

Instant expertise for novice responders performing cardiopulmonary resuscitation (CPR)

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More than 300,000 people die from sudden cardiac arrest (SCA) annually in the United States. As professional responders such as EMTs make efforts to expedite their arrival, critical minutes pass jeopardizing the victim's health. Providing life-sustaining intervention in the first few minutes greatly contributes to healthier outcomes. Often, there are witnesses to SCA events that could respond immediately, but they are incapable of providing treatment. The just-in-time support (JITS) approach aims to assist novice operators in completing unpracticed tasks such as cardiopulmonary resuscitation (CPR) at the moment of need. By providing naïve users plans, cues, and feedback, JITS systems facilitate goal accomplishment. The results of this work suggest a JITS device could empower novice responders with CPR capabilities. Widespread deployment of such a device could greatly decrease response time and save lives.

INTRODUCTION

Sudden cardiac arrest (SCA) victimizes more than 300,000 people annually in the United States (AHA, 2005). Tragically, most SCA victims are subject to discouragingly low survival rates and many die without ever receiving medical intervention such as CPR (Stiell, Nichol, Wells, De Maio, Nesbitt, Blackburn, & Spaite, 2003; Zipes & Wellens, 1998). Increasing the probability of survival requires skilled and knowledgeable responders. Usually EMTs, firefighters, or other highly trained individuals are called upon to provide life-sustaining treatment. Unfortunately, skilled response alone does not ensure healthy outcomes. Studies continue to implicate the importance of response *time* in improving survivability (Cummins, 1989, ILCOR, 2005).

Many out-of-hospital SCA episodes occur in the absence of expert responders. These scenarios require the notification and mobilization of trained personnel. Typical transit times for professionals exceed 6 minutes from 911 call to on-scene arrival (Valenzuela et al., 2005). This delay is excessive and pernicious for the victim as treatment in the first minutes following the cardiac event is vital for healthy outcomes. Every second is precious as the probability for survival declines 7-10% each minute the victim is left unattended (Cummins, 1989). The lack of intervention in this critical window is largely responsible for the abysmal national survival rates of 3-5% (Zipes & Wellens, 1998).

With time-to-treatment identified as the paramount variable, witnesses to the cardiac event are best positioned for immediate response. However, they usually have neither the expertise nor the resources to provide adequate treatment. While many laypersons may know breaths and chest compressions are needed in such a crisis, they likely don't have the skills to perform quality CPR. Additionally, the naïve responder has no ability to decipher the effectiveness (or damage caused) of the effort. Responders must be adequately trained to not only perform the technique, but also assess the state and needs of the victim. Unfortunately, training as it is currently conducted has garnered only limited success.

Two significant obstacles have impeded the effectiveness of training programs available to the general public. First, not many are volunteering to take part; participation rates are only a fraction of one percent (Culley, Rea, Murray, Welles, Fahrenbruch, Olsufka, Eisenberg, & Copass, 2004). Second, trained volunteers demonstrate substantial degradation of skills and knowledge. Only six months after training, Morgan, Donnelly, and Lester (1996) found less than 10% of trained responders were capable of providing safe, effective CPR.

In addition to CPR, defibrillation may be necessary given specific heart malfunctions. Though automatic external defibrillators (AEDs) are available in public spaces such as airports and malls, their effectiveness has been minified. Training is again implicated in this shortcoming. Not only are responders required to undergo training to operate the AED, but training beyond the AED (e.g. CPR) is also critical for a comprehensive response.

Due to the limited automatic diagnostic and treatment capabilities of AEDs, they alone do not ensure optimal patient support. For example, defibrillation is only one component in the American Heart Association's (AHA) recommended "chain of survival". As a consequence, without respiratory support a victim may still die from hypoxia despite successful defibrillation.

Our goal is to integrate the AED with respiratory support and do so in a manner that enables untrained responders to initiate life-saving actions while professional help is on the way. There is an enormous benefit to early intervention even when it is not performed by professional responders. The time to response can be greatly reduced by willing bystanders even though they lack expertise.

Though most people have no experience offering critical medical interventions, there are data showing that sixth graders have been able to apply AEDs effectively. The reason for successful utilization of AEDs is credited to human factors contributions in the interface design

(Callejas et al., 2004). While the integration of CPR support will increase the demands of the task, well-designed instruction delivery can assuage many of these complexities and guide untrained users to successful performance.

A just-in-time support (JITS) solution could provide the “instant expertise” and resources necessary to facilitate immediate novice intervention. Enabling novice responders the ability to provide defibrillation and respiratory support could drastically reduce response times. Widespread deployment of a portable, JITS designed device could greatly increase survival the of SCA victims by providing an effective, immediate intervention.

Just-in-Time Support (JITS)

Just-in-Time Support (JITS) is a framework developed to provide nonexperts guidance and information to enable the completion of unfamiliar tasks. Beyond intelligent tutoring, JITS strives to provide real-time, adaptive support in order to immediately augment user performance.

The JITS framework employs Hollnagel’s (1993) Contextual Control Model (COCOM) as a means to characterize human performance. The COCOM sketches human performance qualities along a progressive continuum describing four states of control. It is important to note these control states are offered as “regions” of operator behavior and lack well defined bounds for generic use. Only by specifying the context may researchers begin to define control boundaries

The first control state, *scrambled*, represents minimal control as operator actions are randomly generated and largely unproductive in driving the system toward the goal state. Progressing along the continuum, operators in an *opportunistic* mode can leverage cues and feedback in a goal-directed manner. More robust control results in a *tactical* or *strategic* mode and permits the operator an opportunity to manage multiple goals and plans.

The intent of JITS is to elevate novice performance (often in the region of scrambled control), to an opportunistic level by providing appropriate plans, directive cues, and corrective feedback. JITS facilitates goal completion by decomposing the objective in to manageable subtasks and guiding the user with actionable information. Feedback then serves to improve actions as well as provide working knowledge to enhance the operator’s mental model.

METHOD

Participants

Data from 40 participants were analyzed. The participants registered a mean age of 22.6 years ($SD=6.7$). A pre-experiment survey screened potential volunteers for basic life support (BLS) knowledge. Participants demonstrating intermediate knowledge of CPR (or current certification) were excluded. None of the participants demonstrated sufficient CPR knowledge to meet any exclusion criteria. All

participants demonstrated novice familiarity concerning emergency medical response.

Apparatus

Figure 1 shows the JITS device in use. A customized headrest and stock anesthesia breathing mask served as the respiratory support instruments. The headrest was customized from the foam of a bicycle helmet. Two pressure sensors were inserted at the neck and in the center of the bowl in order to detect proper head placement (the change in pressure served as a cue to the system that the “place headrest” subtask was complete and the algorithm moved on to the next step). The mask apparatus consisted of a standard anesthesia mask, bacteria filter and a one-way valve (to direct victim’s exhalation away from the responder). Defibrillator pads from Zoll’s AED-plus®, and 8-inch touch screen LCD were also integrated as part of the JITS device.

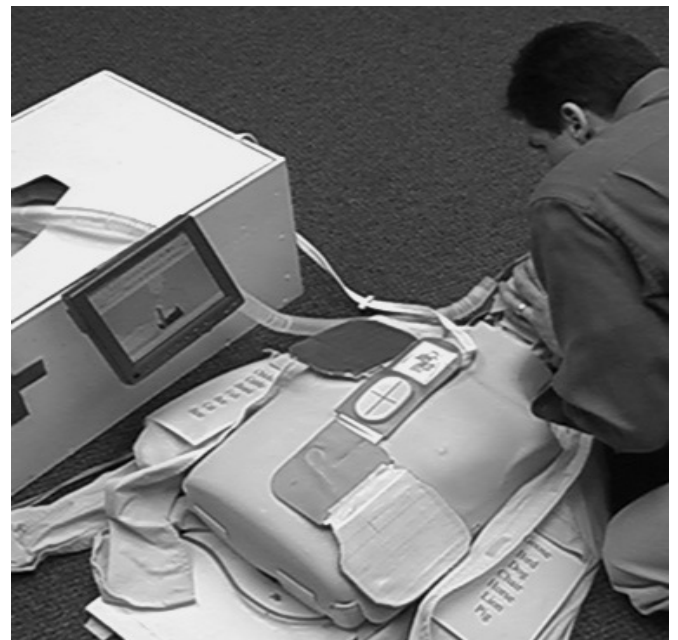


Figure 1. The JITS device in use on training mannequin

Procedure

Participants were unaware they would be performing CPR until they received their instruction at the beginning of the trial. All participants were then informed they would enter a room and find an unconscious victim (not breathing, no pulse). Their task was to perform CPR until help arrived as the victim would not gain consciousness over the duration of the scenario.

Of the 40 volunteers, half the participants were randomly assigned to the control group. They could rely only on themselves to determine treatment actions and received no external assistance. The group without the device was informed that tools were available adjacent to the victim. The tools included the mask apparatus for providing the victim ventilations as well as the pads associated with the defibrillator.

The 20 responders in the experimental condition utilized the JITS device equipped as described above. The video screen and speakers transmitted the audio and visual cues to initiate responder actions, and offer corrective feedback. Participants in the device group were encouraged to follow the instructions given by the device as closely as possible.

After completing the scenario, the researcher praised the participants' efforts and reassured them it was only a simulation with an inanimate object. They were thanked for their involvement and paid \$30.

Measures

Physiological and behavioral dependent measures were collected for assessment. The dependent physiological measures quantified performance with data describing CPR performance variables such as ventilations and chest compressions and provided a means to evaluate responder effectiveness. The behavioral data captured information characterizing each participant's control mode based on Hollnagel's (1993) taxonomy. These data served to describe the orderliness of control. In addition, each responder's ability to complete the required subtasks was also examined.

The researchers hypothesized that the group without the JITS device would demonstrate gravely inadequate CPR performance. Breaths and ventilations were predicted to provide no benefit to the victim and responders in this group would exhibit traits of the scrambled mode of control.

In contrast, novices supported by the device were expected to provide clinically beneficial interventions. All physiological dependent measures were expected to be congruent with AHA recommendations suggesting effective CPR. The plans, cues, and, feedback offered by the device were postulated to afford opportunistic control for the participants supported by the device.

RESULTS

Physiological Measures

The group supported by the JITS device (device-enabled) outperformed the no-device group in every physiological measure ($Wilks' \Lambda(5,30) = 0.19, p < 0.001$). At the time of the study (prior to the November 2005 revisions), the AHA recommended the following performance guidelines: a 15:2 chest compression to ventilation ratio; 800 – 1200mL inspired volume with each breath; and 100 chest compressions per minute at a depth of 1.5-2.0 inches.

Table 1 summarizes the means for each physiologic measure by group. Statistical analyses showed 4 of the 5 group mean differences were statistically significant ($p < 0.001$), with only the chest compression depth measure failing to achieve significance ($p = 0.52$). As predicted, the physiological performance of the no-device group severely lagged the performance of the device-enabled group. More importantly, the no-device group failed to achieve performance values that would result in clinical benefits.

In contrast, the means for device-enabled group conformed to the AHA guidelines. These values are in-line with what would be expected of fully trained volunteers as well as professional responders.

Table 1. Group means for CPR performance variables. (Standard deviations in parentheses below).

Performance Measure	No-Device	Device-Enabled
Breath : chest compression ratio	0.7 : 4.8 (1.2 : 4.7)	2.7 : 14.7 (0.9 : 4.6)
Inspired volume delivered with each breath (mL)	125 (204)	982 (383)
Chest compression frequency (per min)	43.4 (31.0)	75.7 (21.8)
Chest compression depth (in.)	1.2 (0.8)	1.4 (0.3)

Behavioral Measures

Four research assistants coded individual actions of the responders from video. The assistants were blinded to hypotheses and their impact on the coding scheme. They learned a rudimentary classification procedure to code operator actions specific to the given context and task.

For example, giving breaths with a two-handed hold on the anesthesia mask as directed by the device was considered an opportunistic action. Failing to use the mask or using only one hand while securing it to the victim's face represented scrambled control. With every action of each responder classified per the COCOM, the researchers then compiled behavioral profiles for each participant based on the assessments of the research assistants. Percentages for the three control modes were tallied for each participant (e.g. each participant had x% scrambled, y% opportunistic, z% tactical). The proportion of actions in each mode fostered the overall mode classification for the responder. Table 2 displays these results.

Table 2. Group means describing the proportion of actions executed in each control mode (in percent). (Standard deviations in parentheses below).

Control Mode Behavior	No-Device	Device-Enabled
% Scrambled	90 (12)	30 (15)
% Opportunistic	4 (7)	66 (15)
% Tactical	5 (7)	4 (8)

Based on derivation from the COCOM taxonomy (Hollnagel, 1993), the no-device group performed nearly all of their actions in a scrambled control mode (M = 90%, SD = 12%). On average, approximately 90% of all the actions performed by each responder in the no-device group portrayed characteristics of scrambled control. Evaluating the percentage of actions by mode for each responder provided a means to categorize every participant as either scrambled, opportunistic, or tactical. All twenty participants in the no-device group were classified as scrambled operators. These results align with expectations for novice responders.

In contrast, the device-enabled group performed the majority of their actions in the opportunistic mode (M = 66%, SD = 15%). Only 30% (SD = 15) of their actions were described as scrambled and these errors were largely committed early in the scenario. The aggregate category assessment also converges to the opportunistic classification for the device-enabled group. Eighteen participants were categorized as opportunistic while only two of these responders received the designation of scrambled controller.

Accurate completion of subtasks (based on the AHA protocol) provided a final performance indicator. The study defined nine fundamental subtasks requisite for protocol adherence. These included placing items such as the mask and pads, providing breaths and compressions, and exposing the victim’s chest for pad placement. The device-enabled group completed almost 8 of the 9 required actions consistently (M = 7.8, SD = 1). The no-device group was clearly unaware of the need for most tasks and completed very few successfully (M = 1.6, SD = 1.5). The difference between these groups was significant and asserts the superior task completion performance by the device-enabled group (t(38) = -15.35, p < 0.001).

DISCUSSION

Untrained responders require significant support to achieve a desirable result. Novice operators are devoid of plans to achieve their objective, unfamiliar with resources required for the task, and have little ability to track their progress or correct errors if detected. All of this was evident in the performance of the no-device group.

On average, they performed only one of the nine required subtasks. Responders in this group showed they could not conjure nor deploy an adequate plan. They overlooked or ignored available resources and it must be assumed they had no ability to monitor their progress. Had they recognized the inefficaciousness of their response, it is likely they would have changed their actions to improve their performance.

The implementation of the JITS solutions in this study was designed to mitigate all of these issues. First, the device provided a plan based on the AHA recommendations, providing a course of action for the untrained responder to follow. The overall plan was decomposed into manageable subtasks and paced by changes in state such as head placement or breath delivery. The device imparted the plan through actionable cues and improved performance with corrective feedback. Instructions were carefully orchestrated in content, and timing to accommodate the novice responder. This functionality allowed the user to manage the incoming information, apply it, and receive feedback on those actions.

The JITS approach fostered ventilations and compressions on par with AHA recommendations and elevated the user from scrambled to opportunistic control as designed.

The finding of opportunistic control in the device-enabled group is not simply an artifact, but was the primary driver of achievement in the clinical measures. Opportunistic control is not just an outcome, but necessary to guide novice performance toward a desired performance level. JITS design intentionally induces opportunistic control in order to guide and track user actions in the pursuit of goal-directed activity.

In order to achieve healthier outcomes for victims of SCA, response methods must foster rapid treatment. The current conundrum usually finds professional responders separated by critical minutes and proximal witnesses with no ability to intervene. The impetus for this study was to empower those at the scene with life-sustaining capabilities. Deployment of a JITS device could vastly increase the number of people able to provide life saving treatment.

CONCLUSION

In a real cardiac event, the intervention described in this work would take place during the transit time of professional responders. This four to eight minute duration is often void of resuscitation efforts. These data suggested novices were capable of providing effective life-saving measures during this interval when equipped with a JITS device. This study was limited by the fact that it was only a simulation with a mannequin. It is difficult to suggest that responder behavior would be identical in the case of a real victim. Nonetheless, these findings show great promise in the pursuit of empowering an untrained bystander with the

capability of providing life-saving treatment. Widespread deployment of such a device could drastically improve survival probabilities for the many victims of SCA.

REFERENCES

- American Heart Association (AHA). (2005). Heart Disease and Stroke Statistics: 2005 Update. Dallas, TX.: American Heart Association.
- Callejas, S., Barry, A., Demertsidis, E., Jorgenson, D., & Becker, L.B. (2004). Human factors impact successful layperson automated external defibrillator use during simulated cardiac arrest. *Critical Care Medicine*, 32, 9, 403-413.
- Culley, L., Rea, T., Murray, J., Welles, B., Fahrenbruch, C., Olsufka, M., Eisenberg, M., & Copass, M. (2004). Public access defibrillator in out-of-hospital cardiac arrest. *Circulation*, 109, 1859-1863.
- Cummins R. (1989). From concept to standard-of-care? Review of the clinical experience with automated external defibrillators. *Ann Emerg Med*.18: 1269–1275
- Hollnagel, E. (1993). Human Reliability Analysis and Control. London: Academic Press
- International Liaison Committee on Resuscitation (ILCOR) (2005). 2005 International Consensus on Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC) Science With Treatment Recommendations. *Circulation* 112, (suppl III). American Heart Association.
- Morgan, C., Donnelly, P., & Lester, C. (1996). Effectiveness of the BBC's 999 training roadshows on cardiopulmonary video performance of cohort of unforwarned participants at home afterwards. *BMJ*, 313, 912-916.
- Stiell, I., Nichol, G., Wells, G., De Maio, V., Nesbitt, L., Blackburn, J., & Spaite, D. (2003). Health-related quality of life is better for cardiac arrest survivors who received citizen cardiopulmonary resuscitation. *Circulation*, 108, 1939-1944.
- Valenzuela, T., Kern, K., Clark, L., Berg, R., Berg, M., Breg, D., Hilwig, R., Otto, C., Newburn, D., Ewy, G. (2005). Interruptions of chest compressions during emergency medical systems resuscitation. *Circulation* 112, 1259-1265.
- Zipes, D. & Wellens, H. (1998). Sudden cardiac death. *Circulation*:98:2334-2351.