

determine if there were observable differences between four AEDs in terms of usability. The primary goal of this study was to gain insight into AED usage with untrained volunteers. This information could then be incorporated into the design improvements of AEDs. The four usability factors evaluated were: 1) number of volunteers able to remove pads from packaging, remove the liner, and apply the pads to the manikin skin, 2) appropriate pad placement as guided by the manufacturer's pad icon, 3) time from room entry to shock, and 4) safety in terms of touching the patient during shock delivery.

METHODS

Volunteer Selection and Randomization

The study was conducted in April 2003 at the Usability Testing Research Facility of Interface Analysis Associates, a human factors, ergonomics, and usability consulting firm. Adult participants between the ages of 35 and 55 years were recruited via public advertisement and direct-mail letters to local businesses. Participants were prescreened via phone interview and excluded if they worked in medical or related fields, or had any exposure to, prior training, or familiarity with AEDs. Participants were also excluded if they self-disclosed any of the following: poor English comprehension, cardiopulmonary resuscitation (CPR) training within the last 24 months, sight or hearing impairment (that was not corrected), or injuries or disabilities that would prevent the participant from bending down, kneeling on the ground, or holding a package. All participants granted written permission and received \$50 for participation. The study was exempted from institutional review board approval because it did not meet the criteria of an investigational study and was determined to have nonsignificant risk.

Volunteers were assigned to one of the four AED groups using a stratified random sampling technique, where gender and age were equally distributed across the four groups. Within the block randomization strata, volunteers were sequentially assigned to an AED in the order they presented for testing. Each of the four AEDs was used by a different group of 16 participants.

AEDs Used

To examine our assumption that AEDs differ in the quality of voice and graphical prompts, thus affecting usability, four different AEDs were studied: AED1 was the Philips HeartStart OnSite (Seattle, WA), AED2 was the Zoll AED Plus (Chelmsford, MA), AED3 was the Cardiac Science Powerheart (Irvine, CA), and AED4 was the Medtronic CRPlus (Minneapolis, MN). To make the simulation more realistic, clinical AEDs were used as opposed to AED trainers. The AEDs were



FIGURE 1. The manikin with wires stitched into the skin covering the right and left sides from the upper chest through the abdomen. The wires were attached inside the manikin to a rhythm simulator to provide the electrocardiographic (ECG) ventricular fibrillation (VF) signal. The wires allowed transmission of impedance and ECG signals to the electrode pads simulating a patient in VF.

modified so that, when the shock button was pressed, no actual shock was delivered. No other modifications were made to the AEDs. Fully charged batteries and clinical pads were used throughout the study.

Resuscitation Simulation Setup

The volunteers were asked to rush into a room and attempt to use an AED to resuscitate a victim of sudden cardiac arrest. Volunteers were provided with only basic information about the main functions of an AED ([Appendix A](#)) before they entered the room where they found a fully clothed, full-sized adult manikin (Resusci Anne; Laerdal Medical, Wappingers Falls, NY) on the floor and one of the four AEDs nearby. The volunteers were guided only by the instructions (the AED voice and graphical prompts) specific to that AED. The manikin was dressed in pants, a button-front shirt, and zippered jacket. Wires were stitched into the plastic skin covering the right and left sides of the manikin from the upper chest through the abdomen and attached to a rhythm simulator (Symbio AED Simulator; Symbio Corporation, Beaverton, OR) to provide the electrocardiograph (ECG) VF signal ([Figure 1](#)). The wires allowed transmission of impedance and ECG signals to the electrode pads simulating a patient in VF. The AEDs were able to detect that the

pads had been placed and analyze the signal when one pad was placed on the right side of the chest, and the other pad placed on the left side of the chest. Note that the wires intentionally covered a large area of the manikin so that the volunteers would not deduce correct pad position. The AED would then analyze the signal and advise a shock. Note that a limitation of the test setup was that if both pads were placed on the same side of the chest, only an asystolic signal was transmitted to the AED (so no shock was advised). In addition, any pad placed in the middle of the chest (where no wires were present) or with only a small portion making contact with the wire, resulted in an inability of the AED to recognize that the pads had been placed on the manikin. Two remote-controlled video cameras were used to record the AED use; three observers were located in a control room behind a one-way mirror.

Assessment of Usability Factors

The number of volunteers who were able to remove pads from packaging, remove the liner, and apply the pads to the manikin skin was recorded for each AED and volunteer. The "ideal" pad position was determined before the study began based on each manufacturer's recommended location, as depicted on the pad icon for each AED. The position was agreed on by three observers (ADA, DBJ, JEP) and then a template defining the "ideal" pad location for each AED was created from a plastic sheet laid over the manikin thorax. This was then used to measure pad displacement from the ideal by placing the sheet over the pads after each trial and measuring the discrepancy between actual pad placement and the template-indicated ideal pad location. Measurements were made from the ideal center of the template pad to the actual center of the pad placed by the volunteer on the manikin. Electrode pad placement measures were collected immediately after each trial. Digital photos were also taken of pad positions after each trial, and these were later reviewed to further record and verify pad displacement, contact with manikin skin, and removal of pad liners.

The number of volunteers who were able to proceed through the trial to the point of pushing the shock button was recorded for each of the AEDs tested. The time from entry into the room until the AED was

turned on, pads were positioned, a shock was advised, and the shock was delivered was recorded. Timing was accomplished via video recording and stopwatch. Safety was defined in terms of instances of users' touching the manikin during shock delivery. The trial ended after the volunteer had successfully delivered a shock, 5 minutes had elapsed from entry into the room, the device did not advise a shock or entered the CPR pause mode, or the volunteer expressed a desire to stop.

Statistical Analysis

The statistical analysis was performed with StatXact, version 5 (Cytel Software, Cambridge, MA) and Statistica, version 6 (StatSoft, Tulsa, OK). Outcome variables were tested for statistical significance of overall effect using exact nonparametric methods. The Fisher-Freeman-Halton test was employed for categorical data, and the Kruskal-Wallis analysis of variance was used for continuous variables. If a statistically significant overall effect was identified, between-group comparisons were performed using Fisher's exact test for categorical data and exact Mann-Whitney tests for continuous data.

RESULTS

Volunteer Demographics

There were 64 volunteers who participated in the study. The occupations of the volunteers spanned a wide range of industries and activities, including teachers, security guards, sales representatives, software developers, office administrators, waitresses, and truck drivers. Each AED group comprised eight male and eight female participants. Table 1 summarizes the demographic characteristics of the four volunteer groups. The median age of the volunteers was 44 years; the distributions of ages were not statistically significantly different between the groups ($p = 0.70$). The educational levels of volunteers were not statistically significantly different between the groups ($p = 0.77$).

Simulation Setup and Data Collection

In several instances, pads were placed on the manikin in areas where no wires were present. One volunteer (using AED4) placed the right sternal pad over the sternum where there were no wires; we included the pad-placement data from this case, but time-to-shock data were not available. In two other cases (one AED1 and one AED4), both pads were placed on the same side of the chest, so again pad-placement data were included but there were no time-to-shock data. In a final case (AED1), pads were properly placed on the

TABLE 1. Demographics of Study Participants

Device	AED1	AED2	AED3	AED4
Age in years (mean \pm SD, $n = 16$)	44 \pm 7	43 \pm 7	45 \pm 6	43 \pm 5
High school/vocational	3	3	5	5
Post-high school	13	13	11	11

AED = automated external defibrillator; SD = standard deviation.

TABLE 2. Shock Delivery and Pad Placement Measures

Device	AED1	AED2	AED3	AED4
Pads applied to skin	*100% (16/16)	50% (8/16)	56% (9/16)	*100% (16/16)
Pad displacement error (cm)	†S 4.8 [3.0–5.9] A 4.5 [2.3–7.0]	†S 3.5 [2.8–5.5] A 3.5 [2.4–5.5]	S 6.5 [3.8–8.4] A 6.5 [4.4–10.0]	S 7.5 [4.6–16.3] A 12.3 [2.8–17.4]
Separation of pads (cm)	‡16.0 [12.0–17.9]	‡15.0 [13.0–15.3]	11.0 [7.3–12.8]	5.5 [3.8–13.8]
% Pads placed adjacent	†6% (1/16)	†11% (1/9)	†0% (0/13)	56% (9/16)
% Successful shock delivery	*100% (14/14)	§44% (7/16)	75% (12/16)	*100% (14/14)
Time to shock (sec)	*99 [84–109] n = 14	§210 [170–287] n = 7	132 [96–196] n = 12	*93 [78–115] n = 14

S = right upper parasternal pad; A = left apex pad, median [interquartile].

*p < 0.05 vs AED2 and AED3.

†p < 0.05 vs. AED4.

‡p < 0.05 vs. AED3 and AED4.

§p < 0.05 vs. AED3.

manikin chest, but the AED did not recommend a shock; this was subsequently identified as caused by an ECG artifact originating within the test setup, so only pad-placement data were included.

In terms of the number of volunteers able to remove pads from packaging, remove the liner, and apply the pads to the manikin skin, Table 2 contains a summary of the pad-placement results. Significant proportions of volunteers were unable to attach pads directly to the manikin skin (50% AED2 and 44% AED3). Many volunteers did not remove the pads from the packaging, placed the pads on top of clothing, or left liners on the pads. Two of the AED2 users and three of the AED3 users never managed to open the pad package. Another two AED2 users and four AED3 users failed to remove the liner from one or both electrode pads. Five AED2 users placed the pads directly over the victim's clothes (see Figure 2). Further, we observed that, in 31% of AED4 uses, participants inadvertently pulled the pad connector plug out of its socket while attempting to open the pad package.

In terms of appropriate pad location placement as guided by the manufacturer's pad icon, Table 2 summarizes the average displacement from ideal center for apical and right sternal pads for all four AEDs tested. The greatest displacement error (12.3 cm) was noted with AED4. More important was the observation that, in some instances, pads were placed in positions that were *adjacent* to each other, meaning locations 1) side by side, 2) on the same side of the chest, 3) at the same vertical level, or 4) touching each other. Our results demonstrated inappropriate pad adjacency in 56% of uses of AED4 (Figure 3) uses versus a range of 0% to 11% with the other devices. Table 2 also contains the measured separation between the pads. Median separation was as low as 5.5 cm (AED4). The close proximity of the pads resulted primarily from placement of the apical pad medially and cranially.

For the time from room entry to shock delivery, nine of the 16 users of AED2 (56%) and four of the 16 users of AED3 (25%) failed to administer a shock to the simulated victim (Table 2). Three of the four AED3 users who failed to remove the liner from one of the pads still received a shock command, because the AED3 liner has small holes that allow a fraction of the pad to contact the skin even with the liner left on. These were counted as successful shock deliveries, though appropriate energy delivery for defibrillation would likely be severely compromised.

In contrast, AED1 and AED4 users were successful in delivering a shock in all valid trials. In the time it took users to deliver a shock, AED1 and AED4 were mathematically similar (Figure 5, Table 2). The median times were well under 2 minutes, at 99 and 93 seconds, respectively. The other two devices were significantly slower, with users of AED3 taking 132 seconds (just over 2.0 minutes), and users of AED2 taking 210 seconds (or 3.5 minutes). We also looked at time per AED task for each of the four AEDs, broken down into



FIGURE 2. An example of electrode pads placed over the victim's clothes.

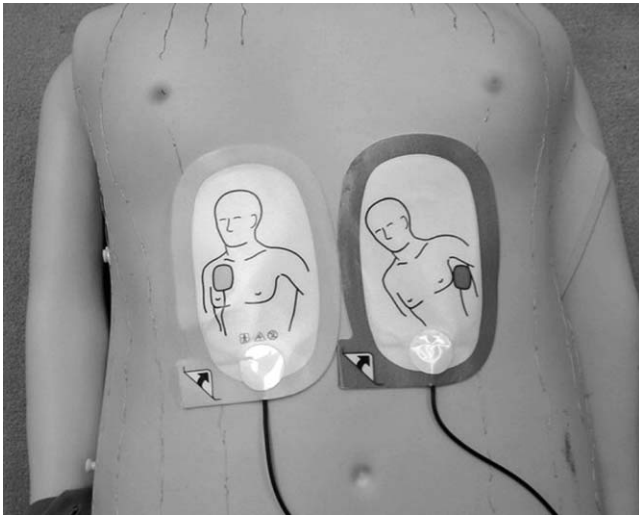


FIGURE 3. An example of electrode pads placed adjacent to each other.

five time segments: AED power on, first pad on (attached), second pad on, shock command given, and shock delivered. As shown in Figure 5, the "lost" time for AED2 and AED3 compared with AED1 and AED4 was primarily in achieving pad placement.

For safety in terms of touching the patient during shock delivery, in three cases the volunteer was in contact with the manikin during shock delivery. In two cases (AED4), the contact was clothing to clothing, with the participant's right knee touching the manikin's right arm and the participant's right knee touching the manikin's right knee. In one case (AED2), the participant's right knee touched the manikin's right hand (clothing-to-skin contact).

DISCUSSION

Success with untrained users is a critical goal for the broad public deployment of AEDs. We investigated the ability of untrained volunteers to use an AED without prior exposure or training with an AED. Specifically, we wanted to observe how well a layperson could initiate usage of the AED and follow through with the given directions to the point of delivering a shock. Previous studies have suggested that this is possible with some AEDs.⁷⁻¹¹ For example, the majority of patients who survived a sudden cardiac arrest in Chicago airports over a two-year period were saved by persons who had no duty to act and no prior training in the use of AEDs.⁷ Another study showed that naive 6th graders could successfully employ an AED.⁸ A recent study by Eames et al. compared ease of use of three AEDs by untrained laypeople.⁹ They found statistically significant differences among AEDs, including time to shock and pad position. The Eames study differs from this study in that they used AED training devices (Larsen P, personal communication,

2003), they scored all pad positions against the same criteria regardless of manufacturer's instructions, and volunteers randomly used all devices, thus introducing learning effects.

In this study of simulated cardiac arrest, we observed several important mistakes made by untrained volunteers when attempting to follow the voice and visual AED prompts. A specific focus of this study was the ability of participants to correctly position pads on the manikin. Obvious errors that would affect defibrillation success included failure to remove the pads from the packages or to remove the pad backings, or placing the pads on top of the clothes. Pad location was evaluated and compared with the manufacturer ideal location as directed by the pad icons. "Correct" or "ideal" position varies between the four AEDs, but they share the similarity of a right upper sternal and a left apical pad position. Displacement from ideal center may not have a clinical significance as long as an appropriate vector for defibrillation can be maintained. We therefore highlighted pad displacement that might raise concerns in a true clinical setting. Those were the instances when pads were placed adjacent to each other, often at the same level on the chest or on the same side of the chest. One of the AEDs (AED2) has a fixed connection between the apical and sternal pads that prevented the two pads from being placed in adjacent positions. Whether a fixed pad position would be adequate for a variety of different thorax sizes is unknown.

Another observation was the tendency to displace the left apical pad medially and cranially, which if anything would be more likely to decrease defibrillation efficacy as the two pads come into proximity of each other and the apical pad moves *away from* overlying the left ventricular myocardium, particularly in patients with dilated hearts. One wonders if this tendency, as well as the instances of pad adjacency, is derived from television scenarios of defibrillation where handheld paddles are usually placed in right upper and left upper parasternal positions. The risk of current shunt between the pads is a function of distance and the resulting vector defined by the specific pad placement. Caterine et al. found that, when one electrode was placed in the right parasternal position and the other within 2 cm in the left parasternal position, the theoretical percentage of current traversing the heart was significantly reduced.¹²

Pad placement has been well documented as the Achilles' heel for lay responders and those with advanced training alike.¹³⁻¹⁵ Heames et al. tested the ability of doctors to position paddles correctly on a manikin and found 35% of the sternal and 78% of the apical paddle placements to be incorrect.¹³ Meischke et al. reported that the most difficult task in a simulation study with seniors was correct pad placement.¹⁴

Approximately 17% following initial training and 48% at the retesting three months later did not correctly place the pads on the manikin. Mattei et al. tested untrained nurses and physiotherapists and reported that 53% failed to initially position the pads correctly, although all participants were able to place the pads appropriately following training.¹⁵ This study is consistent with these previous findings and extends them to the realm of public use. We found that the least pad placement error occurred with AED1 both in terms of displacement from ideal center and in no instances of pad adjacency error. This probably is because of the very specific voice prompt “Look carefully at the pictures on the white adhesive pads . . . place pads exactly as shown in the picture” and the fact that both pad placement icons are shown on each pad, giving users a good sense of the relative placement of the two pads (Figure 4). This was also true of AED2 and AED3, which had a low instance of pads’ being placed in adjacent positions. In addition, AED1 includes sensor technology that detects the current action of the user and adjusts the voice instructions to match that action. We observed many instances with the other three devices where the audio instruction and the user’s current action were incongruent.

An important issue in AED usage is how quickly a shock can be delivered. Brillhart et al. used AED recordings and emergency medical services (EMS) reports to study the time elapsed for EMTs to arrive on scene and recognize cardiac arrest to shock delivery.¹⁶ They found the median time for the EMTs was 51 seconds. The investigators suggested a 1-minute goal and a 90-second minimum standard for time to first shock by EMTs using AEDs in the field. Although most of the users of the AEDs in this study were able to deliver a shock in less than 2.0 minutes, the users of AED2 took 3.5 minutes. One difference is that users of this AED found it difficult even to turn on the device (Figure 5). Nevertheless, the time to shock for all the devices tested, if used in an actual SCA, would likely result in a significant time reduction compared with that which can be achieved by awaiting the arrival of most EMS responders.¹⁷

One concern that has been raised regarding layperson usage of an AED is whether the rescuer might inadvertently receive a shock by touching the victim. We observed only three instances of participants’ contacting the manikin during the simulated shock; none of these instances would likely cause serious harm. In each case, the volunteer’s knee or hand made a single point of contact with the victim’s clothes during shock delivery.

Resuscitating a victim of cardiac arrest involves much more than operation of an AED. Recognizing the cardiac arrest, calling EMS, and performing CPR as a bystander are all important steps; however, timely



FIGURE 4. Icon for AED1 (one of the four automated external defibrillators studied) depicting the relative locations for both pads.

defibrillation is a critical factor for those patients in VF. Defibrillators that are to be used by lay responders should be designed from a human-centered perspective. That is, they should provide useful, timely guidance, include effective and salient graphics, and induce acceptable levels of workload and stress. This study demonstrated that all AEDs share a common set of functionality and, if used correctly, result in the delivery of a shock to the victim, but the objective experiences of the users are likely to vary greatly based on the presence or absence of critical usability design attributes.

To be effectively used by untrained laypersons, AEDs targeted for use by the lay public must be tested to determine whether they are intuitive enough. In the present study, we found that performance suffered for AEDs that 1) had to be manually turned on, 2) provided a minimal and implicit set of instructions, 3) incorporated components that easily became loose or detached, 4) did not provide an image of both pads on the pad placement graphic, and 5) failed to guide the user explicitly through the pad-placement process. These five critical usability design attributes accounted for nearly all performance and behavioral deficiencies observed in this study.

LIMITATIONS

This study is limited in that it was a simulation of a cardiac arrest. However, an actual emergency situation would likely increase the stress and confusion of the rescuer and amplify some of the results found here. A limited number of volunteers participated in this observational study, which was not powered to test any specific hypothesis. Training would likely increase the ability of users to place pads appropriately and deliver a shock and is recommended in all AED manufacturers’ labeling. However, in the context of public access, defibrillation users may very well be

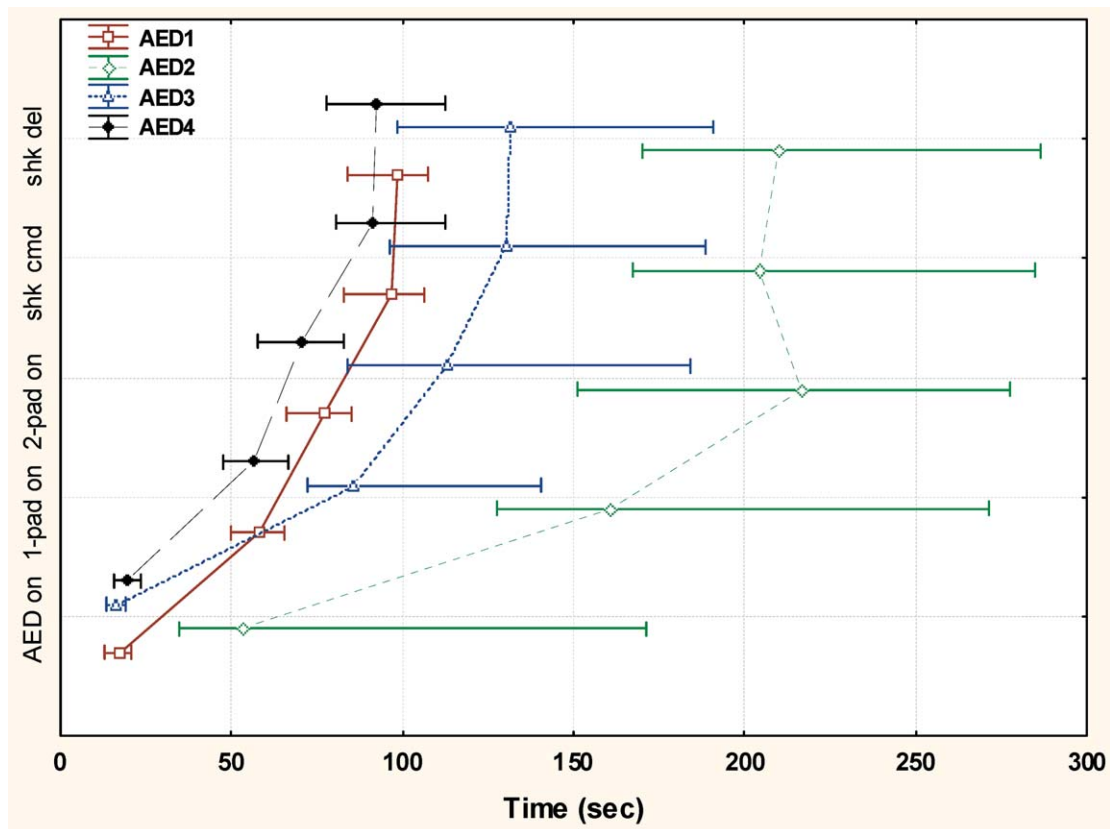


FIGURE 5. Breakdown of automated external defibrillator (AED) tasks and timing for each device, median [interquartile range]. Note that pad application times are inclusive of all uses with pads placed on clothes and liners left in place, even if shocks were not delivered.

untrained.⁷ Further, issues with training retention may limit the ability of a previously trained caregiver to use an AED.

CONCLUSIONS

Because laypersons and innocent bystanders with no prior exposure to, training with, or understanding of AEDs may use them in public settings during an unexpected emergency, the devices must be intuitive to use. We found observable differences among the AEDs we studied and have identified a number of AED pad-placement errors that could theoretically lead to ineffective defibrillation. Untrained laypersons require a categorically different level of guidance and design support than do traditional medical professionals or trained laypersons. Pad icon graphics, voice prompts, and industrial design significantly influence the ability of caregivers to deliver a shock appropriately and quickly. Although the majority of our study's rescuer volunteers were able to deploy the AED to the point of shock delivery, not all AEDs were able to guide the rescuer through AED use in a manner that would ensure the highest likelihood of successful defibrillation. We conclude that untrained laypersons can safely and effectively use an AED in the public-use context

simulated in this study only when a clear, comprehensive, and explicit instruction scheme is employed.

References

- Zheng Z, Croft JB, Giles WH, Mensah GA. Sudden cardiac death in the United States, 1989 to 1998. *Circulation*. 2001;104:2158–63.
- Myerburg RJ. Sudden cardiac death: exploring the limits of our knowledge. *J Cardiovasc Electrophysiol*. 2001;12:369–81.
- American Heart Association. *Heart Disease and Stroke Statistics—2003 Update*. Dallas, TX: American Heart Association, 2002.
- Jorgenson DB, Skarr T, Russell JK, Snyder DE, Uhrbrock K. AED use in businesses, public facilities and homes by minimally trained first responders. *Resuscitation*. 2003;59:225–33.
- Caffery S. Feasibility of public access to defibrillation. *Curr Opin Crit Care*. 2002;8:195–8.
- Marenco JP, Wang PJ, Link MS, Homoud MK, Estes NA 3rd. Improving survival from sudden cardiac arrest, the role of the automated external defibrillator. *JAMA*. 2001;285:1193–200.
- Caffrey SL, Willoughby PJ, Pepe PE, Becker LB. Public use of automated external defibrillators. *N Engl J Med*. 2002;347:1242–7.
- Gundry JW, Comess KA, DeRook FA, Jorgenson D, Bardy GH. Comparison of naive sixth-grade children with trained professionals in the use of an automated external defibrillator. *Circulation*. 1999;100:1703–7.
- Eames P, Larsen PD, Galletly DC. Comparison of ease of use of three automated external defibrillators by untrained lay people. *Resuscitation*. 2003;58:25–30.

10. Valenzuela TD, Roe DJ, Nichol G, Clark LL, Spaite DW, Hardman RG. Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. *N Engl J Med*. 2000; 343:1206–9.
11. Lawson L, March J. Automated external defibrillation by very young, untrained children. *Prehosp Emerg Care*. 2002;6:295–8.
12. Caterine MR, Yoerger DM, Spencer KT, Miller SG, Kerber RE. Effect of electrode position and gel-application technique on predicted transcardiac current during transthoracic defibrillation. *Ann Emerg Med*. 1997;29:588–95.
13. Heames RM, Sado D, Deakin CD. Do doctors position defibrillation paddles correctly? Observational study. *BMJ*. 2001; 322:1393–4.
14. Meischke HW, Rea T, Eisenberg MS, Schaffer S, Kudenchuk P. Training seniors in the operation of an automated external defibrillator: a randomized trial comparing two training methods. *Ann Emerg Med*. 2001;38:216–22.
15. Mattei LC, McKay U, Lepper MW, Soar J. Do nurses and physiotherapists require training to use an automated external defibrillator? *Resuscitation*. 2002;53:277–80.
16. Brillhart AM, Rea TD, Becker L, Eisenberg MS, Murray JA. Time to first shock by emergency medical technicians with automated external defibrillators. *Prehosp Emerg Care*. 2002;6:373–7.
17. Becker LB, Ostrander MP, Barrett J, Kondos GT. Outcome of CPR in a large metropolitan area—where are the survivors? *Ann Emerg Med*. 1991;20:355–61.

APPENDIX A

PARTICIPANT INSTRUCTIONS

This is a study of your response in a simulated emergency to a victim of sudden cardiac arrest. Sudden cardiac arrest is a condition that occurs unexpectedly when the heart stops pumping effectively. Soon you will be asked to enter a room across the hall where you will find a simulated cardiac arrest victim (a mannequin). I hope this is never the case, but let's assume it is a friend of yours who suffered a cardiac arrest while you were out shopping together. You should assume the following:

- 9-1-1 has already been called.
- The victim is not breathing and does not have a pulse.

In the room you will also find an Automatic External Defibrillator, or AED device. Defibrillation with an AED is the delivery of an electrical shock to a patient's heart. Defibrillation is intended to allow the heart to restart itself and begin pumping again. Unless a shock is successfully delivered, your friend will die in minutes. I want you to use this AED to attempt to save your friend's life.

People will be observing and videotaping your actions; but you may not ask them questions or ask for help until after you have saved your friend. During the test we will be timing you. Keep in mind that we would like you to act in the same manner as you might during an actual emergency where timing is important and every second counts.

Note that this is a simulation; you will not actually deliver a shock, but the product will work in all other aspects. You cannot pass or fail this test. I only ask that you act with the same sense of urgency, determination, and care that you would bring to a real emergency situation of this kind.

Some final things to note:

- When you enter the room, the victim will be lying on the floor in the center of the room.
- The AED device will be located on a chair to your left.
- You already know that the victim is not breathing and has no pulse and therefore you should immediately use the AED rather than initiate any form of CPR. 9-1-1 has already been called.
- Remember, when I open the door for you across the hall, you are about to attempt to save a life. Your goal should be to deliver a shock to your friend's heart as quickly as possible. Every second counts.

