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System to Improve AED Resuscitation using Interactive CPR Coaching

P. A. Lichter, *Member IEEE*, R. North, PhD*,* A. D. Andre, PhD, T. H. Riehle, *Member, IEEE,* and S. M. Anderson, *Member, IEEE*

***Abstract*—A positive impact on cardiac arrest survival has been demonstrated with the substantial reduction in time to defibrillation provided by the widespread deployment of automated external defibrillators (AEDs). However, recent studies have identified the importance of performing chest compressions before defibrillation in facilitating effective recovery from long duration ventricular fibrillation (VF). Despite the importance of cardiopulmonary resuscitation (CPR), effective performance of it in the field is hampered by many problems including the dependence on rescuer technique, which is known to be variable even with trained professionals. This research seeks to enhance survival outcomes following resuscitation. A full experimental system was developed that used an instrumented CPR manikin to provide interactive CPR coaching while collecting performance data. This system was utilized in a controlled human CPR performance study comparing the differences in chest compression performance with and without visual coaching and with and without interactive performance feedback coaching. Results from the human study support a number of conclusions and recommendations. In general using any type of coaching provided improvements in all of the CPR performance measures excluding chest recoil where there was a slight decrease in performance. The statistical results also indicated that the audio/visual coaching conditions provided a more effective coaching condition with respect to chest compression rate. Most notably, the feedback conditions both provided a statistically significant or trends toward improving chest compression effectiveness and produced superior performance as a whole.**

I. Introduction

THIS research seeks to enhance survival outcomes following resuscitation. According to the National Institutes of Health (NIH), circulatory arrest is a significant public health problem cutting across age, race, and gender. It often occurs without warning in persons who are healthy prior to their collapse. The national estimated mortality for all cause arrest is 330,000 lives per year. In contrast to most problems in cardiovascular medicine, current death rates have not improved significantly despite scientific advances throughout medicine [7].

Optimal resuscitation therapy for out of hospital (OOH) cardiac arrest is the subject of substantial ongoing research. Research has been clear in demonstrating that the timing of resuscitation is of critical importance. For example, there is less than a 10% chance of recovery after just ten minutes of Ventricular Fibrillation (VF). This knowledge led to the recent widespread deployment of AEDs, primarily in public areas with a high population concentration such as airports and shopping malls. A positive impact on cardiac arrest survival has been demonstrated with this substantial reduction in time to defibrillation. Despite these improvements, survival for out-of-hospital cardiac arrests is reported at 6.4% or less in the United States [8],[11],[13],[17],[18].

Research is presently underway to further improve the results achieved with AEDs. Recent studies have shown that the quality of CPR has a direct effect on patient outcome from cardiac arrest. High-quality CPR can double or triple survival rates. Unfortunately fewer than one third of victims receive high-quality CPR. Secondly, research also indicates rescuers, on the whole, do not perform CPR within established guidelines associated with compression rate and depth, and ventilation rate [3],[4],[6],[9],[10],[19],[21].

II. Methods

A full experimental system was developed that used an instrumented CPR manikin to provide interactive CPR coaching while collecting performance data. This system was utilized in a controlled human CPR performance study comparing the differences in chest compression performance with and without visual coaching and with and without interactive performance feedback coaching. Hardware and software development in the project concentrated on completing the design of a system architecture suitable for application in a production system. This architecture was prototyped to obtain an experimental system suitable for testing the key aspects of the design in feasibility testing.

The phase I prototype used an instrumented CPR manikin made by Laerdal Medical and developed a software interface to provide interactive CPR coaching while collecting performance data. The Resusci® Anne with

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P. A. Lichter, T. H. Riehle, and S. M. Anderson are with Koronis Biomedical Technologies Corp. 6901 E. Fish Lake Road, Suite 190, Maple Grove, MN 55369 USA (phone: (888) 274-1317; e-mail: plichter@koronisbiotech.com).

R. North, is with Human Centered Strategies, LLC 10710 Teachout Road Colorado Springs, CO 80908.

A. D. Andre is with Interface Analysis Associates, 6800 Redwood Retreat Rd., Gilroy, CA 95020.

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SkillReporter from Laerdal Medical is primarily intended for CPR testing and training. It has built-in sensors to detect chest compression depth, hand placement, and ventilation.

Manikin Sensor Interface

Laerdal Medical provides a software interface allowing OEM customers to develop custom software to gather CPR performance data directly. This software interface was utilized by the investigative team to obtain CPR procedural data real-time and provide feedback to the responder as to the effectiveness of the CPR. Figure 1 shows a block diagram of the coaching software platform developed.

The Laerdal Medical software development kit provides an application programming interface (API). The API encapsulates and exposes the manikin functionality in a standard way using a function library. Using this API, a software application that directly interfaced to the Resusci® Anne data output can be developed.

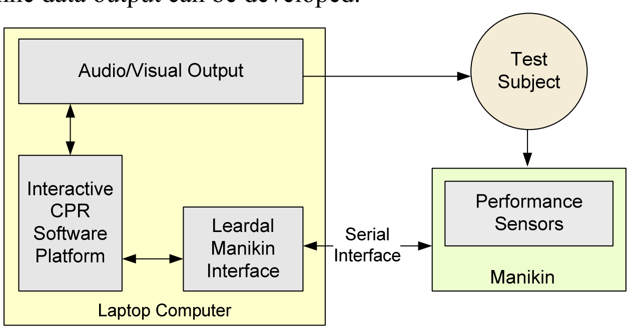

Figure 1: Block diagram of the Interactive CPR Coaching Software Platform

Interactive CPR Software Platform

The investigators developed an Interactive CPR Software Platform (CPRiP) as a research tool to evaluate the efficacy of interactive audio and video in coaching responders to perform effective chest compressions in order to improve the quality of CPR delivered during treatment with an AED. A depiction of this software's architecture is shown in Figure 2. CPRiP consists of a core module (CM) and four supporting components:

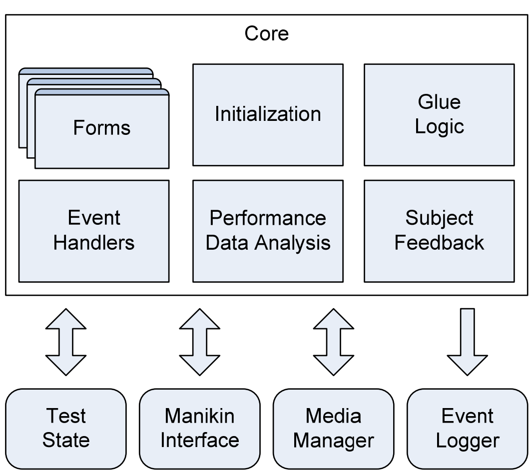

Figure 2: High level architecture of the interactive CPR software platform.

- Test State (TS),
- Manikin Interface (MI),
- Media Manager (MM), and
- Event Logger (EL).

The core module consists of three forms and code to initialize the application, logic to glue the component into adhesive application, handlers to process the events generated by the components, algorithms to analyze the subject's performance, and media to provide the subject with constructive feedback.

Test State: The Test State (TS) component implements a simply state machine consisting of three states: Running, Paused and Stopped.

Manikin Interface: The Manikin Interface (MI) component controls the interaction with the CPR manikin.

Media Manager: The Media Manager (MM) component controls the playback of image, audio and video media. Images may be displayed for a specified period of time. Video may be rendered in real time. Related media are first grouped into a playlist. Once grouped, the media are referred to as tracks. Tracks within a playlist play sequentially. MM contains methods to create playlists and add tracks. MM also contains methods to queue, interrupt and clear playlists as depicted in Figure 3.

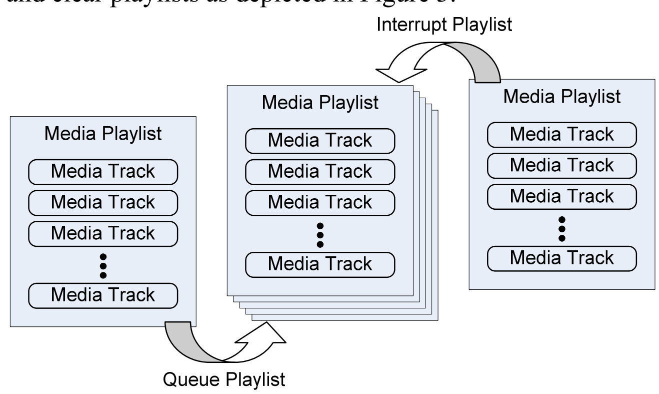

Figure 3: Queuing and interrupting lists of image, audio and video tracks for eventual and immediate playback.

Event Logger: The Event Logger (EL) component facilitates the generation of a log file with time stamped events. Compression events are generated when complete compressions are detected. Likewise, ventilation events are generated when complete ventilations are detected.

Core Module: The core module (CM) contains three forms. The main form has a system menu in the upper left corner that has been customized by the TS component. The majority of this forms area is used to display images and video. The subject information form is displayed at the start of each test in order to collect the subject's identification code and group number.

CM contains initialization code and glue logic. CM contains the algorithms to convert the raw data sent from the

CPR manikin, analyze and log computed performance data, and provide feedback (coaching), if selected, to the test subject. Feedback may either be auditory or a combination of auditory and visual.

Audio and Visual Coaching Content

The development of interactive CPR coaching content using an auditory and visual user interface was developed based upon input from AHA guidelines [21] by walking through the coaching sequence and refining the content, timing and feedback mechanisms and language. The investigators then generated and edited individual audio and video tracks for each coach instruction using the software Studio Plus from Pinnacle Systems. This software allows one to combine, edit and generate audio and video content from a number of sources. The investigators generated spoken audio tracks using a standard USB microphone and any special sound affects were overlaid within the recorded tracks. A male voice was used to provide the CPR instructional steps while a female voice gave the performance feedback coaching instructions. The majority of instructional video tracks and still images were spliced from the American Heart Association Heartsaver® AED instructional DVD. The audio content was developed such that it was utilized in all four conditions to further facilitate the comparison analysis with/without visual and with/without feedback. The audio and visual content was also developed to maintain exact timing for each step of the coaching given each of the four test conditions.

The interactive coaching algorithm was primarily based on the guidelines established by the AHA using the ABC's of CPR "Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care". Input from the manikin was utilized to provide feedback to the responder based upon the effectiveness of the CPR administration and the steps of the protocol. There was several decision points established in the interactive software that lead the responder through the rescue.

Human Subjects Evaluation

The program conducted controlled human CPR performance tests comparing the differences in chest compression performance with and without visual coaching and with and without visual interactive coaching. Forty (40) test subjects were recruited from the local Twin Cities area and assigned randomly to one of four testing groups of ten subjects each corresponding to a particular coaching strategy for CPR. The criteria for selection of test subjects was individuals formally trained and certified in CPR no less than 1 year ago and no more than 3 years ago, have not performed CPR on a real person in the last three years, are not CPR instructors and are not emergency professionals (EMTs, trained first-responders, fire and rescue, or police officers). These criteria allowed us to better assess typical degradation of performance skills in the CPR-certified layperson population.

Study Design

In order to evaluate the effectiveness of providing performance-driven feedback and coaching modality (auditory vs. auditory/visual) investigators tested four separate groups of subjects representing the conditions shown in Table I. Group 1 had a set of auditory instructions with no feedback during CPR performance. Group 2 had both auditory and visual instructions with no feedback. Group 3 had auditory coaching instructions that are sequenced based on subject performance determined by the sensor suite. Group 4 had both auditory and visual coaching also based upon performance. The feedback coaching conditions instruct participants when compression depth, rate, chest recoil and/or hand placement is outside of prescribed range.

Each subject performed two CPR performance trials 1) An initial base-line CPR performance test trial with no interactive coaching for a four minute period and 2) A CPR performance trial with interactive coaching based upon the grouping as assigned in Table I for a four minute period.

Table I
Subject group assignments

	Auditory Coaching Only	**Auditory and Visual Coaching**
No Feedback	Group 1	Group 2
Feedback	Group 3	Group 4

Testing Apparatus: A Laerdal Rescusi-Anne manikin was used to assess CPR performance instrumented with sensors that recorded and assessed participant performance. The manikin was positioned on the floor of the testing room along with the laptop that provided the session instructions and introductory video as well as software for recording performance. Audio/video recording equipment was used to record the participant's session for additional reference during data collection. The testing suite consisted of:

(1) CPR physical simulation equipment including a patient manikin equipped with the sensing technology for various chest compression parameters.
(2) A notebook computer simulating the interactive video coaching capability with an interface to the recording sensors from the manikin to capture, analyze, and store of performance parameters.
(3) Video recording equipment.

Testing Session Protocol

The test subject was not asked to interactive with any of the equipment other than to perform CPR on the instrumented manikin while following any visual or verbal instructions from the notebook computer. The study proctors configured and started the interactive software running on the notebook prior to each test session.

Measures of Performance

The major performance parameters of effective chest compressions included chest compression depth, rate, compression recoil depth and hand placement. The performance measures recorded by the sensing suite integrated into the manikin formed the basis for overall measures of CPR quality. The sensors in the manikin were recorded to a computer where software analysis was performed after the test trial completion. Each of the CPR trials was video recorded for all test groups providing researchers additional information on subject performance and usability. The interactive CPR coaching and feedback content were based upon the American Heart Association 2000 CPR Guidelines. For the feedback groups (3 and 4), a set of algorithms were used to decide when feedback was needed. Table 4 shows five dependent measures of computed performance for each participant during the CPR sessions.

Each of these measures was computed for both the baseline and the test condition to which the participant was assigned. An analysis of variance (ANOVA) was conducted on each measure to assess the effects of coaching (difference between baseline and coached conditions), feedback vs. no feedback, and coaching modality (auditory vs. auditory/visual), and various interactions of these conditions.

Table III

The five dependant measures of computed CPR performance

Measure	Target	How Computed
Chest Compression Deviation from Target Depth	5.1 cm (2 inches)	Deviations of each compression from the prescribed 5.1 cm target averaged over entire CPR session.
Chest Compression Rate Deviation from Target Rate.	100 comp./min	Deviation of average chest compression rate from the prescribed 100/min over entire CPR session.
Hand Placement Accuracy	Center of chest between nipples	Percentage of compressions over entire CPR session that occurred within the specified target chest zone.
Ventilation Volume	850 mL	Average rescue breath volume for each breath given over entire CPR session
Chest Compression Recoil Depth	0 cm	Average recoil depth after each chest compression over entire CPR session.

III. Results

Data Analysis

The following study questions were addressed through statistical analysis.

1) *Did coaching produce improvement from the baseline condition (no coaching) to the coached conditions?*

A “repeated measures” analysis of variance (ANOVA) was conducted to assess the difference in performance from baseline to coached conditions. In our case, the “repeated measure” is represented by the second session of CPR performance which was performed with one of coaching conditions. In this analysis, the mean for the baseline condition is compared to the mean of the coached condition in terms of any significant improvement produced by that condition. A summary of results is described below:

Chest Compression Deviation from Target: The Audio-Visual/Feedback coaching condition produced significantly better performance over baseline ($p=0.011$), and the Audio/Feedback coaching condition also produced a trend ($p=0.078$) towards better performance in the coaching condition.

Chest Compression Rate from Target: All four coaching conditions produced significant differences favoring the coaching conditions (Audio/No Feedback, $p=0.06$; Audio/Feedback, $p=0.0005$; Audio-Visual/No Feedback, $p=0.01$; Audio-Visual/Feedback, $p=0.0001$)

Hand Placement Accuracy: There were no significant improvements in percent correct hand placement scores in the coaching conditions. Although, weak trends ($p=0.11$, $p=0.15$) were observed for the Audio-Visual/No Feedback and Audio-Visual/Feedback conditions favoring performance in the Audio-Visual coached conditions.

Chest Compression Recoil: Recoil depth showed a significant improvement in the Audio-Visual/No Feedback and Audio-Visual/Feedback conditions ($p=0.027$ and $p=0.063$ respectively) over baseline performance trials.

Ventilation Volume: Ventilation volume showed only a statistical trend in the Audio/Feedback condition ($p=0.059$) with increased volume moving closer to the target in the coached condition.

2) *What type of coaching was responsible for the most improvement and/or produced the best overall CPR performance?*

An analysis of variance (ANOVA) was conducted on each measure to assess the effects of coaching measured by the *difference between baseline and the coached conditions*.

Two types of scores were used for these ANOVAS. First, we computed a difference score, reflecting the improvement from the baseline to the coaching condition for each participant. Second, we assessed the “raw score” performance—the score that was recorded in the coached conditions alone, without regard to improvement from the baseline condition. The statistical computations on the data produce the following conclusions:

1) Feedback (without regard to coaching condition) significantly improved chest compression depth performance over the baseline condition in accordance with the specified target of 5.1 cm (p=0.02). Feedback also produced better chest compression raw score performance in the study conditions without regard to improvement from the baseline (p=0.0041).
2) Compression rate improvement over baseline performance was not significantly improved by feedback or coaching modality. Compression rate, without regard to baseline comparison, was significantly improved in the auditory/visual coaching condition (p=0.02). *Having the visual stimuli appears to help with maintaining or matching the coaches' counting cadence during compressions.*
3) Hand placement was not significantly affected by the coaching conditions or by feedback, although the means show an apparent superiority for the audio/visual coaching modality.
4) Chest compression recoil depth actually appears to *increase* instead of improving in the coached conditions, thus producing the negative scores. Feedback conditions were significantly different from the non-feedback conditions, with feedback producing less of a degradation effect on recoil than the non-feedback conditions.
5) Ventilation performance improvement from baseline produced a statistical trend favoring the audio coaching with feedback condition and the audio/visual coaching with no feedback condition over the other two conditions (p=0.06). There was a highly significant interaction effect for raw ventilation performance (p<.05) again showing superiority for the audio with feedback and the audio/visual without feedback conditions.

IV. Conclusion

Based on the human study results a number of conclusions and recommendations can be made. In general using any type of coaching provided improvements in all of the CPR performance measures excluding chest recoil where there was a slight decrease in performance. The statistical results also indicated that the audio/visual conditions provided a more effective coaching condition with respect to chest compression rate. Most notably, the feedback conditions both provided a statistically significant or trends toward improving chest compression effectiveness and produced superior performance as a whole.

Even though the improvement in correct hand placement was not statistically significant, the researchers believe the results could be substantially improved based upon the comments received by the participants as well as observing the video tape of the test sessions. The researchers have realized the difficulty in properly instructing the subjects in proper hand placement. This problem simplified when using visual instructions and this also indicated in the results where the percent of correct hand placements is higher for the audio/visual conditions.

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