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Training and education

An innovative Hearing AED alarm system shortens delivery time of automated external defibrillator – A randomized controlled simulation study

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ABSTRACT

Background: Early defibrillation with an automated external defibrillator (AED) is a key element in the out-of-hospital cardiac arrest (OHCA) chain. However, a public automatic defibrillator (PAD) is often not easily accessible during emergency situations. Here, we have developed an AED-based alarm system together with a smartphone Hearing AED application (APP) that would activate registered public access AED within 300 m radius from the location of an OHCA event. It also alerts nearby related personnel to bring in the AED to the OHCA location for emergency assistance. The aim of this study is to determine if this novel Hearing AED alarm system shortens the AED delivery time.

Methods: This was a randomized controlled simulation study. Participants were randomly assigned to one of the 3 groups: (a) bystander group, (b) APP responder group, and (c) AED alarm responder in equal ratios. The bystanders were stationed at the OHCA scene, and must access a nearby AED by the instruction of the dispatcher of emergency medical services. APP responders were stationed within 300 m of the cardiac arrest scene, and were activated by the Hearing AED APP. The AED alarm responders were brought to AED location, and were activated by the AED-based alarm device mounted on an AED case. We measured the time taken to find and bring the nearby AED to the OHCA scene. The primary outcome was the total delivery time in each group. The secondary outcomes were times needed: (a) from the starting point to AED place, (b) from AED place to the OHCA scene, and (c) the operation time.

Results: We enrolled 90 participants in this study. The total AED delivery times were significantly different across the 3 groups. The shortest time was in the AED alarm responder group, compared with the other two groups. The median time from the starting point to AED was statistically shorter in the bystander group than in the APP responder group (116.0 sec, IQR 80.0–135.0 vs 159.0 sec, IQR 98.5–200.5, $p = 0.029$). In the analysis with the general linear model, we found statistically shorter total AED delivery time in the AED alarm responder group ($\beta = -122.4$, $p = 0.004$). In contrast, the APP responder group was associated with a markedly longer total AED delivery time ($\beta = 104.6$, $P=0.016$).

Conclusion: In this simulation study, the Hearing AED system contributed to shortening the AED delivery time. Further studies are needed to determine its validation in the real world situation in the future.

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Introduction

Sudden cardiac arrest is a worldwide important public health issue, with over 3 million patients experiencing out-of-hospital cardiac arrest (OHCA) each year.[1] Early cardiopulmonary resuscitation and defibrillation using a public automatic defibrillator (PAD) before the arrival of emergency medical services (EMS) play a pivotal role in OHCA survival rate.[2–3] Patients with OHCA receiving PAD defibrillation have a better chance of survival, and their neurological outcomes are also more favorable.[4–5] Survival rates of OHCA are from 2 % to 11 % globally,[1] and such survival with favorable neurological outcomes increases up to 60 % if victims of OHCA with cardiac origin have received defibrillation within 5 min of their collapse,[6] indicating the importance of early defibrillation.

Although PADs are increasingly deployed in many countries, their utility rate remains low.[7–9] One reason may be related to the difficulty for lay responders to find a nearby PAD, creating a barrier for its use during an emergency situation. To resolve this problem, the International Consensus on CPR and Emergency Cardiovascular Care Science encourages the use of social media technologies to activate lay responders to perform CPR and to apply an automated external defibrillator (AED).[10] Studies have reported that activation of lay responders by text-message or smart phone can shorten the time to resuscitation in real practices,[11–12] and these technologies can improve bystander CPR and defibrillation rate before EMS arrival.[11,13] However, utilization of these devices relies on nearby voluntary responders, and the round-trip to retrieve AEDs is often time consuming. Therefore, we here modified the idea to focus on optimizing AEDs' accessibility, and established a connection between dispatch center and PADs. Once an OHCA event has happened, we hope that the dispatch center can alert and activate volunteers nearby AED via an AED alarm system.

We thereby developed an AED-based alarm system to activate lay responders who are close to PAD to join the emergent rescue. We hypothesized that such an innovative system activates local lay responders and shortens AED delivery time.

Methods

Study design

We performed a randomized controlled study from November 2023 to December 2023, using a simulated cardiac arrest scenario.

AED-based alarm system – Hearing AED

Emson Social Enterprise Co., Ltd. developed an AED-based alarm device (Fig. 1) together with a smartphone application Hearing AED system (Fig. 2). The alarm device was designed to mount on the case of a registered AED, connecting to the EMS dispatch center every 15 sec through Wireless Fidelity to acquire information on OHCA events. When EMS had received a call of suspected cardiac arrest, the dispatcher assigned an ambulance to the scene, and at the same time, activated the Hearing AED system. An AED-based alarm device located within 300 m radius of the OHCA event was activated, emitting a buzzer sound, with accompanying voice instructions. A QR code indicating the location of the OHCA event also occurred on the display screen of the alarm device. The alarm buzzer sound was 106 dB loud, lasting for 2 min. Then a voice signal followed: "Someone has collapsed nearby. Please pick up the AED and scan the QR code to assist the rescue". When a potential rescuer was close to an AED alarm device, he/she could have heard the alert buzzer sound and voice instructions, and responded to this emergency event. These AED alarm responders used their smartphones to scan the QR code on the display screen of the AED alarm device and brought the AED to OHCA scene through the Hearing AED smartphone application (APP). This APP was supplemental to the AED-based alarm device. Once the dispatcher activated the Hearing AED system, a signal notification was

Fig. 1. AED alarmer on an AED case.

sent to the APP-loaded smartphones within 300 m of OHCA scene (Fig. 2**a**). After receiving the notification, the APP responder was able to choose either trying to find a nearby AED and bring it to the OHCA scene, or going directly to the OHCA scene (Fig. 2**b**). A geographic information and built-in navigation system were shown on the display screen of smartphones to guide the rescuers according to their choice (Fig. 2**c**).

Registered PADs location and available time were provided by the Ministry of Health and Welfare of Taiwan. The AED-based alarm device and Hearing AED smartphone application were allowed to retrieve information on the EMS system through the National Fire Agency, Ministry of the Interior prior to the start of this study.

Participants and randomization

We enrolled subjects aged between 18 and 55 years old, and each owned an internet-accessible smartphone. We excluded those with major chronic illness, and those who had any difficulties in their movements. Participants were recruited via advertisement in social media as well as by word of mouth from the existing participants. Informed consents were acquired from participants prior to the study.

Participants were randomly assigned to one of 3 groups in a 1:1:1 ratio using simple randomization: (a) bystander group, (b)APP responder group, and (c) AED alarm responder group. The allocation was notified to the participants just before the simulation scenario. After randomization, study participants were informed about their allocated group, but were blinded to the purpose of the study. All participants received a prepaid card of 100 New Taiwanese Dollars as token thanks for their participation.

We documented the demographic data (age, sex, education, occupation), basic life support training, and experience of CPR/resuscitation of all participants.

Setting of simulations

The study was conducted at the street near a registered PAD in the North District of Taichung City. Thirty OHCA scenarios with the same

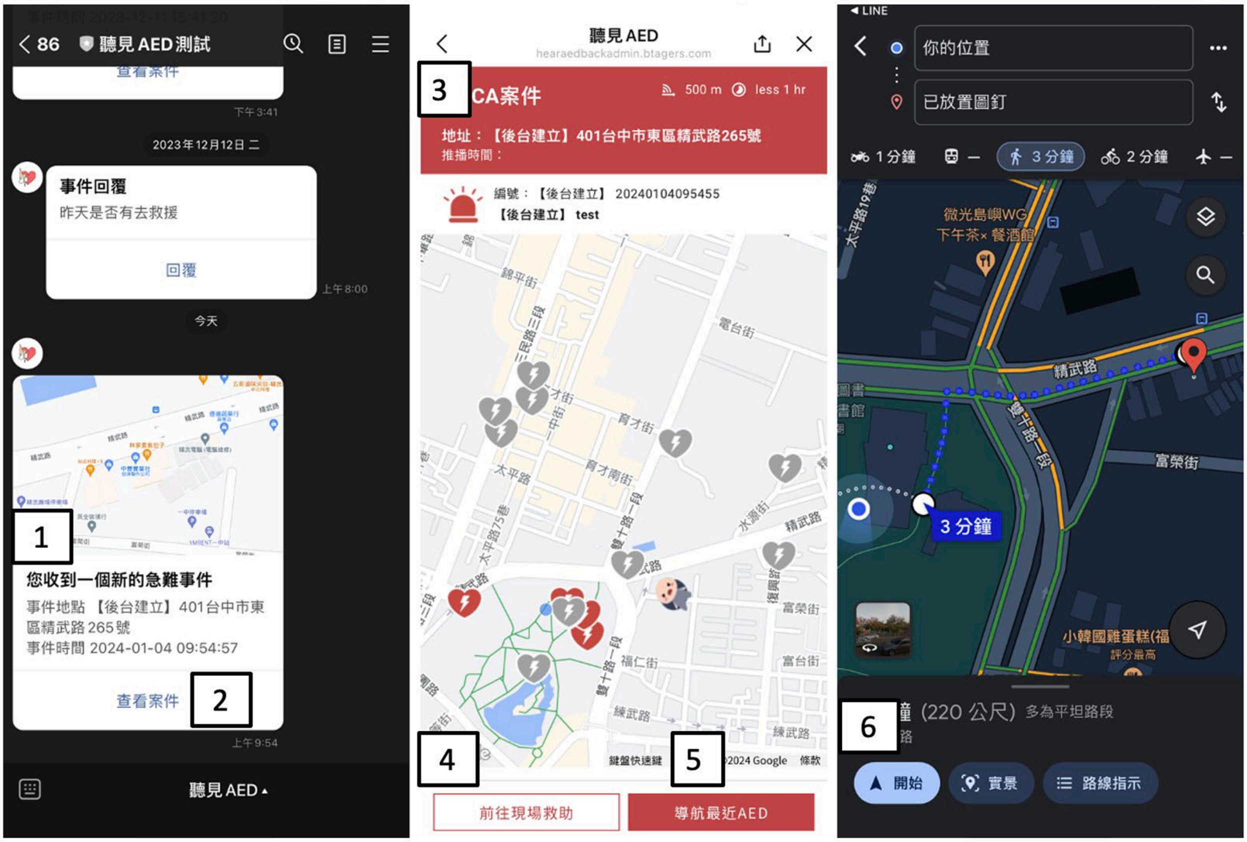

Fig. 2. Displays of application operation on the smartphone. Three steps of the application operations. a, Signal notification about nearby OHCA event (1), then responders push the event button (2). b, Map indicating location (3) of cardiac arrest and nearby accessible AED were shown on the display. Responders can choose either "go to OHCA scene directly " (4) or "pick up nearby AED "(5). c, the APP connected to the built-in map in the smartphone automatically and provide navigation (6).

location were prepared. Simulated OHCA location was prepared within 300 m of this PAD. The researchers planned in advance the order of the scenarios, and set the time schedule.

In each scenario, 3 participants were stationed. They acted each as: (a) the bystander, (b) the APP responder (activated by smartphone application system), and (c) the AED alarm responder (activated by buzzer sound of AED alarm device). Smartphones with the APP were provided to the APP responder and to the AED alarm responder, but not to the bystander. We first briefed participants outlines of the simulation scenario and the role of each participant, but without introducing the operation steps of the APP prior to the start of the scenario. Participants of each group were brought to corresponding designated places respectively by researchers before the scenario. Bystanders were brought to the OHCA scene, and APP responders were brought to a designated location within 300 m of the OHCA scene. AED alarm responders were brought to the place of AED. They were all informed of the actions they were supposed to take on receiving a signal notification on a simulated OHCA event.

Once the OHCA event signal notification had been sent off, bystanders were given the following scenario: "Someone just collapsed in front of you. He has no response. I will perform CPR. So, please find and bring an AED as soon as you can." A researcher told the bystander the location of the nearest AED, and the bystander had to find the nearby AED alone. At the start of each scenario, another researcher activated the Hearing AED APP, and sent a signal notification on the OHCA event to smart phones within 300 m of the OHCA scene. After receiving the notification, the nearby APP responders were to look for the nearest AED through the APP. Meanwhile, the APP system activated the AED-based alarm and generated a buzzer sound to alert the AED alarm responder. He/she was to scan the QR code on the display screen of the AED alarm device, and to bring an AED to the OHCA site based on instructions given in the APP. During the AED searching process, participants were allowed to ask lay people in the neighborhood regarding AED locations. The simulated scenario is shown in Supplementary 1.

Data collection

We placed real AEDs in the scheduled AED place, and instructed bystanders, APP responders and AED alarm responders to carry a real AED to the OHCA scene. AED delivery time of each group and their operation time were recorded by researchers using a stopwatch. During each scenario, researchers were not allowed to helping bystanders and responders in their task of looking for an AED and carrying it to the OHCA location.

Primary outcome and secondary outcomes

The primary outcome was the total AED delivery time, taken together by the bystander, the APP responder, and the AED alarm activated responder. The total AED delivery time was the interval from the start of the scenario until the AED had been delivered to OHCA place. Secondary outcomes were multiple time intervals during the AED delivery, including: time from starting point to AED place, time from AED place to OHCA place and the operation time. The operation time was the length of time between the simulated collapse happened to the time when signal notification on the OHCA event was sent by the APP.

Ethical consideration

The study was carried out under the Declaration of Helsinki from the World Medical Association. All participants submitted their prior written informed consent. This study was approved by the Institutional Review Board of Jen-Ai Hospital, Taichung (IRB approval code 202300016A3).

Statistical analyses

Sample size for each group was calculated to be 30 participants based on a 5 % type I error at 80 % power. Baseline characteristics were compared between groups using the Kruskal-Wallis test for numerical variables, and the Chi-square test for categorical variables. Primary and secondary outcomes were analyzed with the Mann-Whitney *U* test and Kruskal-Wallis test. P values < 0.05 were considered statistically significant. We also used general linear model to evaluate bystander group as a reference, as compared with APP responder group and AED alarmed responder group. All statistical analyses were performed using SAS software (version 9.4, SAS Institute, Inc., Cary, NC).

Results

We enrolled a total of 90 participants in this study. Their baseline characteristics are shown in Table 1. We found no significant difference across groups of participants regarding their demographics and basic characteristics, including first aid training license.

Distributions of all time intervals measured in the study are shown in Table 2. The total AED delivery time was significantly different across study groups (p < 0.001), with the shortest delivery time in the AED alarm responder group (median and IQR: 110.0 and 90.0–133.0 sec, vs 224.0 and 204.0–266.0 sec in the bystander group, and vs 296.0 and 203.5–423.5 sec in the APP responder group). The median time for the starting point to AED place was shorter in the bystander group, compared with APP responder group (median and IQR: 116.0 and 80.0–135.0 sec vs 159.0 and 98.5–200.5 sec, p = 0.029). Moreover, the median time for operation time in the AED alarm responder group (median and IQR: 67.5 and 38.0–94.0 sec) was longer compared with the APP responder group (median and IQR: 48.0 and 41.0–70.0 sec) (Fig. 3).

Table 1
Demographics of participants.

	Bystander group (n = 30)	App responder group (n = 30)	AED alarmer responder group (n = 30)	p-value
Age, median (IQR)	33.5 (29.0–39.0)	34.0 (28.0–39.0)	37.0(32.0–43.0)	0.280[a]
Sex,-male, n(%)	25 (83.3)	18(60.0)	23(76.7)	0.109[b]
Place familiarity, n (%)				0.619[b]
Very familiar	13(43.3)	10(33.3)	10 (33.3)	
Familiar	16 (53.3)	18 (60.0)	20 (66.67)	
Not familiar	1 (3.3)	2 (6.7)	0 (0.00)	
Basic life support training, n (%)				0.270[b]
Not trained	3 (10.0)	4 (13.3)	2 (6.7)	
Trained, within date of validity	27 (90.0)	25 (83.3)	24 (80.0)	
Trained, expired validity date	0 (0.0)	1 (3.3)	4 (13.3)	

a: Mann-Whitney *U* test; b: Kruskal-Wallis test.
IQR: interquartile range.

In the analysis with the general linear model, the AED alarm responder group was associated with a significantly shorter total AED delivery time (β = -122.4, p = 0.004). Conversely, the APP responder group was associated with a markedly longer total AED delivery time (β = 104.6, p = 0.016), as shown in Supplementary 2**.** The time for traveling from the AED place to the OHCA place in the APP responder group was significantly longer (β = 48.8, p = 0.035), when compared with the bystander group.

We noticed that some participants had a total delivery time > 480 sec; specifically, they included 4 (13.3 %) in the bystander group, 6 (20.0 %) in the APP responder group, and 1 (3.3 %) in the AED alarm responder group. with > 480 sec However, such differences were not statistically significant.

Discussion

This simulation study evaluated the effectiveness of an innovative Hearing AED system to speed up activated responders to deliver AED in the neighborhood to an OHCA scene. This is the first study with a design to activate responders to nearby AED for patient resuscitation, to markedly reduce the time for AED delivery to the OHCA place. Timely defibrillation is critical for the effectiveness of AED. If responders to a nearby AED can be activated successfully, it is the fastest way to deliver AED to the scene of OHCA since they only need to travel a one-way distance. We found that the median AED delivery time in the AED alarm responder group was 122.4 sec shorter than the bystander group, and 227 sec shorter than the APP responder group.

Despite broader overall coverage of PAD for cardiac arrest in recent years, only a small percentage of AEDs are applied to patients prior to EMS arrival.[14–15] In Japan, only 8 % bystander-witnessed OHCA receives PAD before EMS arrival.[4] In addition, a study in Denmark reported that only 3.8 % of all OHCAs have an AED applied before ambulance arrival, while 15.1 % of all OHCAs have occurred within 100 m of a public accessible AED.[7] In the real world, AEDs are often inaccessible[16] or difficult to find when needed despite the availability of many AED maps.[12,17–19] The expected life-saving potential of AEDs may be of no value if they cannot be brought timely to the victim. We developed this AED-based alarm system that can be activated directly by the EMS dispatch center when someone has collapsed nearby. This system alerts and activates responders nearby AED, and provides the opportunity for the AED to be delivered to the patient and be used for life-saving. This innovative Hearing AED system also included a supplemental smartphone application which provided a geographically coordinate system for personnel navigation, facilitating responders to rapidly locate the OHCA scene.

The survival of OHCA without resuscitation is known to drop by 10 % for every passing minute.[20] In order to speed up the application of CPR, and the use of AED for cardiac arrest, several countries and communities have promoted and implemented dual dispatching EMS systems, which encourage lay responders dispatched to OHCA scene before ambulance arrival. A number of studies reported that involving lay first responders in resuscitation markedly shortens the time between collapse and the initiation of resuscitation,[11–13,21–23] improving the survival outcome.[21–22] Smartphone APPs are currently being developed and have been implemented in many countries to activate community responders to initiate first aid.[17,21,23] They helped to increase the chance of bystander CPR, bystander defibrillation[18] and eventually improve survival rate.[13] Similar technological solutions for improving the AED functionality are also recommended by Lancet commission.[24] Our study found that the AED-based alarm system not only activates nearby rescuers by APP, but also triggers the AED alarm device to alert nearby responders. Our study also found that both the time needed to travel from the starting point the AED place, and the time taken to travel from the AED place to the OHCA place were the longest in the APP responder group. In addition, 20 % participants in the APP responder group were unable to deliver AED within 8 min. The 8 min time is a standard EMS

Table 2
Outcomes.

Outcomes	A. Bystander group (n = 30)	B. App responder group (n = 30)	C. AED alarmer responder group (n = 30)	p-value	A vs. B p-value	B vs. C p-value	A vs. C p-value
Primary outcome							
Total AED delivery time (sec), median (IQR)	224.0 (204.0–266.0)	296.0 (203.5–423.5)	110.0 (90.0–133.0)	<0.001[b]	0.026[a]	<0.001[a]	<0.001[a]
Secondary outcomes							
Time from starting point to AED place (sec), median (IQR)	116.0 (80.0–135.0)	159.0 (98.5–200.5)	–	0.029[a]	0.029[a]	–	–
Time from AED place to OHCA scene (sec), median (IQR)	110.0 (90.0–123.0)	148.5 (102.5–213.0)	110.0 (90.0–133.0)	0.041[b]	0.013[a]	0.080[a]	0.544[a]
Operation time (sec), median (IQR)	–	48.0 (41.0–70.0)	67.5 (38.0–94.0)	0.274[a]	–	0.274[a]	–

a: Mann-Whitney *U* test; b: Kruskal-Wallis test.
IQR: interquartile range.

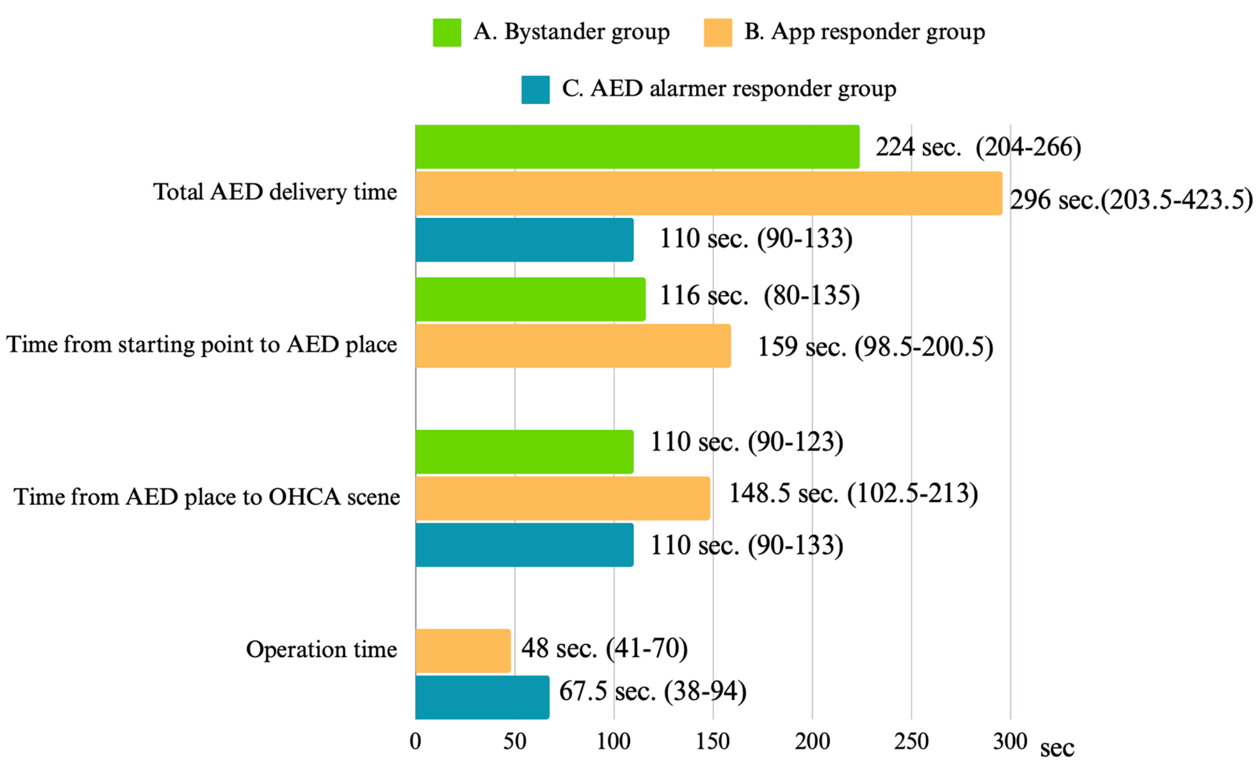

Fig. 3. Distribution of each time parameter in each group, present as Median (IQR).

response time aimed for OHCA patients.[25] This longer time taken is likely related to the fact that APP responders need to use the APP two times to locate two different places in the simulation test. Therefore participants' map navigation skills and proficiency in operating mobile phones may have a great impact on the delivery time. Besides, the familiarity with APP operation also influences the time intervals. Although the operation time in the AED alarm responder group was the longest, the total AED delivery time can be reduced by 50 to 60 %.This is because of the fact that the AED alarm activated responders only need to locate the OHCA place once and make a trip in one-way. As the survival benefits of public AEDs are overwhelming if applied within the first few minutes after a patient's collapse,[6,26] we intend in the future to simplify operating steps in APP to further reduce the operation time.

Early defibrillation is key to improve patient survival due to the initial presence of a shockable heart rhythm after an OHCA.[2,22] Within minutes after a cardiac arrest, it is critical that bystanders promptly locate and deliver the AED to the victim. Though the PAD coverage rate is high, few people know the location of the nearest PAD,[27] and they may have difficulty in finding one when needed. In the simulation scenario, we found some participants were unable to locate the AED, even if the AED was within their sight. This situation is similar to the real world since many current PADs have no standard label nor prominent signage. In the UK, the inadequacy of signage for PADs was noted: 2/3 of community PADs had no signage.[28] The majority of AED locations labeled on mobile APPs are accurate only in terms of the address, or a prominent landmark, but no information regarding the exact floor in case of city high-rises or building compounds. Lin *et al* reported that very few buildings provide guides and AED signs outside the proximity of AED location. This situation is worse than those of the emergency exit, fire extinguisher and restroom.[29] The absence of clearly marked signage likely impedes or limits the availability of PADs, failing to raise awareness on AED in the local community. As in the case that someone has collapsed nearby, despite sufficient PAD installed for geographic coverage, and a willing bystander to retrieve and deploy the device, the

PAD cannot be applied in time. Therefore, to maximize PAD effectiveness, the presence of clear on-site visual guides or signs becomes important for effective navigation and the landmark-associated strategies for its identification. Some measures can be beneficial, such as placing PADs next to restrooms. Proper lighting of the AED cabinet also helps to improve the effectiveness of signage. Our innovative AED alarm device also had an audible signage that was a buzzer sound together with voice instructions to alert nearby community volunteers once the dispatch center had activated the system. Though the current alarm sound duration is only 2 min, extending duration beyond 2 min should be considered in the future. That may assist bystanders and APP responders in finding an AED more effectively.

According to recommendations in the American Heart Association guidelines[30] for AED placement, an AED is expected to cover an area reachable within 1 to 2 min walking, or equivalent to ~ 100 m. However, no consensus has been reached regarding the effective range of AED coverage (i.e., the distance from an AED to the location of an OHCA), at which its retrieval is potentially beneficial. Some have proposed distances like 100 m,[7–8] 200 m,[31] 300 m[17] and 500 m.[32] Mortality of patients is known to increase at 10 % per 100 m distance between an AED and the site of OHCA.[33] To expand the area of AED coverage and to maximize AED effectiveness in our Hearing AED system, APP responders and alarm activated responders should be waiting at each starting point within 300 m of the OHCA scene. Similar to most countries, OHCA events in Taiwan predominantly occur in residential areas. Residential and commercial areas overlap in most cities in Taiwan. This situation differs from Europe and America. We believe our Hearing AED system may also benefit OHCA events that occur at home, if the AED-based alarm system can be widely applied, and Hearing AED system can be well implemented in the communities.

Limitations

Our study has several limitations. First, this was a simulation in an ideal setting, not a real emergency. Some bystanders may have difficulty following the voice instructions in the real emergency situation.[34] Second, the study was carried out in only one area which was an open space in the city center. In reality, AEDs are actually located in various places non-uniformly. Therefore, our findings can not be safely generalized. The future implementation of this model in a variety of locations is needed to confirm benefits of the system. Third, though all participants were randomized allocated, neither the participants or the researchers were blinded. This may attributed to performance bias.

Lastly, participants of the alarm activated responders group had received the introduction of the AED alarm device and the system before the scenario. This was inconsistent with the actual event. Since lay responders do not always opt to retrieve the AED in the real world, the actual benefits may be less. We need to conduct education and training in sites where AEDs are installed to teach site personnel the importance of timely resuscitation.

Conclusion

This innovative system-Hearing AED alarm system can shorten the AED delivery time by activating laypersons nearby AED in the simulation scenarios. Further studies are needed to determine its effectiveness in the real world situation in the future.

CRediT authorship contribution statement

Chih-Yu Chen: Writing – original draft, Validation, Methodology. **Jeffrey Che-Hung Tsai:** Writing – original draft, Validation, Methodology. **Shao-Jen Weng:** Writing – review & editing, Validation, Supervision. **Yen-Ju Chen:** Investigation, Data curation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100781.

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