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Effects of AED device features on performance by untrained laypersons[☆,☆☆]

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ABSTRACT

Objective: Our study evaluates the impact of features of automated external defibrillators (AEDs) on the performance and speed of untrained laypersons to deliver a shock and initiate CPR after a shock.
Methods: This was a randomized trial of volunteer laypersons without AED or advanced medical training. Subjects were assigned to use one of six different models of AEDs on a manikin in simulated cardiac arrest. No instructions on AED operation were provided. Primary endpoints were shock delivery and elapsed time from start to shock. Secondary endpoints included time to power-on, initiation of CPR, adequacy of pad placement and subjects' ratings of ease of use (1 = very easy, 5 = very difficult).
Results: Most subjects (109/120; 91%) were able to deliver a shock. Median time from start of scenario to shock delivery was 79 s (IQR: 67–99). Of the 11 participants who did not deliver shock, eight never powered on the device. Time to power-on was shorter in devices with open lid (median 12 s, IQR 8–27 s) and pull handle (17 s, IQR 9–20 s) mechanisms than with a push button (37 s, IQR 18–69 s; $p = 0.000$). Pad position on the manikin was judged adequate for 86 (77%) of the 111 subjects who placed pads. Devices which gave more detailed voice instruction for pad placement had higher rates of adequate pad position [38/39 (97%) versus 50/73 (68%), $p = 0.001$]. With AEDs that provided step-by-step CPR instruction, 49/58 (84%) subjects began CPR compared to 26/51 (51%) with AEDs that only prompted to start CPR ($p = 0.01$). Participants rated all the models easy to use (overall mean 1.48; individual device means 1.28–1.71).
Conclusions: Most untrained laypersons were successful in delivering a shock. Device features had the most impact on these functions: ability and time to power-on device, adequacy of pad position and initiation of CPR.

1. Introduction

Sudden cardiac arrest (SCA) is the leading cause of death among adults in the United States, striking as many as 325,000 individuals per year.[1] A common cardiac rhythm disturbance associated with sudden cardiac arrest is ventricular fibrillation (VF), for which the only effective treatment is rapid defibrillation.

New simplified automated external defibrillators (AEDs) enable untrained laypersons to deliver shocks to victims of cardiac arrest. A simulation study showed that sixth graders can deliver a rescue shock only 30 s slower than an experienced emergency medical technician or paramedic.[2] Another study showed that a 30 min course in CPR and AED use was equivalent to the traditional full length course even after 6 months had passed, and that the AED was applied 93% of the time.[3] Additionally, a recent study using three distinct methods of instruction to teach AED application and CPR, showed that all three methods were highly effective at instructing participants on AED use.[4]

There are many AED models available and these models have been shown to have varying success rates when used by laypersons. These models have similar functions, but features that affect the ease and speed of use vary among the devices. Simulation studies have shown marked variation in layperson operation.[5–9] Since rapid defibrillation is of paramount importance in the treatment of SCA, it is important to identify what makes a device easy to use.

The majority of studies involving layperson AED use focus on the operation of the overall device and how quickly a shock can be delivered.[5–10] One study looked at pad placement and successful shock delivery,[4] and another study looked at the time from first shock to the initiation of CPR.[8]

This study focuses on specific ergonomic features of AEDs and how they affect the ease and speed with which a shock can be delivered, and how quickly after a shock CPR is initiated. We

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hypothesized that successful device operation is based on the ability to rapidly perform these main steps: turning the device on, placing the pads, delivering a shock, and starting CPR.

2. Methods

This was a prospective, randomized, observational evaluation of features of selected trainer AEDs in a controlled simulation environment. Volunteer subjects were assigned to one of the devices using a computer generated randomization table (Microsoft Excel). Cross-over design was not used due to concern for learning effect. The study was conducted at a university-affiliated sports medicine clinic and at a university event center.

A "trainer AED" was defined for this study as a training device designed to not deliver an electrical current while simulating shock or a clinical device with the shock function modified to prevent actual shock delivery. The devices were otherwise similar to the actual clinical devices.

The model of AED for each manufacturer was selected and provided by the manufacturer as the model that would be easiest for use by untrained lay persons. Device features were categorized a priori by the authors as shown in Table 1. Voice instruction for pad placement was categorized as simple or detailed. Simple instruction was voice prompt stating only to place pads on chest; detailed included more step-by-step instruction such as to remove backing from pads and more specific location description. All AEDs were programmed according to The American Heart Association 2000 Guidelines.

Volunteer subjects were recruited by flyers and direct contact with the investigators. The only exclusion criteria were prior training or experience in the use of an AED. Subjects received a five dollar gift card for use at the on-site coffee shop.

The study protocol was as follows: after agreeing to participate, subjects were screened for prior AED training and/or use and informed consent was obtained. The subject was given an instruction card that read, "In the adjacent area you will find a manikin and an Automated External Defibrillator. The manikin represents a person who is unconscious and not breathing. When instructed, enter the room and attempt to use the device as quickly as you can." No instructions on AED operation were given. The subject entered the room and attempted to use the device. The scenario was designed such that the first analysis made by the AED recommended a shock and, if a shock was delivered, the next analysis advised shock not indicated. The scenario was stopped when CPR was initiated, 5 min of time had elapsed, or the subject expressed the desire to stop. The subject then completed a questionnaire. Questions addressed device operation, ability to locate and place pads, and voice, text and graphic prompts.

Time and event data were collected using simulation training software (SimMan, Laerdal Corporation) and transferred to Microsoft Excel. Times for the following actions were documented: start of scenario, AED power-on, pads placed, shock delivered, and start of CPR. The manikin's chest was photographed at the end of the scenario. Using the photos, a paramedic and a nurse not associated with the study independently evaluated the adequacy of pad placement for every scenario. They were instructed to judge each case as "adequate" or "not adequate" based on pad location and placement on bare skin to deliver successful shock. In the event they were unable to agree, an EMS physician not involved in the study was consulted to make the final determination.

Primary endpoints were shock delivery and elapsed time from start of scenario to shock. Sample size determination was calculated based on power of 0.8 to detect 25% absolute difference from 90% of subjects performing shock delivery with alpha at 0.05; this yielded need for 102 subjects. Secondary endpoints included time to power-on, time from second rhythm analysis to initiation of CPR, adequacy of pad placement and subject survey responses. Dichotomous data were compared with Chi-square or Fisher's exact test and continuous data with ANOVA. We compared performance differences among ergonomic features using survival analysis. Subjects rated the ease of use on a 5-point Likert scale (1 = very easy, 5 = very difficult). Data were analyzed using Microsoft Excel and STATA. We compared elapsed time differences using the Kaplan–Meier log-rank and Kruskal–Wallis tests. Only subjects who completed the specific task were included in time analyses.

This study was approved by the university Institutional Review Board.

3. Results

One hundred and twenty persons participated in the study. All but one completed high school and 45% had obtained a bachelor

Table 1
Comparisons of individual characteristics of AEDs by model.

Device name	Power on mechanism	Pad location	Pad placement voice instruction[a]	Shock instruction	CPR instruction	Extras
Cardiac Science PowerHeart AED G3	Open lid button	In lid upon opening	Detailed	Flashing light, voice and audio prompt	Step by step	Backlit screen to reinforce audio prompts, CPR countdown
Heartsine Samaritan PAD	On/off button	Pre-connected, underneath machine	Simple	Flashing lights, voice prompt	Prompt to start	Voice instruction for rescuer, audible manikin clicking noise every time a chest compression is to be delivered
Medtronic CR Plus	Open lid button	Pre-connected, pull handle to release	Simple	Flashing lights, voice prompt, audible tone	Step by step	CPR Timer, audio instruction to check breathing, if not breathing to start CPR
Phillips Heartstart OnSite	Large pull handle	Under cover, pull handle to release	Detailed	Flashing light, voice prompt, audible tone	Step by step	Detailed voice instructions, button to push for detailed help with CPR instructions
Welch Allyn AED 10	On/off button (inside zippered case[b])	Pre-connected, in pouch on top of case	Simple	Button illuminates, voice and audio prompt	Prompt to start	Audio instruction to check airway, check breathing, start CPR
Zoll AED Pro	On/off button (inside zippered case[b])	Pre-connected, in pouch on top of case	Simple	Button illuminates, voice prompt, audible tone	Prompt to start	

[a] All devices provide visual prompts on pads, packaging, device or all three. See methods for definition of simple and detailed.
[b] Case required to stow pads.

Table 2
Participant characteristics.

	Cardiac science	Heartsine	Medtronic	Phillips	Welch Allyn	Zoll	All AEDs	*P*-Value
Age (years)								
Median (range)	21.5 (18–59)	25.5 (19–61)	23.0 (18–66)	27.0 (18–77)	24.5 (18–60)	32.0 (18–64)	25.0 (18–77)	
Average	28.7	29.5	28.2	35.5	33.8	35.6	31.9	0.663
Sex								
Male (%)	9	13	9	9	9	15	64 (53)	
Female (%)	11	7	11	11	11	5	56 (47)	0.166
Language[a]								
English (%)	18	19	19	19	18	20	113 (94)	
Other (%)	2	1	1	1	1	0	7 (6)	0.527
Education[a]								
Some high school (%)	1	0	0	0	0	0	1 (1)	
High school (%)	3	2	1	2	4	3	15 (12)	
Some college (%)	9	9	9	7	8	6	48 (40)	
Bachelors (%)	4	5	6	5	5	6	31 (26)	
Masters (%)	1	2	2	5	2	2	14 (12)	
Doctorate (%)	2	2	1	1	0	1	7 (6)	
Other (%)	0	0	0	0	0	2	2 (2)	0.888
Medical training[a]								
None (%)	8	9	13	11	11	8	60 (50)	
CPR (%)	3	4	1	2	3	3	16 (13)	
First aid (%)	4	2	1	1	0	2	10 (8)	
Both (%)	5	5	5	6	6	7	34 (28)	0.982

[a] One participant in the Welch Allyn group did not report a primary language, level of education, or medical training.

or post-graduate degree. Nearly half (42%) of participants reported prior CPR training (Table 2).

Most subjects (91%) were able to deliver shock. The most common individual step leading to failure to deliver shock was failure to power-on device (eight of 11 subjects) (Table 3). One hundred and eight (90%) subjects delivered shock within 180 s of starting the scenario. Median time from start to shock was 79 s (IQR: 67–99) but varied by device model (56–103 s, $p = 0.001$) (Table 4 and Fig. 1).

Feature-based analysis (Table 5) revealed that time to power-on was shorter in devices with open lid (median 12 s; IQR 8–27 s) and pull handle (median 17 s; IQR 9–20 s) mechanisms than with a push button (median 37 s; IQR 18–69 s) ($p = 0.000$). Pad position was judged adequate for 86 (77%) of the 111 subjects who placed pads. Devices which gave detailed audio instruction for pad placement had higher rates of adequate position [36/38 (95%) versus 50/73 (68%), $p = 0.001$].

Only 75/109 (69%) subjects began CPR after shock delivery. With AEDs that provided step-by-step CPR instruction, 49/58 (84%) subjects began CPR compared to 26/51 (51%) among those who used AEDs that only prompted to start CPR ($p = 0.01$) (Table 5).

Participants rated all the models easy to use (overall median 1, IQR 1–2). However statistical differences were noted among the devices when participants were asked how easy it was to turn the device on ($p = 0.049$), ease of removing the backing from the AED pads ($p = 0.002$), when to call 911 ($p = 0.003$), and the ease of understanding the instructions for appropriate pad placement ($p = 0.019$).

4. Discussion

Many cardiac arrest victims who now die can be saved with prompt defibrillation.[5] For this to occur, laypersons must be able to use AEDs quickly and effectively. Our study found that a high per-

Table 3
Subject performance of individual steps by device model.

Device (*N*)	Powered on, *N* (%)	Pads placed on chest, *N* (%)	Adequate pad location[a], *N* (%)	Shock delivered, *N* (%)	CPR started, *N* (%)
Cardiac science (20)	19 (95)	18 (90)	16 (89)	18 (90)	16 (80)
Heartsine (20)	16 (80)	17 (85)[b]	11 (65)	16 (80)	9 (45)
Medtronic (20)	20 (100)	20 (100)	17 (85)	20 (100)	15 (75)
Phillips (20)	20 (100)	20 (100)	20 (100)	20 (100)	18 (90)
Welch Allyn (20)	19 (95)	17 (85)	12 (70)	17 (85)	8 (40)
Zoll (20)	18 (90)	19 (95)[b]	10 (53)	18 (90)	9 (45)
All models (120)	112 (93)	111 (92)	86 (77)	109 (91)	75 (62)

[a] Percentage reflects only the number of participants who placed the pads on the manikin.
[b] One participant in each group placed the pads on the chest without turning the device on.

Table 4
Comparison of individual step time intervals by device model – median times (s (IQR)).

Device	Start to on	On to pad placement	Pad placement to shock	Overall time to shock	Shock to CPR
Cardiac science	8 (5–9)	68 (57–80)	34 (32–35)	101 (90–110)	45 (38–69)
Heartsine	32 (13–51)	43 (21–44)	23 (21–25)	62 (62–70)	34 (34–45)
Medtronic	25 (17–38)	48 (40–53)	26 (24–32)	76 (67–86)	44 (35–51)
Phillips	17 (9–20)	59 (51–65)	25 (25–26)	84 (77–97)	44 (34–55)
Welch Allyn	37 (19–54)	27 (18–45)	21 (16–28)	56 (36–74)	47 (40–48)
Zoll	66 (25–112)	74 (63–106)	25 (23–28)	103 (74–137)	39 (28–42)
All models	20 (10–44)	51 (39–67)	25 (23–33)	79 (67–99)	42 (35–53)

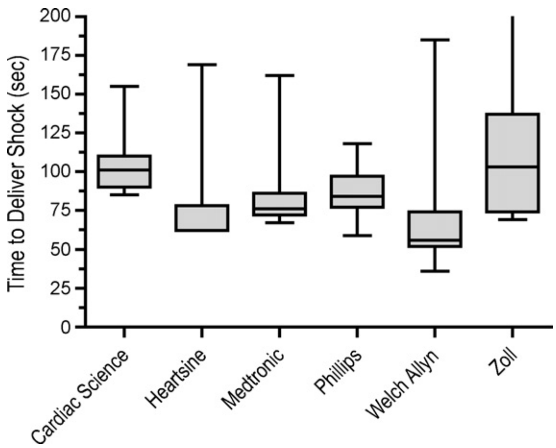

Fig. 1. Time intervals from start of scenario to shock delivery (median, IQR, and range shown).

centage of participants were able to deliver a shock within 180 s, which was also reported by other studies.[5–12] Other studies found that removing unnecessary voice prompts can shorten the amount of hands off time for the performance of CPR, and efforts to decrease the time to delivery of first shock and to encourage chest compressions after the first shock are likely to improve resuscitation success.[13,14] Prior studies have compared different models of AEDs but this study is unique in its findings that specific device features impact AED operation and subsequent initiation of CPR. Our study found that ergonomic features had the greatest impact on three actions: powering on device, proper pad placement, and starting CPR after shock.

The devices with the open lid and pull handle power-on mechanisms had large identifying words or indicators easily noticed by the participants. The start buttons proved to be more difficult to locate and when the device was housed in a zipper case the amount of time it took for the study participant to push the start button increased by doubling their task load. Only two models took users significantly longer than the others to deliver a shock and one of the devices also took subjects longer to power-on by pushing a button. Overall, powering on the device on was the single most rate limiting step as eight participants were unable to accomplish this task.

Proper pad placement is likely affected by multiple variables, including visual and audible instructions, location of pads in device or device case, and ease of backing removal. Pad placement was deemed adequate more often when the device gave more detailed voice instruction. One exception was the Medtronic device, which was associated with high rate of adequate pad placement but was judged pre-trial to have less detailed voice instructions. This device has color coded visual prompts on pads and packaging which may have increased proper positioning. Pad placement was also found to be adequate more often when the storage location of the pads was sitting on top of the device than when underneath the device or in a pouch or carrying case. This may be due to the layperson's ability to see the pads immediately upon opening the device. The device with both pads adhered to one backing tended to take rescuers longer to apply compared to those with separate backing. Inadequate pad placement was reported by Andre, who found that voice instruction and visual aids available to the lay rescuer led to more optimal pad placement for an adequate shock to be delivered.[3] While pad placement was often deemed inadequate by independent evaluators, it must be recognized that shock efficacy for some placements deemed inadequate is not known.

Laypersons (with or without prior CPR training) were more likely to start CPR when using devices that provided more specific instructions on doing CPR. Although this would seem to take longer, time from shock to beginning CPR did not significantly differ between the devices with more detailed instruction (Cardiac Science, Medtronic, Phillips) and those that simply stated to start CPR (Heartsine, Welch Allyn, Zoll). It is important to note that during this study there was a time delay for the AEDs to re-analyze after a shock, as the AEDs were programmed according to the 2000 American Heart Association Guidelines. Initiation of CPR was looked at in another study, which had similar findings that the key factors for failure to do CPR were the content and the volume of the voice prompts, and that lay rescuers placed a great deal of trust in device prompts.[8]

While all participants rated the devices easy to use, there were some significant differences reported in the post scenario survey. Being able to turn the device on is critical to operation of any AED. The pull handle and push to open (devices started automatically once the lid was opened) AEDs were rated easier to use when compared to the AEDs with an on/off button. Our participants found that most of the devices provided clear prompt to call 911, but they rated the Zoll unit less clear than the others.

The ability of participants to remove the backing from the pads varied among the models of AEDs as well. This may have had to do with instruction on removing the backing from the pads, pad adherence to the backing material, or the participants' lack of understanding that some of the pads are placed back to back with one piece of material in between them. The Cardiac Science and Zoll pads were rated as the most difficult to remove, whereas the Heartsine and Medtronic pads were deemed the easiest.

Based on our findings, the authors propose combining the best features from different models into an "optimal" AED. The open lid or pull handle are superior to the push button in ease and speed of powering on the device. Design not requiring a separate case, such as the zippered cases, also decreases time to power-on. Device design should allow immediate visibility of pads upon initiation of use, and pads should have separate backing which is clearly marked with a removal tab. Pad placement instruction should be as detailed as possible, as the more detailed the pad placement instruction the more likely pad placement is to be adequate to deliver a successful shock. CPR instruction should be given as step-by-step instruc-

Table 5
Subject performance of individual steps by device feature.

Feature	Participant success, *N* (%)	*P*-Value	Median time (s (IQR))	*P*-Value
Power-on mechanism (*N* = all subjects)	Powered on			
Open lid (40)	39 (97)		12 (8–27)	
Pull handle (20)	20 (100)		17 (9–20)	
Push button (60)	53 (88)	0.079	37 (18–69)	0.000
Pad placement instruction (*N* = subjects who turned on device)	Adequate placement			
Simple voice instruction (73)	50 (68)			
Detailed voice instruction (38)	36 (95)	0.001		
CPR instruction (*N* = subjects who delivered shock)	CPR initiated			
Start CPR only (51)	26 (51)			
Step-by-step instruction (58)	49 (84)	0.01		

tion, including talking the user through chest compressions, as lay rescuers are more likely to perform CPR with instruction than without, as concluded in another study.[15] The visibility of power-on mechanism, the ease of finding pads, clarity and preciseness of pad placement instructions and step-by-step CPR instruction are ergonomic features that can be modified to assist the lay rescuer in increasing the ease and speed of use of the AED. We suggest that for each step of AED operation, both the clarity and completeness of instructions (aural and visual) and the intrinsic ergonomic attributes of the device should be optimized.

Device features associated with increased performance rate were not always associated with shorter times to shock. This may reflect benefit of more detailed instructions for untrained users. Trained users may be able to deliver shock faster with less intensive verbal instruction.

Our study has a number of important limitations. Performance in a simulated setting may not reflect actions in an actual cardiac arrest. Subjects may not have represented the general US population, as 45% completed college, only 2 were over the age of 65, and none were under the age of 18. We presumed all subjects were truthful and did not use an AED or have any prior AED training. In six cases English was not the primary language and this may have impeded those subjects' ability to follow the instructions and prompts correctly. Some photos of pad placement were not labeled properly so we could not determine the number of subjects who both delivered shock and placed pads in adequate position. Features not assessed in this study may also impact device use; we tried to select those that seemed most important.

Future studies could explore the effect of non-standard pad location on shock success, factors that might improve the location of pad placement and the ability of untrained individuals over the age of 65 or under the age of 18 to operate an AED.

5. Conclusion

In a simulated cardiac arrest setting, most untrained AED users were able to deliver a shock within 180 s. Pad placement was often inadequate. Device features were found to have the most impact on time to power-on, accuracy of pad placement and initiation of CPR.

Conflicts of interest

VNM receives compensation for serving as medical director from the Sudden Cardiac Arrest Association, Washington, DC, a non-profit organization which promotes greater awareness and prevention and better treatment of sudden cardiac arrest.

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AED devices were loaned and disposable supplies provided by the manufacturers of the six devices used in the study. The final study design and manuscript were solely determined by the authors. Manufacturers did not have access to the study database.

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