Impact of bystander-focused public health interventions on cardiopulmonary resuscitation and survival: a cohort study

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Summary

Background **Bystander cardiopulmonary resuscitation (CPR) increases an individual's chance of survival from out-of-hospital cardiac arrest (OHCA), but the frequency of bystander CPR is low in many communities. We aimed to assess the cumulative effect of CPR-targeted public health interventions in Singapore, which were incrementally introduced between 2012 and 2016.**

Methods **We did a secondary analysis of a prospective cohort study of adult, non-traumatic OHCAs, through the Singapore registry. National interventions introduced during this time included emergency services interventions, as well as dispatch-assisted CPR (introduced on July 1, 2012), a training programme for CPR and automated external defibrillators (April 1, 2014), and a first responder mobile application (myResponder; April 17, 2015). Using multilevel mixed-effects logistic regression, we modelled the likelihood of receiving bystander CPR with the increasing number of interventions, accounting for year as a random effect.**

Findings **The Singapore registry contained 11 465 OHCA events between Jan 1, 2011, and Dec 31, 2016. Paediatric arrests, arrests witnessed by emergency medical services, and healthcare-facility arrests were excluded, and 6788 events were analysed. Bystander CPR was administered in 3248 (48%) of 6788 events. Compared with no intervention, likelihood of bystander CPR was not significantly altered by the addition of emergency medical services interventions (odds ratio [OR] 1·33 [95% CI 0·98–1·79]; p=0·065), but increased with implementation of dispatch-assisted CPR (3·72 [2·84–4·88]; p<0·0001), with addition of the CPR and automated external defibrillator training programme (6·16 [4·66–8·14]; p<0·0001), and with addition of the myResponder application (7·66 [5·85–10·03]; p<0·0001). Survival to hospital discharge increased after the addition of all interventions, compared with no intervention (OR 3·10 [95% CI 1·53–6·26]; p<0·0001).**

Interpretation **National bystander-focused public health interventions were associated with an increased likelihood of bystander CPR, and an increased survival to hospital discharge. Understanding the combined impact of public health interventions might improve strategies to increase the likelihood of bystander CPR, and inform targeted initiatives to improve survival from OHCA.**

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Introduction

Bystander cardiopulmonary resuscitation (CPR) can double an individual's chance of survival from out-of-hospital cardiac arrest (OHCA), but bystander CPR frequency is low in many communities.[1–3] The National Academy of Medicine and the International Liaison Committee on Resuscitation have highlighted increasing bystander CPR as a crucial international objective.[4,5] Few studies have examined the combined effect of bystander-focused public health interventions on bystander CPR frequency and subsequent survival.

Several studies have examined the large-scale impact of single, city-wide, public health interventions on bystander CPR. For example, in Phoenix, AZ, USA, implementation of a bundled dispatch-assisted CPR protocol conferred a 7% increase in bystander CPR frequency and subsequent survival also increased (odds ratio [OR] 1·64, 95% CI 1·61–2·30).[6,7] Furthermore, a Swedish study demonstrated an ecological correlation between mass CPR training and increased rates of bystander CPR before the arrival of emergency medical services.[3] Additionally, mobile-phone dispatching of layperson volunteers was shown to be associated with a significant increase in bystander CPR frequency in the population.[8] Although many of these studies have shown the independent impact of interventions on bystander CPR frequency, few studies have examined the cumulative impact of each additional intervention. This knowledge could help inform future public health planning and public policy initiatives surrounding OHCA, by helping to identify the core components

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Research in context

Evidence before this study

We searched PubMed for articles published between Jan 1, 2010, and Oct 1, 2019, with the terms "cardiopulmonary resuscitation", "bystander", "CPR", "bystander CPR", "bystander cardiopulmonary resuscitation", "sudden cardiac arrest", "cardiac arrest", and "out of hospital cardiac arrest". We also cross-referenced this search with "dispatch-assisted CPR", "dispatch CPR", "telecommunicator CPR", "CPR training", "AED training", "resuscitation training", and "mobile phone technologies". We reviewed the referenced lists of articles and selected those deemed most relevant. Bystander cardiopulmonary resuscitation (CPR) increases an individual's chance of survival from out-of-hospital cardiac arrest (OHCA), but the frequency of bystander CPR is low (approximately 40% likelihood) in many communities. Community-level, bystander-focused public health interventions might affect likelihood of bystander CPR and survival. Some analyses have examined the effect of individual interventions, but few studies have examined the combined effect of these interventions on bystander CPR and survival.

Added value of this study

We aimed to assess the cumulative effect of bystander-focused public health interventions on the likelihood of bystander CPR and subsequent survival to hospital discharge. We found that national bystander-focused public health interventions (dispatch-assisted CPR, CPR and automated external defibrillator training, and the myResponder mobile application) increased the likelihood of layperson bystander CPR. Additionally, these findings were associated with increased survival to hospital discharge. This study provides insight into ways to potentially increase bystander CPR and survival through community-level, bystander-focused public health interventions.

Implications of all the available evidence

These findings could help inform future public policy initiatives and considerations for allocating resources to increase the likelihood of receiving bystander CPR and improve outcomes from cardiac arrest.

necessary to improve bystander CPR frequency and survival, while simultaneously reducing the resources required.

Singapore has been collecting prospective nationwide OHCA data through the Pan-Asian Resuscitation Outcome Study (PAROS), and has implemented a series of public health interventions to increase bystander CPR frequency. We aimed to assess the cumulative effect of a bundle of public health interventions on bystander CPR and survival. We hypothesised that implementation of three interventions together: dispatch-assisted CPR, CPR and automated external defibrillator training, and a first responder mobile application (myResponder), would increase bystander CPR frequency by at least 100%.

Methods

Study design and setting

We did a secondary analysis of a prospective cohort registry study, examining differences in likelihood of bystander CPR and survival after the implementation of national bystander interventions in Singapore. Singapore is a single city-state island in southeast Asia and has a population of 5·7 million residents. The population is projected to continue to grow at a rate of 1·4% per year, and is comprised of a mixture of Chinese, Malay, Indian, and other ethnic populations. The population density is 55 623 people per km².[9] The heterogeneity in ethnicities and density of Singapore's population allows for a unique, contained assessment of the effect of bystander public health interventions on outcomes after OHCA. The Centralised Institutional Review Board (2013/604/C) and the Domain Specific Review Board (2013/00929) granted approval for this study. For the primary PAROS study, each participating site obtained Insitutional Review Board approval from their respective national board and met the criteria for minimal risk. As the data were de-identified, the SingHealth Institutional Review Board determined this study to be exempt from requirements for informed consent.

Data sources

We used de-identified registry data collected prospectively by PAROS in Singapore from Jan 1, 2011, to Dec 31, 2016. PAROS represents a clinical research network formed in 2010 by pre-hospital health-care providers and emergency care physicians conducting research in the Asia-Pacific region, with data from Japan, Malaysia, Singapore, South Korea, Taiwan, Thailand, and the United Arab Emirates.[10–12] Collected variables use the Utstein definitions for OHCA and include bystander CPR and other time-sensitive OHCA data elements.[13] Data from the emergency medical services system and hospital are linked and governed by the Unit for Prehospital Emergency Care, Ministry of Health for Singapore's national OHCA registry. De-identified data are then sent to the PAROS network, as Singapore is a participating site.[12] Data collected are entered into a secured online electronic data capture system developed with assistance from the US Center for Disease Control and the Cardiac Arrest Registry to Enhance Survival. All data entered into the data capture system are assigned a unique case number to ensure patient de-identification. Each participating site has their own local research coordinator who is responsible for ensuring data accuracy and completion. Additional quality assurance measures include a built-in validation rule that cross-checks data fields and flags missing fields to ensure accurate and complete data capture. The PAROS data administrator manages the online data entry system and performs additional data quality audits. In Singapore, OHCA data from seven participating tertiary hospitals (including one children's hospital) are collected prospectively by a research coordinator following similar data quality checks and verification. All OHCA patients transported by the national emergency medical services agency to the tertiary hospitals were included in the study. PAROS epidemiological data and in-hospital data have also been reported elsewhere.[14–17] From 2011 to 2016 (the period of the study), Singapore did not have a termination of resuscitation rule; the termination of resuscitation protocol would allow paramedics to terminate ongoing resuscitation and pronounce the death at the scene if certain conditions were fulfilled.

Procedures

During the study period, various public health interventions to improve the effectiveness of CPR in OHCA were introduced across Singapore, including improved equipment in emergency response vehicles, protocols for dispatch-assisted bystander CPR, and community first responder training. We determined the date of implementation of each intervention, and approximated a 6-month run-in period to account for intervention dissemination (informed by the original report[18] of one of the interventions, dispatch-assisted CPR, in which greater than 50% of dispatch-assisted CPR calls correctly followed the new protocol by 6 months). The implementation information was gathered from the individuals and organisations that enacted the programmes nationwide. The comparison group was all cases that occurred prior to the intervention periods (pre-intervention category; from Jan 1, 2011, to Dec 31, 2011).

The first set of interventions (commenced Jan 1, 2012; run-in completed June 30, 2012) focused on emergency medical services, including providing emergency medical services access to mechanical CPR devices in ambulances, and the Firebiker scheme in which fire and rescue specialists trained in appropriate resuscitation techniques are dispatched on a motorcycle ahead of an ambulance.[19] Subsequently, on July 1, 2012 (run-in completed June 30, 2012), a centralised protocol for dispatch-assisted CPR was introduced throughout Singapore.[20] The protocol was adapted from that of the Arizona Department of Health Services,[21] and the dispatcher would use the compression-only protocol to guide the caller. An audit and review of 3371 OHCA events (35·9% of 9400 total cases) between July 1, 2012, and Dec 31, 2016, found that 2435 (72·2%) of patients in these 3371 cases were given dispatch-assisted CPR in compliance with the protocol.

After successful implementation of dispatch-assisted CPR, a community-based training programme for dispatch-assisted first responders was introduced in April 1, 2014 (run-in completed Oct 31, 2014), providing free training on CPR and automatic external defibrillators to school children and members of the general public. The dispatch-assisted first responder training programme focuses on training individuals to telephone the emergency services on 9-9-5, push hard and fast on the centre of the chest (compression-only CPR), and use an automatic external defibrillator. From April 1, 2014, to Dec 31, 2016, 41 021 individuals were trained through this programme; 36 936 through at least 100 schools and 4085 in public settings including workplaces, offices, community centres, places of worship, and government buildings.

Finally, on April 17, 2015 (run-in completed Oct 16, 2015), Singapore supported the centralised availability of the myResponder mobile application, which crowdsources layperson responders with CPR and automatic external defibrillator training to respond to cardiac arrest events within 400 m of their location.[22] Layperson responders do not need to be certified in CPR and automatic external defibrillator use to enrol with myResponder. Additionally, the myResponder application has the ability to show nearby automatic external defibrillators upon acceptance of the case by responders. Since 2015, 12 248 volunteers have enrolled in myResponder. On Oct 1, 2015, the myResponder application was extended to crowdsource Singapore Mass Rapid Transit taxi drivers (n=100) equipped with automatic external defibrillators, who previously had enrolled in the AED on Wheels programme. Taxi drivers were notified via myResponder to assist with suspected cardiac arrests within a 1·5 km radius of their location. For the purposes of this analysis, we compared events after each additional intervention to events in the pre-intervention period. In the sensitivity analysis, we combined events in the pre-intervention period with events after non-bystander, emergency medical services interventions (appendix p 1).

See Online for appendix

Outcomes

Consistent with our prior work, we defined bystander CPR, our primary outcome, as delivery of CPR from a layperson bystander, excluding CPR from law enforcement or emergency medical services first responders.[23] Survival, our secondary outcome, was defined as survival to hospital discharge. This information was taken from the emergency medical services forms and verified by emergency medical services personnel. We excluded paediatric arrests (in individuals younger than 18 years of age), arrests witnessed by emergency medical services, and OHCA events from traumatic injury or non-cardiac causes. We also excluded arrest events that occurred in a residential institution (eg, skilled nursing facility) or health-care centre. Patient ethnicity was modelled categorically; age was modelled as a continuous variable. Location of cardiac arrest was defined as residential (ie, home) or non-residential (eg, public building, place of recreation, or other public location). As bystander response to OHCA varies by location, examining variation by location was warranted.

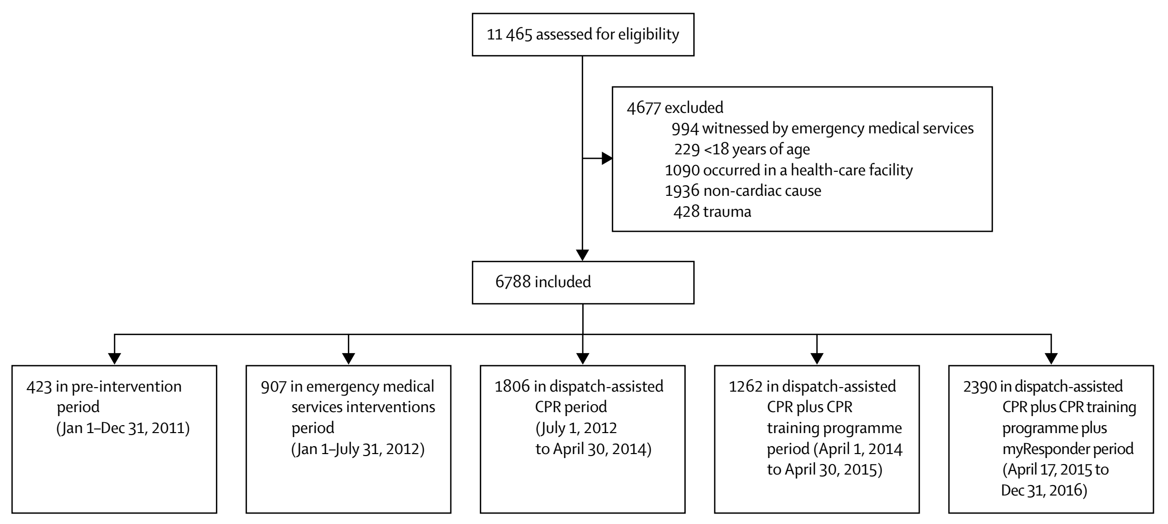

Figure 1: **Out-of-hospital cardiac arrests categorised by intervention period**
CPR=cardiopulmonary resuscitation.

	Overall (n=6788)	Pre-interventions (n=423)	Emergency medical services interventions (n=907)	Dispatch-assisted CPR (n=1806)	Dispatch-assisted CPR plus CPR training programme (n=1262)	Dispatch-assisted CPR plus CPR training programme plus myResponder (n=2390)
Bystander CPR						
No	3540 (52·2%)	344 (81·3%)	701 (77·3%)	1010 (55·9%)	551 (43·7%)	934 (39·1%)
Yes	3248 (47·8%)	79 (18·7%)	206 (22·7%)	796 (44·1%)	711 (56·3%)	1456 (60·9%)
Survival to hospital discharge						
No	6451 (95·0%)	402 (95·0%)	851 (93·8%)	1732 (95·9%)	1205 (95·5%)	2261 (94·6%)
Yes	297 (4·4%)	10 (2·4%)	27 (3·0%)	74 (4·1%)	57 (4·5%)	129 (5·4%)
Location of arrest						
Non-residential	1562 (23·0%)	93 (22·0%)	202 (22·3%)	450 (24·9%)	290 (23·0%)	527 (22·1%)
Residential	5226 (77·0%)	330 (78·0%)	705 (77·7%)	1356 (75·1%)	972 (77·0%)	1863 (77·9%)
Age, years (IQR)	67 (52–82)	65 (50–80)	66 (51–81)	67 (52–82)	67 (52–82)	68 (53–83)
Gender						
Male	4615 (68·0%)	285 (67·4%)	651 (71·8%)	1220 (67·6%)	860 (68·1%)	1599 (66·9%)
Female	2173 (32·0%)	138 (32·6%)	256 (28·2%)	586 (32·4%)	402 (31·9%)	791 (33·1%)
Ethnicity						
Chinese	4434 (65·3%)	266 (62·9%)	585 (64·5%)	1215 (67·3%)	821 (65·1%)	1547 (64·7%)
Indian	819 (12·1%)	57 (13·5%)	120 (13·2%)	182 (10·1%)	157 (12·4%)	303 (12·7%)
Malay	1129 (16·6%)	71 (16·8%)	131 (14·4%)	312 (17·3%)	213 (16·9%)	402 (16·8%)
Other	406 (6·0%)	29 (6·9%)	71 (7·8%)	97 (5·4%)	71 (5·6%)	138 (5·8%)
Receiving hospital						
A	557 (8·2%)	9 (2·1%)	28 (3·1%)	71 (3·9%)	61 (4·8%)	388 (16·2%)
B	1530 (22·5%)	112 (26·5%)	204 (22·5%)	402 (22·3%)	282 (22·3%)	530 (22·2%)
C	1154 (17·0%)	81 (19·1%)	188 (20·7%)	311 (17·2%)	205 (16·2%)	369 (15·4%)
D	1154 (17·0%)	98 (23·2%)	167 (18·4%)	373 (20·7%)	295 (23·4%)	221 (9·2%)
E	1709 (25·2%)	79 (18·7%)	230 (25%)	459 (25·4%)	299 (23·7%)	642 (26·9%)
F	684 (10·1%)	44 (10·4%)	90 (9·9%)	190 (10·5%)	120 (9·5%)	240 (10·0%)

(Table 1 continues on next page)

	Overall (n=6788)	Pre-interventions (n=423)	Emergency medical services interventions (n=907)	Dispatch-assisted CPR (n=1806)	Dispatch-assisted CPR plus CPR training programme (n=1262)	Dispatch-assisted CPR plus CPR training programme plus myResponder (n=2390)
(Continued from previous page)						
Time of day						
2300–0559 h	1316 (19·4%)	84 (19·9%)	167 (18·4%)	340 (18·8%)	267 (21·2%)	458 (19·2%)
0600–0859 h	982 (14·5%)	63 (14·9%)	129 (14·2%)	263 (14·6%)	166 (13·2%)	361 (15·1%)
0900–1559 h	2236 (32·9%)	132 (31·2%)	313 (34·5%)	581 (32·2%)	419 (33·2%)	791 (33·1%)
1600–1859 h	998 (14·7%)	60 (14·2%)	133 (14·7%)	270 (15·0%)	169 (13·4%)	366 (15·3%)
1900–2259 h	1220 (18·0%)	81 (19·1%)	159 (17·5%)	342 (18·9%)	234 (18·5%)	404 (16·9%)
Response time						
<8 min	2245 (33·1%)	192 (45·4%)	361 (39·8%)	602 (33·3%)	332 (26·3%)	758 (31·7%)
≥8 min	4543 (66·9%)	231 (54·6%)	546 (60·2%)	1204 (66·7%)	930 (73·7%)	1632 (68·3%)
ROSC						
No	4887 (72·0%)	327 (77·3%)	686 (75·6%)	1290 (71·4%)	877 (69·5%)	1707 (71·4%)
Yes	1679 (24·7%)	89 (21·0%)	200 (22·1%)	471 (26·1%)	349 (27·7%)	570 (23·8%)
Not applicable*	222 (3·3%)	7 (1·7%)	21 (2·3%)	45 (2·5%)	36 (2·9%)	113 (4·7%)
First arrest rhythm						
Asystole	3313 (48·9%)	239 (56·5%)	477 (52·6%)	904 (50·1%)	625 (49·5%)	1068 (44·7%)
PEA	1560 (23·0%)	86 (20·3%)	200 (22·1%)	392 (21·7%)	319 (25·3%)	563 (23·6%)
Unknown shockable or unshockable	483 (7·1%)	3 (0·7%)	14 (1·5%)	121 (6·7%)	47 (3·7%)	298 (12·5%)
VF or VT	1386 (20·4%)	92 (21·3%)	212 (23·4%)	382 (21·2%)	255 (20·2%)	445 (18·6%)
Not applicable*	42 (0·6%)	2 (0·5%)	1 (0·1%)	7 (0·4%)	16 (1·3%)	16 (0·7%)
Defibrillation						
No	4441 (65·4%)	304 (71·9%)	612 (67·5%)	1192 (66·0%)	795 (63·0%)	1538 (64·4%)
Yes	2301 (33·9%)	116 (27·4%)	291 (32·1%)	607 (33·6%)	451 (35·7%)	836 (35·0%)
Not applicable*	42 (0·6%)	2 (0·5%)	1 (0·1%)	7 (0·4%)	16 (1·3%)	16 (0·7%)
Year						
2011	914 (13·5%)	423 (100·0%)	491 (54·1%)	··	··	··
2012	876 (12·9%)	··	416 (45·9%)	460 (25·5%)	··	··
2013	1020 (15·0%)	··	··	1020 (56·5%)	··	··
2014	1208 (17·8%)	··	··	326 (18·1%)	882 (69·9%)	··
2015	1350 (19·9%)	··	··	··	380 (30·1%)	970 (40·6%)
2016	1420 (20·9%)	··	··	··	··	1420 (59·4%)

Data are n (%) unless otherwise stated. Missing data: survival to hospital discharge (n=40), time of day (n=36), first arrest rhythm (n=4), and defibrillation (n=4). Receiving hospital names are not disclosed. CPR=cardiopulmonary resuscitation. ROSC=return of spontaneous circulation. PEA=pulseless electrical activity. VF=ventricular fibrillation. VT=pulseless ventricular tachycardia. *Refers to arrest patients that were transported to the hospital by transport other than the emergency medical services, as this information is not provided in these cases.

***Table 1:* Patient demographics**

Statistical analysis

There was minimal missing data for the primary outcome, secondary outcome, and independent variables of interest, thus we analysed the data in a complete case analysis, using STATA/SE 16.0. We initially examined the data using descriptive statistics and frequencies. Next, we fit a multilevel mixed-effects logistic regression model (command "melogit" in STATA) to assess the differences in likelihood of bystander CPR, and survival to hospital discharge, with increased public health intervention. We chose to model year as a random effect rather than a fixed effect, to allow for random heterogeneity within the year variable. Consistent with prior investigations, patient-level variables with a p value less than 0·15 for association in a univariate analysis were included in the final multivariable model, in addition to variables added on the basis of clinical significance. The final regression model for both the primary outcome of likelihood of receipt of bystander CPR and the secondary outcome of survival to hospital discharge included intervention (exposure); gender, age, ethnicity, and location of the patient; witness status; receiving hospital; response time; time of day; and year. We included receiving hospital as a fixed effect in the final regression equation. We examined likelihood of bystander CPR with increased intervention, stratified by residential and non-residential locations. To

	Bystander CPR (n=6752)		Survival to hospital discharge (n=6715)	
	OR (95% CI)	p value	OR (95% CI)	p value
Pre-interventions	1·0	..	1·0	..
Emergency medical services interventions	1·33 (0·98–1·79)	0·065	1·62 (0·74–3·53)	0·22
Dispatch-assisted CPR	3·72 (2·84–4·88)	<0·0001	2·12 (1·04–4·33)	0·040
Dispatch-assisted CPR plus CPR training programme	6·16 (4·66–8·14)	<0·0001	2·50 (1·20–5·19)	0·014
Dispatch-assisted CPR plus CPR training programme plus myResponder	7·66 (5·85–10·03)	<0·0001	3·10 (1·53–6·26)	<0·0001

Models for bystander CPR and survival to hospital discharge were mixed-effects regressions controlling for age, gender, ethnicity, and location of the patient, witness status, receiving hospital, response time, and time of day. CPR=cardiopulmonary resuscitation. OR=odds ratio.

***Table 2:* Likelihood of bystander CPR and survival to hospital discharge by number of public health interventions**

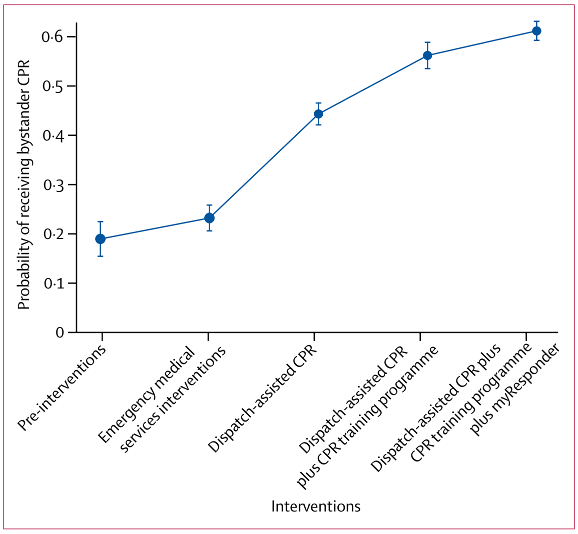

***Figure 2:* Probability of bystander CPR by number of interventions**
CPR=cardiopulmonary resuscitation.

further examine our data, we used predictive margins, specifically the "margins" and "marginsplot" package in STATA to view the data and understand the likelihood of bystander CPR and survival with each additional intervention.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author and senior author had full access to all of the data and had the final responsibility for the decision to submit for publication.

Results

From Jan 1, 2011, to Dec 31, 2016, the Singapore PAROS registry recorded 11 465 OHCA events. After excluding paediatric arrests, arrests in health-care facilities, arrests witnessed by emergency medical services, and arrests of non-cardiac cause, 6788 events were analysed (figure 1, table 1).

Arrests during the period after implementation of interventions focused on emergency medical services were associated with a slight, non-significant increase in bystander CPR frequency compared with the pre-intervention period, from 18·7% (79 of 423 arrests) in the pre-intervention period to 22·7% (206 of 907 arrests) in the intervention period (OR 1·33 [95% CI 0·98–1·79]; p=0·065). Arrests in the period after implementation of dispatch-assisted CPR were associated with an increased likelihood of bystander CPR (44·1%; 796 of 1806 arrests) compared with arrests in the pre-intervention period (3·72 [2·84–4·88]; p<0·0001). The odds of receiving of bystander CPR increased again after the implementation of the dispatch-assisted first responder training programme (56·3%; 711 of 1262 arrests; OR 6·16 [4·66–8·14]; p<0·0001) and after the implementation of the myResponder application (60·9%; 1456 of 2390 arrests; 7·66 [5·85–10·03]; p<0·0001), compared with the pre-intervention period (table 2). The predicted probability of receiving bystander CPR increased with each added intervention (figure 2).

Dispatch-assisted CPR and subsequent interventions were associated with an increased likelihood of bystander CPR compared with the pre-intervention period in arrests that occurred in residential locations (n=5213, p<0·0001). Within residential locations, there was increased frequency of bystander CPR after implementation of dispatch-assisted CPR and the dispatch-assisted first responder training programme (OR 7·89 [95% CI 5·61–11·09]; p<0·0001), as well as after the addition of the myResponder application (9·90 [7·11–13·78]; p<0·0001), compared with the frequency in the pre-intervention period (table 3).

In non-residential locations, interventions were similarly associated with an increased likelihood of bystander CPR (n=1539, p<0·0001). Within non-residential locations, there was an increased frequency of bystander CPR after implementation of dispatch-assisted CPR (OR 2·37 [95% CI (1·42–-3·94]; p<0·0001), and after dispatch-assisted CPR, dispatch-assisted first responder training, and myResponder had all been implemented (3·80 [2·28–-6·34]; p<0·0001), compared with the frequency in the pre-intervention period (table 3).

Dispatch-assisted CPR and subsequent interventions were associated with an increase in survival to hospital discharge (p<0·0001;) figure 3). There were increased rates of survival to hospital discharge after the implementation of dispatch-assisted CPR (OR 2·12 [95% CI 1·04–4·33]; p=0·04), and after dispatch-assisted CPR, dispatch-assisted first responder training, and myResponder had all been implemented (3·10 [1·53–6·26]; p<0·0001), compared with rates in the pre-intervention period (table 2).

Discussion

In Singapore, a bundle of three public health bystander-focused interventions was associated with increased bystander CPR frequency and increased survival to hospital discharge after OHCA, compared with the pre-intervention time period. It is important to note that while the emergency medical services-focused interventions were important to strengthen the pre-hospital infrastructure, the interventions themselves were not designed to target bystanders. As such, an investigation examining the effect of the bystander-focused interventions was warranted. Our findings could be considered when developing targeted community-wide training to improve bystander CPR and subsequent survival outcomes from OHCA.

Studies have demonstrated that dispatch-assisted CPR improves both layperson bystander CPR delivery, and survival, from OHCA. A recent prospective investigation demonstrated an increase in compressions started with community implementation of dispatch-assisted CPR (compressions started in 44% of arrests pre-interventon *vs* 53% post-intervention, p<0·0001).[7] Furthermore, a recent publication from Arizona, USA demonstrated that dispatch-assisted CPR was associated with improved survival compared with before the implementation of dispatch-assisted CPR (OR 1·64 [95% CI 1·61–2·30]).[6]

Prior studies in Singapore have focused on methods to improve dispatch-assisted CPR and examining barriers to this intervention.[24] It is important to consider that dispatch-assisted CPR is centralised in Singapore, therefore there are robust quality and assurance measures to ensure adherence to the protocol and resuscitation process metrics. Additionally, Singapore continues to optimise the dispatch-assisted CPR protocol to improve outcomes and survival from OHCA. Future studies could consider taking aspects of the Singapore dispatch-assisted CPR protocol and implementing it in other locations, such as urban cities in the USA.

Recent publications have supported the notion of mandating CPR training in schools prior to high-school graduation in the USA.[25,26] A recent publication in the USA showed that mandated CPR training legislation was associated with an increased likelihood of CPR training.[27] Although studies suggest CPR training legislation could improve CPR frequency, prospective investigation in Denmark has identified challenges with the implementation of CPR training legislation.[28,29]

The Ministry of Education in Singapore requires that school-aged children are taught CPR in physical education classes. In addition to this requirement, Singapore offers free CPR and automatic external defibrillator training to schools, community-based groups, and workplaces through the dispatch-assisted first responder training programme. Providing free CPR training removes one of the known barriers to CPR training, specifically, cost and access to the course.[30] This study showed the impact of including dispatch-assisted CPR together with free CPR training. Future public health programming considerations might examine the cost-benefit analysis of such a centralised free CPR programme, and investigate whether the strategy is truly reaching the desired population.

Other studies have examined crowdsourcing bystander CPR response through mobile applications.[31,32] Specifically, Stockholm, Sweden has observed an increase in bystander CPR frequency and survival outcomes associated with these crowdsourcing mobile applications.[8] Other parts of the world are working to implement variations of a crowdsourcing bystander CPR mobile application for OHCA and have observed some challenges in implementation.[33]

Singapore's bystander crowdsourcing mobile application, myResponder, is offered to all citizens and is maintained centrally through the emergency medical services and dispatch centre. Furthermore, the application is

	Residential (n=5213)		Non-residential (n=1539)	
	OR (95 CI%)	p value	OR (95% CI)	p value
Pre-interventions	1·00	..	1·00	..
Emergency medical services interventions	1·37 (0·95–1·99)	0·091	1·35 (0·77–2·37)	0·29
Dispatch-assisted CPR	4·51 (3·23–6·30)	<0·0001	2·37 (1·42–3·94)	<0·0001
Dispatch-assisted CPR plus CPR training programme	7·89 (5·61–11·09)	<0·0001	3·29 (1·93–5·61)	<0·0001
Dispatch-assisted CPR plus CPR training programme plus myResponder	9·90 (7·11–13·78)	<0·0001	3·80 (2·28–6·34)	<0·0001

Multilevel mixed-effects logistic regression controlling for age, gender, and ethnicity of the patient, witness status, receiving hospital, response time, and time of day. CPR=cardiopulmonary resuscitation. OR=odds ratio.

Table 3: **Likelihood of bystander CPR by number of interventions, in residential and non-residential locations**

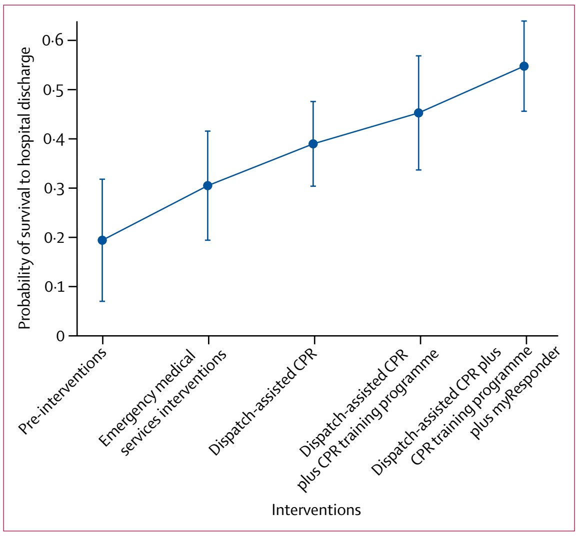

Figure 3: **Probability of survival to hospital discharge by number of interventions**
CPR=cardiopulmonary resuscitation.

linked to the centralised automatic external defibrillator registry, and is offered with the free CPR and automatic external defibrillator training, highlighting the importance of bundling the intervention for the general public. Future studies could consider ways to encourage individuals to maintain the application on their phones and encourage response in OHCA situations. Additionally, it might be important to consider the population density and cultural norms, and how these factors affect bystander response in OHCA situations.

Few studies have examined the bundling of public health interventions to improve bystander CPR response. Our findings are similar to those seen in a study in North Carolina, USA from 2010 to 2013, which examined the impact of a statewide bystander and first responder education programme and found an increased likelihood of survival after implementation of the programme.[34] Similarly, a publication from Denmark reported widespread CPR training efforts from 2001 to 2010 and observed an increase in survival to hospital discharge and bystander CPR rates.[35] This study from Singapore provides a unique opportunity to examine the combined effects of three interventions on bystander CPR frequency and survival outcomes. Although we were unable to examine the individual effect of each intervention, the findings suggest the importance of bundling interventions, especially public health interventions, to improve outcomes for OHCA. It is possible that dispatch-assisted CPR and CPR training are dependent on each other in order to see a benefit.[36] Furthermore, our results could also show the effect of these bundled interventions on overall public knowledge and awareness. This study also highlights the importance of needing different bystander interventions to cover critical aspects of the chain of survival, specifically, chest compressions and defibrillation of a cardiac arrest victim. Future studies might consider the added effect of additional interventions on subsequent outcomes from OHCA in other locations.

There are several inherent limitations in this study. It was a retrospective analysis using a quality improvement database and only provides an estimation of the effects of interventions. The analysis lacks bystander CPR quality, thus we are unable to account for the role of CPR quality on improved OHCA outcomes. Furthermore, data collection through PAROS might directly affect the bystander CPR frequency and survival findings. Unfortunately, we are limited in our ability to measure the effect of PAROS on bystander CPR frequency and survival. Additionally, unmeasured confounders such as improved quality of emergency medical services CPR, in-hospital treatment, mechanical CPR transitions, and post-resuscitation care, could influence the results seen in bystander CPR frequency and survival to hospital discharge. Our exposure is an ecological, estimated exposure, although we matched the data with individual-level data to create a semi-ecological study. By doing so, we were able to reduce the bias inherent in ecological, city-wide study designs, but acknowledge the limitations to causal inference. The nature of this analysis is dependent on the dates set for the interventions, for which we estimated a 6-month run-in period. This estimation might be partially confounded by unmeasured lagged effects and potential pre-intervention confounding. Lastly, the findings are reflective of the nation of Singapore, of which the demographics, centralised emergency medical services systems, and population size might not be generalisable to other locations. Despite this, the findings associated with these bystander-focused public health interventions are encouraging and could assist in generating ideas for many other populations. In conclusion, our study provides a unique perspective on the effect of public health interventions on the frequency of bystander CPR and survival from OHCA. The likelihood of a patient with OHCA receiving bystander CPR increased as the interventions were sequentially introduced, particularly in residential settings, and coincided with increased survival to hospital discharge. These findings could prove useful for future, targeted efforts to increase the use and effectiveness of bystander CPR, and improve survival after OHCA.

Contributors

ALB was responsible for study design, data analysis, data interpretation, and manuscript writing. AFWH was responsible for study design, data interpretation, and manuscript review. NS, AEW, and PPP was responsible for data collection, data analysis, and manuscript review. YYN, DRM, LT, MY-CC, BS-HL, SOC, LPT, JPHK, and SA were responsible for data collection, data interpretation, and manuscript review. TØ, HBB, and MEHO were responsible for study design, data interpretation, and manuscript review.

Declaration of interests

MEHO has licensing agreement and patent filing (application number 13/047,348) with ZOLL Medical Corporation for a study titled "Method of predicting acute cardiopulmonary events and survivability of a patient", and is a scientific advisor to Global Healthcare. All other authors declare no competing interests.

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