatcher since volunteer responders were activated for all patients. However, other unrecognized confounders could have impacted our results. To evaluate the effect on survival, a randomized trial is ongoing in Denmark (ClinicalTrials.gov: NCT03835403).

Conclusion

Bystander defibrillation was approximately 13% higher when a volunteer responder arrived before EMS in private homes and public locations. The probability of bystander defibrillation increased in a standardized population with longer EMS response times in private homes. Our findings support the activation of volunteer responders and suggest that volunteer responders could increase bystander defibrillation, particularly in private homes.

Supplementary material

Supplementary material is available at *European Heart Journal: Acute Cardiovascular Care*.

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Data availability

The data underlying this article cannot be shared publicly due to privacy reasons. The data will be shared on reasonable request to the corresponding author.

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