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Just in Time Support to Aide
Cardio-Pulmonary Resuscitation

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1. Introduction

Cardiovascular disease is the leading cause of death in the United States with over 696,000 cases recorded by the Center for Disease Control (CDC) in 2002 (National Center for Health Statistics, 2002). In particular, Sudden Cardiac Arrest (SCA) claims 300,000 to 400,000 American lives annually (AHA, 2005, Huikuri, Castellanos & Myerburd, 2001, Zipes & Wellens, 1998). Ventricular fibrillation is believed to be the insidious perpetrator associated with the majority of these heart maladies (AHA, 2005, Cummins & Hazinski, 2000). Unfortunately, most victims that experience SCA have only a small chance of survival (Stiell, Nichol, Wells, De Maio, Nesbitt, Blackburn, & Spaite, 2003; Zipes & Wellens, 1998).

Increasing the probability of survival of SCA victims requires skilled and knowledgeable responders. Usually the task falls to EMTs, firefighters, police officers, or other highly trained responders. Unfortunately, these experts are not always available on site which means that critical time is lost by moving responders to the victim. An alternative approach to provide rapid access to responders is to develop and provide supportive technology that guides a novice through the procedure of resuscitating the victim by presenting information and feedback at the time when it is needed. However, such approach needs methodologically and conceptually to be rooted in cognitive psychology and human factors since these fields can direct work that aims at the robust improvement of human performance of novices. The successful application of this approach has the potential to improve usability of medical devices for non-experts, beyond the design of defibrillators.

Below we will outline the elements that need to be included in the development of a system that allows an untrained responder to deal with a SCA by providing elementary cardiopulmonary resuscitation (CPR). This approach is based on the idea of Just-in-Time Support (JITS). First, we will outline the tradition into which such JITS falls conceptually. Then, we will describe the differences between current architectures of Intelligent Tutorial Systems (ITS) and the constraints under which a true JITS has to operate. In the following section we provide a conceptual framework that allows analysis of human performance in the context of complex procedural tasks. Next, we will describe a JITS developed for the purpose of evaluating the feasibility and effectiveness of this approach, and report the results of an experimental study that evaluated a JITS. Finally, we will discuss the findings in the context of future developments of defibrillators and other systems that require guidance of novice users when using these advanced medical technologies in emergency situations.

1.1 Intelligent Tutorial Systems (ITS)
1.1.1 Description of ITS

Intelligent Tutoring Systems (ITS) have been developed over the last decades. Early systems focused on supporting students in acquiring knowledge, thus these systems were similar to flash cards but were also capable of analyzing a student's responses (Uhr, 1969). The next generation systems were more sophisticated because they moved from a scripted hierarchical structure of knowledge towards systems that were able to deal with potentially all requests that a student would submit to the system. For example SCHOLAR (Carbonell, 1970) tutored students in South American geography and was designed to deal with a variety of questions that might be asked by a student learner. The next important step in the development of ITS was embodied in the work of Collins (1977). Earlier that decade Craik & Lockhart (1972) demonstrated that deeper, more elaborate processing improved learning and retention. In application of this line of reasoning, Collins (1977) implemented a Socratic method of exploration for his system. What was remarkable about this approach was that it allowed the student to "discover" knowledge, empowering the student to acquire knowledge from experience and individual cases, through self-directed exploration of the knowledge base. Despite the wide range of ITS there are a number of basic elements that all of these systems have in common. These elements will be outlined next.

Many ITS projects share a basic architecture consisting of the same components. Perhaps the most basic components as described by Burns and Capps (1988) are the "Expert Model", the "Student Model" and the "Tutor". These modules are essential to the development of the JITS framework and will be discussed in depth.

Expert Model. The expert model is designed to encapsulate all available knowledge for a particular domain. Domains for which ITS's have been developed included arithmetic – BUGGY (Brown & Burton, 1978), programming language - LISPIT (Anderson, 1988), and electronic troubleshooting – SOPHIE (Brown, Burton, and deKleer, 1982). Clearly, it is a challenge to develop an expert model for an ITS and the difficulty is a function of how well defined a domain is. For example, when dealing with technical procedures like maintaining an aircraft, the problem space is well understood, i.e., the steps involved in performing a procedure are clearly structured and the means to perform the task are well defined. Clearly less well understood domains provide a significantly higher challenge for the designer of the expert model, and with Anderson (1988) one has to emphasize that, ". . . a great deal of effort needs to be expended to discover and codify the domain knowledge" (p.22). The information contained in the expert model is usually assembled by experts in specific fields and serves as the standard to which the student's actions and knowledge is compared.

Student Model. The student (or user) model is the system's representation of a specific learner's abilities and knowledge concerning the domain under consideration. Because of the dynamic nature of learning, a single or a static student model is not sufficient in an ITS. This is because overall the student acquires knowledge during the use of the system and progesses towards the development of expertise, but this track is not linear and perturbations of the user's proficiency across and even within a training session need to be accommodated. A critical function of ITS is to properly diagnose the user and identify when and what type of assistance is needed. If students perform below their normal baselines, the system must respond according. For the system to accurately gauge a student, it must go beyond a simple comparison to the expert model. One issue of current diagnostic functions implemented in ITS's is that they evaluate response accuracy by comparison with the knowledge base (Linn, 1990; Marshall, 1990). This allows for the categorization of a student,

but offers nothing to guide learning and performance (Linn, 1990). However, the tutor model serves this purpose.

Tutor Model. The tutor model is essential in a ITS since it incorporates the didactic ideas of the designer. Without a tutoring model (e.g., instructional module, or pedagogical agent) an ITS would be limited to the administration and scoring of tests lacking the ability to impart knowledge or understanding to the user. Structurally, the instructional module interacts with the expert model and the student model to formulate relevant information to the user. It evaluates the student model in terms of the expert model and decides what information to present, how to display the information, and when to do so. The tutor model is the visible module for the user. Through the interface, the pedagogical agent serves as the teacher, consultant, assistant, or coach.

1.1.2 Limitations of ITS

The above description of the ITS architecture illustrates some of strength of the approach that guides the development of an ITS. However, there are also limitations that are associated with the development and use of such system. These limitations become particularly salient when the goal is to design a system that does not provide knowledge, but that can be used as a just-in-time support system. Certainly, both systems have similarities– e.g., both are primarily aimed at novices, are computer based, and leverage best practices of expert systems and user-interface principles. However, for the current purpose it is also critical to understand the differences between these systems. The differences can be described with regard to the goals, the time available for performance, the intended cognitive processing strategies and the system input. A brief summary of these issues is provided in Table 1, and will be discussed in detail in the next sections.

Objectives. The disparate objectives of each system are yoked to the temporal constraints associated with their use. With the ITS, the extended time horizon enables the goals of learning, long-term retention and fosters accuracy in the speed-accuracy trade-off. This situation can be contrasted with the JITS that is not focused on learning, since retention is inconsequential and potentially counter-productive in situations where a JITS is being used. The objective is to allow the user to perform the task to a satisfactory degree in the limited time available. Due to the temporal constraints, it is more important to sufficiently complete all requisite steps in the given, limited time rather than to strive for flawless performance on some tasks while failing to complete others.

Paradigm	Objectives	Time Available	Processing Strategies	System Input
Intelligent Tutoring Systems	Long term retention Learning Accuracy over speed	Long time horizon Self paced Low time pressure	Deep/elaborative Adaptive, transferable Declarative	Passive collection Requires user input to computer
Just-in-Time Support	Short term performance Complete task Speed over accuracy	Short time horizon Externally paced Significant time pressure	Shallow /perceptual Mimicking Procedural	Active collection Monitors user actions

Table 1. Differences between Just-in-Time Support (JITS) and Intelligent Tutoring Systems (ITS) on critical dimensions.

Time available. A student using an ITS to acquire some knowledge will not experience time pressure. The user determines the start time, duration, and sets the pace of the interaction with the system. This more relaxed situation can be contrasted with the context in which a JITS is being used. Here, the task will be subject to considerable time pressure due to the task criticality (a non-critical task could tolerate awaiting the arrival of an expert), making the task externally, and not internally paced. The JITS user operates under a limited time envelope in which to perform the task.

Processing strategies. A significant discrepancy between systems is also evident in the targeted cognitive processes involved in performance. The aim of an ITS is to target a deeper level of processing (Craik & Lockhart, 1972) which allows long term retention. Thus, intelligent tutoring systems utilize declarative knowledge permitting extensive mental associations and abstractions. This more elaborative processing strategy serves not only long-term retention, but also pliant, adaptive application with the development of domain expertise. In contrast a JITS targets a shallower, perceptual level of information processing. As a consequence, mimicking-type strategies, though inferior to elaborative processing for memory, are efficient for accomplishing procedural tasks without any previous practice in the task.

System input. The final difference concerns the input mechanisms that are implemented in each system. Traditional ITS requires a direct manipulation by the user (i.e., type, point and click, etc.). The system itself is designed to be passive whereas a JITS is specifically designed to actively collect data from the environment in which the task is performed. Equipped with an array of sensors the JITS system identifies changes of state and updates its models based on those changes. This process is implemented in such way that it is transparent to the operator (sensors are integrated with the tools used), and overall drives updated cues and feedback that guide performance to meet standards that suffice. Feedback and plan adaptability consequentially rely upon the external data the system is able to collect and integrate. The operator is permitted to act in a goal directed manner on the world (essential for performing a task), and is not required to provide additional information necessary to update the system's representation of the environment and the task progress.

Clearly, there are significant differences between the traditional ITS approach and the JITS design. One of the additional differences relates to the challenge of assessing performance of a human operator. To do this, a control theoretical perspective as proposed in the COCOM model can be useful. In the next sections we will describe this framework.

1.2 COCOM as conceptual framework

Erik Hollnagel (1993) developed the Contextual Control Model (COCOM) that describes a continuum of human control and can serve JITS development in both design and evaluation of operator performance. The model provides designers with a tool to identify parameters and determine control characteristics of an operator, which not only enables prediction of control conditions, but also establishes means to manipulate control states. Additionally, the model provides an effective assessment tool to evaluate performance hypotheses.

Before the nominal control modes can be described it is important to explain the parameters that characterize a given state of control of an operator. Based on Holnagel's model it is possible to distinguish several dimensions that help characterize the level at which a person is performing a control task. *Determination of outcome* is a reflection of an operator's ability to

detect and interpret a change in system state. The *subjectively available time* is a measure that assesses the time pressure that is subjectively perceived by an operator. The *number of simultaneous goals* reflects the number of objectives the user can maintain concurrently and their relevance to the overall goal. The *availability of plans* is an expression of the controller's access to heuristics, plans, procedures or something rule-like to guide actions that are performed to accomplish the overall goal. The *event horizon* is composed of the extent to which previous information on the control task is being utilized in a given decision, plus the "prediction length", which is an extrapolation of the future state of the system. Finally, the *mode of execution* is a reflection of the overall way how an operator performs the control task. Two modes are possible, a "subsumed" (ballistic or feed forward) mode where actions are executed automatically. This mode requires assumptions and predictions with regard to the dynamics of the controlled system. The second mode is a "feedback" mode in which data of the tasks' state and progress guide future actions because a constant assessment of performance changes the guidance that is provided.

1.2.1 Control modes

The control continuum that describes the level of control of an operator is anchored by an absence of control at one end of the continuum, and highlights several milestones as control progresses to a very high-level of control at the other end of the continuum. Hollnagel identified four characteristic regions of control. From the level of least control to level of greatest control the regions are labeled: *scrambled, opportunistic, tactical,* and *strategic* levels of control. A more detailed description of these levels with regard to the dimensions outlined above will be provided next.

The level of *scrambled* control resides on the lowest end of the continuum, and is an expression of a lack of control of the operator. The user performs the next action at random and the choice of action is unpredictable, resulting in a trial and error approach with limited determination of the outcome. Here, this approach results in user actions being incongruous with the situation. Clearly, a user operating in a scrambled control mode has no knowledge about the process and lacks any heuristics, rules or procedures that would allow performing the task. Consequentially, the user experiences a great deal of stress due to high cognitive workload, time pressure, and a futile understanding of the system and/or the current environmental conditions.

The *opportunistic* level of control is the next region on the continuum of control. What is important at this level is the fact that the operator expresses some ability to move the system toward the overall goal state. Similar to the scrambled mode of control, the operator still perceives significant time pressure, but it is possible for the user to plan the next action that is being performed. In addition, actions are no longer characterized by chance. Overall these changes are a reflection of the fact that control now becomes a cognitive problem, i.e., control is based on the user's ability to recognize and act on salient cues in the environment and that are provided by the system. Thus, the operator moved from a subsumed mode of execution to a feedback based mode, with feedback being accessible and interpretable and the environment being somewhat familiar.

A the level of *tactical* control a noticeable change in perceived time pressure occurs which allows for short range planning. The user experiences an expansion of the event horizon that is involved in planning, in both directions (previous states and predicted states). Performance now is based on previously acquired rules or procedures and the operator is now in a position where it is possible to anticipate needs associated with the control task

that are in the near future. The meanings of the outcomes of actions are more completely understood, and two or three goals the operator pursues may be active at once, with a plan, rule, or procedure supporting each of the goals. Feedback is an important input and being utilized for comparison with higher level goals.

Finally, the *strategic* level of control is a state of high stability and planning that is well beyond the immediate context of the control task. Performance at this level is effective and robust with the event horizon being further extended in both directions. The operator has the opportunity to contemplate the highest level goals and performs at both modes of execution (i.e., feedback and feed forward control). Finally, performing at the strategic level of performance requires substantial motivation to do so. The user must embrace the high cognitive load associated with this level of performance that is a result of extended planning, reasoning, and observation to attain a strategic mode of control. Because of this high cognitive demand, strategic control often cannot be maintained for long periods. A summary of the different modes of control and their association with the different COCOM parameters is displayed in Table 2.

Parameters	Scrambled	Opportunistic	Tactical	Strategic
Determination of Outcomes	Obscured	Limited	Context dependent	Elaborate + prediction
Subjective Time Pressure	Severe	Significant – Severe	Light-Moderate	None
Simultaneous Goals	0-1	1	2-3	2-many
Availability of Plans	None employed	Minimal	Most goals supported by plans	Plans and contingencies available for all
Event horizon	Present only	Some history, little planning	Planning (based on current situation), use of previous data	Extensive planning & use of historic data
Mode of Execution	Subsumed	Feedback	Feedback	Feedback + subsumed
Action Selection	Random	Cue driven	Plan driven	Prediction driven

Table 2. Summary of COCOM parameters and control states (adapted from Hollnagel, 1993).

One important aspect with regard to the different modes of control is related to how an operator can switch between these modes. Below we will discuss the process of transitioning between modes.

1.2.2 Mode transitions
The transition between control modes is also of importance, and can be discussed in terms of changes in the parameters outlined above. Since those characteristics describe a state of control, it is appropriate to speak about an operator moving along the control continuum as result of a change in one or more of those parameters.

The most direct transition is a simple step to an adjacent level of control. This shift may be either an increase or a reduction of control performance. However, it is possible to have

transitions that skip a level. For example, an operator in a tactical control mode may encounter a completely novel crisis. During such encounter the subjectively available time may diminish and no heuristics for employment are available. Clearly, a scrambled condition has resulted. Hollnagel (1993) insists that there is a constraint in moving to and from strategic control with strategic control only being reached from the tactical region and also only be able to degrade to the tactical level.

Knowing the characteristics of each control mode, allows identifying the region in which an operator is performing. Knowledge of the task, tools, and context permits a developer of a system to articulate mode control predictions which provide a workspace that can be manipulated in an effort to improve an operator's level of control. For example, one implementation is to make accessible a plan to a user where the person did not have any previously. In addition, it is possible to rectify the absence of salient features by providing guidance. Finally, clear feedback can be presented to promote interpretation that can guide action.

Lastly, the application of COCOM as a model of human performance provides some guidance for the development of assessment tools of human performance in the context of complex tasks, i.e., the assessment of performance using a JITS system. Thus, Hollnagel's model provides valuable characteristics to describe the task and desired performance which can allow prediction of performance in a given situation.

1.2.3 Design considerations based on COCOM

After the above description and analysis of the COCOM model it is now possible to identify several important design recommendations. These recommendations guided the implementation of the Just-in-Time System to provide CPR expertise. Below each of these principles is outlined.

- Provide a plan of action to the user that is adaptable to dynamic conditions and needs
- Provide salient, action-directing cues to the user
- Provide easily interpretable feedback to help the user correct actions and update system state continuously
- Work within time constraints that are derived from the task.

Clearly any direction provided to a user of a JITS needs to include the visual and auditory modality to provide instructions and feedback. Visual displays can inform a novice on how to proceed when performing individual steps of the task. This implies that a dynamic visual display has to

- demonstrate sequential actions in a procedural task
- obtain attention focused on specific tasks or presentation displays
- illustrate a task which is difficult to describe verbally
- represent invisible system functions or behaviors in a transparent fashion.

1.3 Additional design considerations
1.3.1 Expertise

A substantial amount of research has been conducted to identify what characterizes expert behavior and expert performance (e.g., Chi, Glaser, & Farr, 1988,). Glaser and Chi (1988) established seven general attributes representative of experts. These attributes are presented in table 3.

1.	Experts excel in their own domain.
2.	Experts perceive large meaningful patterns.
3.	Experts solve problems quickly with little error.
4.	Experts have superior short- and long-term memory in their domains.
5.	Experts represent problems more abstractly.
6.	Experts are able to spend great deal of time analyzing a problem qualitatively.
7.	Experts have strong self-monitoring skills.

Table 3. Expert characteristics (Glaser & Chi, 1988).

1.3.2 Expert-novice differences

Johnson (1988) observed that novices do not have extensive domain knowledge, and cannot encode information well (e.g. they lack an adequate representation and experience pattern matching difficulties) nor process new information quickly. Miller & Perlis (1997) also discussed novices' inferior knowledge base and structure, adherence to superficial cues, and utilization of small, fragmented information units. Not only did novices utilize more superficial knowledge, but the knowledge base lacked cross referencing and the organization that experts are able to impose.

In developing a system for non-experts it is of critical importance to understand the limitations of novices. This can lead to an implementation of guidance that truly supports performance but does not exceed novices' abilities. Below are the design recommendations pertinent to each expert characteristic described in Table 3.

- Novices do not excel in the given domain, they need help. Thus, there is a need for JITS.
- Novices need to parse information into simpler, more digestible chunks. Critical parameters and combinations must be salient. The system helps the user to construct patterns in small increments.
- The pace at which information is delivered to novices should be slowed. Information about sequential steps may also need altering. Repetitions in displaying this information may be necessary. The pedagogical model should monitor and control the pace and sequence pursuant to operator needs.
- The system should relieve burdens to short term and long term memory of novices by holding the information and making it visible, accessible, and congruent with the current subtask.
- Novices do not understand abstract concepts of the domain. Cues and feedback must utilize concrete representations. Designers cannot assume knowledge on the part of the user. Metaphors, higher level concepts, and domain knowledge are likely to be lost on a novice.
- Novices will not have time or ability to analyze the situation on a deeper level. A context-aware system will be responsible for identifying the proper course of action.
- Novices will likely be far too stressed to have any resources available to deal with the challenges required in building situation comprehension. Smart algorithms and sensors take over this job in conjunction with the situation assessment the system monitors operator performance in order to optimize cues and feedback to assist the user optimally.

The emphasis in employing these design recommendation is that it is imperative to provide information congruent with the operator's knowledge. For the development of an effective system it is important to design systems that are suited for the user's level of expertise. It

also is important to not attempt to transform novices into experts when developing JITS systems since acquisition of expertise exceeds available time. Often, tasks may consist of a single trial, which is clearly not sufficient to establish expertise. However, by abandoning the effort to create an expert and embracing the task of mimicking one, several advantages arise. For example, a shallow level of information processing can be targeted. Certainly such level of processing is inferior for retention, but it reduces the demand on the novice's limited cognitive resources and leverages more primitive processes such as perception-action mechanisms. To summarize the following design principles with regard to expertise need to guide the development of a JITS:

- Break information down into comprehensible chunks
- Use concrete (as opposed to abstract) representations
- Ensure the pace of information delivery is apt for user population
- Minimize cognitive burdens (memory, search, attention capture) as much as possible.
- System should assume monitoring role
- Keep information visible

1.3.3 Feedback

Feedback can be defined as information that is provided to an operator that is relevant in the context of assessing performance or outcomes. In order to provide closed-loop control, feedback must be communicated directly to a user, and if provided correctly it has the potential to enhance operator control.

Numerous reviews and meta-analyses demonstrated the effectiveness of accurate feedback in a variety of tasks (Azevedo & Bernard, 1995, Kluger & DeNisi, 1996, Salmoni, Schmidt, & Walker,1984). Reliable feedback enhances learning and performance. In support of immediate task facilitation, Goodman (1998) concluded that frequent and immediate feedback to study participants improved performance during practice. Similarly, Young & Lee (2001) found that more feedback in the "acquisition phase" facilitated task performance (but not retention). In JITS supported tasks, "practice" occurs simultaneously with the "test". Therefore, frequent and immediate feedback will likely generate desired effects for JITS systems. An additional benefit of feedback is that it increases motivation. Participants often invest more effort, show more interest in the task, and persist longer than those who do not receive feedback. Interestingly, Salmoni, Schmidt, & Walker (1984) found these effects persisted for some time even after removing feedback.

Based on the above, a number of recommendations for optimal delivery of feedback in a JITS can be provided:

- Customize feedback pursuant to operator knowledge
- Feedback provided must be reliable
    i.   Conflicting information can confuse the user
    ii. Excess precision (based on user knowledge) will likely be ignored
- Feedback timing is critical
    i.   User must be able to relate feedback to relevant activity
    ii. User must be ready to attend to feedback information
- Feedback may serve as motivation in completing the task

1.3.4 Visual displays

Since most of the tasks supported by JITS entail spatial arrangements, information needs to be presented visually to the user. Technology-intense domains typically require visual

displays to support detection and interpretation of events, particularly when governed by capricious constraints (Sanderson, Haskell & Flach, 1992). This assessment certainly applies to the CPR/defibrillation task. Park and Hopkins (1992) outlined six conditions in which dynamic visual displays (DVDs) are effective. The majority of those conditions are highly cogent with JITS system development to support CPR. The use of DVDs is effective when:

- Demonstrating sequential actions in a procedural task
- Obtaining attention focused on specific tasks or presentation displays
- Illustrating a task which is difficult to describe verbally
- Explicitly representing invisible system functions or behaviors.

Based on the above the following design recommendations for dynamic visual displays can be used in the context of JITS development:

- Important for conveying dynamic visuo-spatial information which is often difficult to verbalize
- Appropriate for sequencing and procedural information
- Effectively portray motion and trajectory
- Animations should be simple and relevant
- Pacing of dynamic visuals must be carefully considered

1.4 JITS framework

After the previous sections outlined the design recommendations for a JITS, in the next sections the JITS framework will be presented.

1.4.1 Real time support

Because the primary application of a JITS system is in the context of performing urgent tasks without the user of the system having task expertise available, system based support needs to be provided in real-time. With the task being one of urgency, any implementation has to address the fact that performance is under high time pressure and the time horizon of the task is short.

The main purpose of the JITS system is to support performance of a user by structuring the instructions in such way that they can be easily followed, even by a complete novice. This goal is accomplished by breaking down the overall task into its elements or sub-tasks and by presenting these sub-tasks individually to reduce the cognitive load that is imposed on the user of the system (see section 1.3 for design recommendations).

Because the JITS systems' focus is on short term performance and immediate task completion, it supports the user with the goal to mimic an expert without the necessity of long-term retention which is the main focus of intelligent tutorial systems. This goal is achieved by adaptive information presentation. This information presentation approach aims at supporting shallow, perceptual processing of the information that enables the user to mimic the displayed procedures to a level of proficiency that meets minimal performance standards. The goal can be achieved through effective information presentation (see section 1.3 for design recommendations).

1.4.2 Information presentation

Visualization of information is optimal for conveying complex, temporally constrained, spatial information. In many cases, a task will require a space-dependent manipulation of the environment through effectors such as tools or direct contact. According to Schmidt and

Kaysor (1987) who report the superiority of simple graphics compared to photographs, a simple graphical presentation can lead to superior information processing (see also Harrison, 1995). Further, displaying information based largely on graphics and animation can transcend language-induced barriers. Though, if language is not likely to be a concern, the combination of graphics and text produces superior results to either alone (Booher, 1975).

Animation has the advantage of allowing the novice to mimic expert behavior simply through observation. For example, Palmiter and Elkerton (1991) found that participants using animation performed training session tasks in approximately half the time required of a text using group and this without sacrificing accuracy! In training, the animation group surpassed the text group by performing over 90% of their trials correctly, while the text-based group failed to achieve 80% correct. The findings suggest that participants in the animation group adopted a mimicking strategy.

A JITS system's real-time support displays manual/technical aspects of the subtasks by showing animations of how and where to perform a task (e.g., tilting the head of the victim) and instructs how to attach the sensors. After attaching sensors to a patient, the system provides real-time feedback about the patient's vital signs and offers context dependent suggestions for the next step of the treatment protocol. This reduces the cognitive load and eliminates the requirement of planning next steps that are conditional on current situation assessment.

1.4.3 Adaptive support

Another important implication of the task setting under which a JITS can be maximally effective is that the speed at which the task needs to be performed and the sequence of the sub-tasks is determined externally. This implies that changes in the environment need to have a direct impact on the selection and execution of procedures by the user. The basic idea of a JITS is that it addresses these requirements by providing adaptive support to the user. Adaptive support is possible because the system collects continuously data in the task environment by using advanced sensor technology. The collected data are then used to provide context specific instructions that can lead to performance that addresses the problem at hand optimally. Support for this approach is provided by Carlson, Lundy, and Schneider (1992) who report evidence that guidance is effective in supporting novices when dealing with novel tasks where long-term retention is not required. Guidance also supports a novice by taking advantage of the hierarchically structured task that is the basis for any task that can be implemented using a JITS. This structure allows the presentation of information in the exact order that is needed to execute the procedure optimally (see Bovair & Kieras, 1991; Jansen & Steehouder, 1996).

The JITS system guides the user by providing a plan that effectively provides the novice operator with the expertise necessary to successfully perform the task. However, as JITS will have to accommodate novices, it is important to understand the differences and communalities of information requirements for experts and novices. There are important differences in information requirements between experts and novices that are based on the different cognitive representations used by the two groups during task performance. For example, experts tend to think more abstractly, perceive meaningful patterns, and organize tasks based on their domain expertise (Chi, Farr, & Glaser, 1988). In contrast, novices are less likely to reason and organize abstractly in the domain, fail to recognize patterns, and rely on

concrete representations (Miller & Perlis, 1997). Thus, simply transmitting expert knowledge to novices is likely to yield errors.

Overall, in the context of the current JITS system user guidance is implemented as context dependent recommendations about the next step in the procedure that needs to be taken to achieve satisfactory performance. In addition, the system supports decision making at decision points in the protocol by highlighting the correct protocol branch. Novice decision-makers tend to be overwhelmed when provided with multiple alternatives. By highlighting the recommended course of action the cognitive load is reduced and no alternatives have to be evaluated requiring careful assessment of the current situation.

A schematic overview of the Just-In-Time system that was evaluated in the experimental study is illustrate in Figure 1 below.
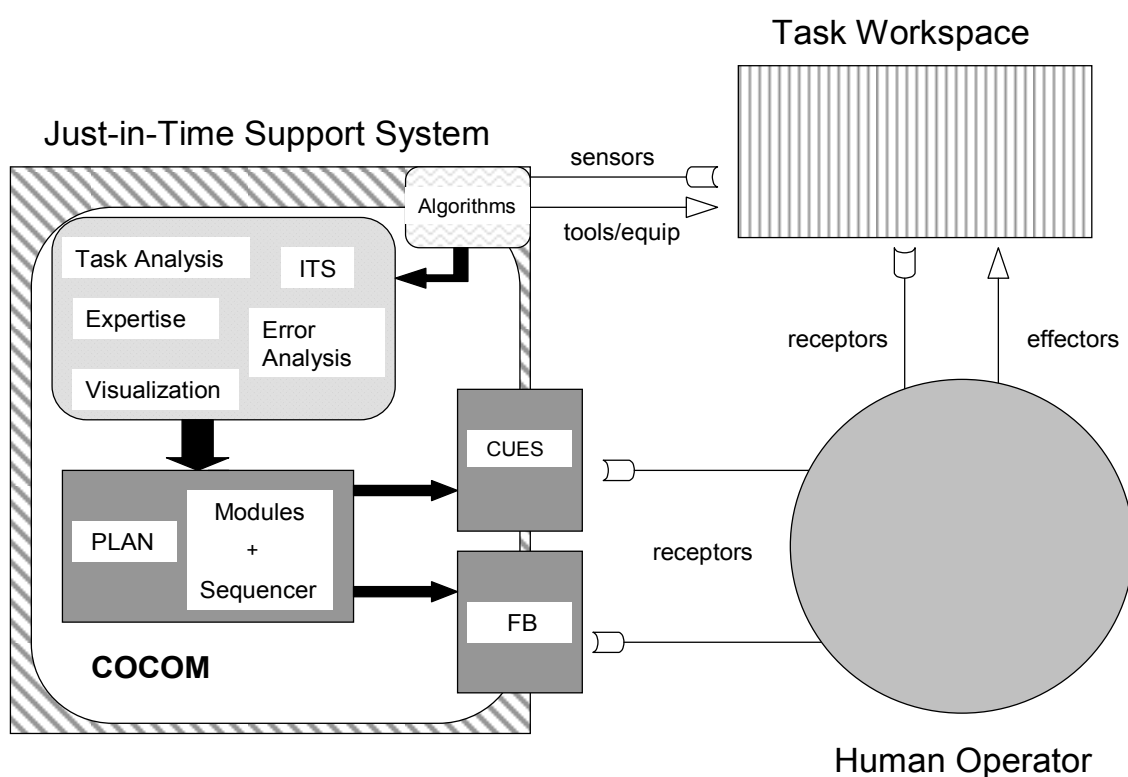
Fig. 1. Schematic of a Just-in-Time Support System.

2. Methods

The experimental study used a randomized 3 (training) x 2 (device) nested factorial design. Naïve participants received one of three training programs and returned 2 weeks later to complete the experimental procedure in one of the two conditions (either with or without device assistance). Device-based sensors collected multiple measures providing means to analyze participant performance during the assessment phase.

2.1 Participants

A total of 100 participants took part in the study. The participants were largely members of the University of Utah community. The mean age for participants was 22.6 (SD=6.7) years. Because of the focus of the study, it was a requirement that participants did not have knowledge in CPR or first aid. Forty-five participants claimed prior CPR training with a mean of 6.5 years (SD=6.5) since the training (it is common that high school students from the area receive a training class however, it does not result in certification). A questionnaire was administered with the goal to screen for the extent of CPR knowledge. The researchers asked if participants had been trained in CPR or with an AED and asked basic skill questions such as the ABCs of CPR. None of the participants was able to answer all of the knowledge questions correctly. Correct answer of all of the simple questions would have resulted in exclusion from participation in the study.

2.2 Training

Three different training conditions were utilized in the experiment. The "CPR" training consisted of a slightly modified version of the American Heart Association (AHA) protocol. The modifications included dropping portions of the procedure including checking for pulse and calling for help as these were not emphasized in the present study. Two groups of twenty (total 40) participants received CPR training. Twenty (20) more participants received "device" training (*DEV-DEV* in Table 4) mirroring CPR training and incorporating the device into the instruction process. A registered nurse administered the CPR and device training. Prior to completing the training, each individual demonstrated aptitude to an adequate level and trained to criteria. Finally, two more groups (20 per group) trained in a fashion unrelated to the task. The experimental design called for two control groups in which no task relevant training was given. These participants learned strategies to improve verbal scores on the graduate record examination (GRE). *Table 4* provides a visual representation of the design and names the groups according to experimental condition.

N=100		no device	device
Training	**CPR trained (n=60 total)**	*GRE-NO (n=20)*	*CPR-DEV (n=20) / DEV-DEV (n=20)*
	GRE trained (n=40 total)	*GRE-NO (n=20)*	*GRE-DEV (n=20)*

Table 4. Experimental Design.

2.3 Apparatus

The JITS device aims at providing a means for novice users to perform effective CPR and defibrillation tasks. Based on the American Heart Association (AHA) protocol from 2006, the device delivered instructions crafted for novice understanding via visual and auditory prompts. Utilizing smart sensors and algorithms, the device assessed user actions and customized feedback to guide and ultimately improve performance. For example, if the sensors detected the chest compressions were too shallow and too slow, it prompted the user to "push harder" and "push faster" for the next set of compressions. The sensors not only drove feedback algorithms but also collected data on task performance. In addition to relieving many cognitive burdens, there were also engineered improvements such as the integrated headrest and mask. Pre-experiment investigation revealed many novice responders had difficulty maintaining an open airway while giving breaths. The headrest

was designed to ensure victim head-tilt to keep the airway open without requiring the responder to manually perform the task each time while giving breaths. *Figure 2* shows the device in use.
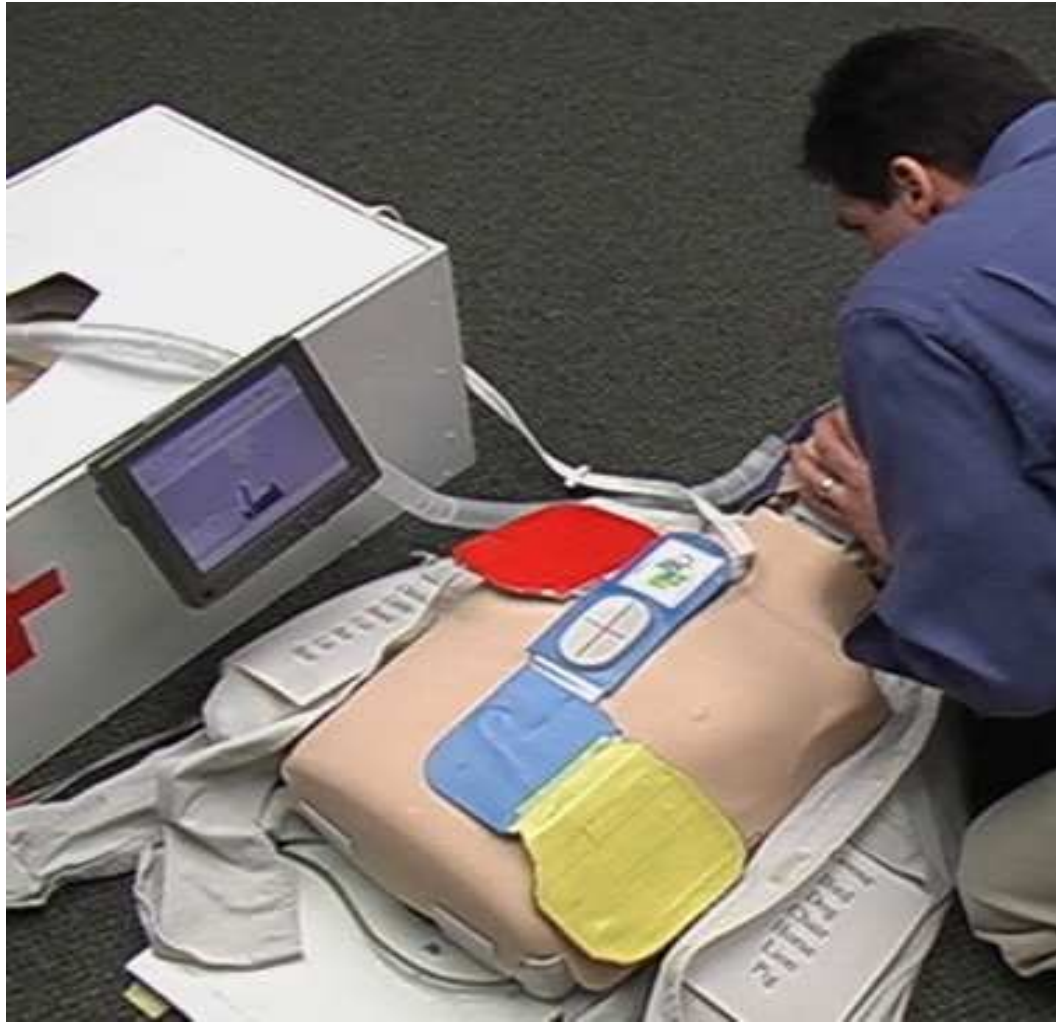

Fig. 2. The device in use on training mannequin.

The system provided the first visual and auditory cues to initiate the actions of the novice responder. The system governed the pace and content in accord with the operator performance by monitoring changes in the task space (i.e. tool placement, flow meter readings). For example, the instructions required for rescue breaths were withheld until the system recognized correct head placement. Pressure sensor in the headrest determined the placement of the victim's head. The system managed the action plan and provided the user simple, actionable commands.

After giving simple instructions and monitoring performance, the system then provided feedback if necessary. For example, after placing the mask, the system stated 'give two breaths" and provided an animation demonstrating the proper method. Then the sensors actively monitored the inspired volume of air into the lungs. If the rescuer delivered insufficient volumes, instead of moving to the next step, the system encouraged the responder to "give two large breaths". Feedback of this kind was critical in elevating and stabilizing performance early in the scenario.

A headrest, anesthesia breathing mask (with one-way valve), and defibrillator pads from Zoll's AED-plus®, and Lilliput® 8-inch touch screen LCD served as the tools available to the responders in the "device" condition (Figure 3.). The headrest was customized from foam. Two pressure sensors were inserted at the neck and in the center of the bowl of the headrest (in order to detect proper head placement). The mask apparatus consisted of a standard anesthesia mask, bacteria filter and a one-way valve (directs victim's exhalation away from the responder).

A desktop and a laptop computer provided the computing resources for generating the displayed animations and auditory cues as well as collecting data from: two Novametrix Medical Systems, Inc. CO_2SMO Plus flow monitors (one inside the mannequin, a second externally in the mask); pressure sensors (headrest), and linear potentiometer placed on the spring inside the mannequin.

The signals collected from the sensors were converted by a PMD 1208 LS, Measurement Computing Systems analog-to-digital converter. All software was written in C++. A Laerdal Medical Little Annie® mannequin portrayed the victim for each responder. The mouthpiece was exchanged and discarded for every responder while the bacteria filter and mannequin "lungs" were replaced every five participants or fewer as needed.
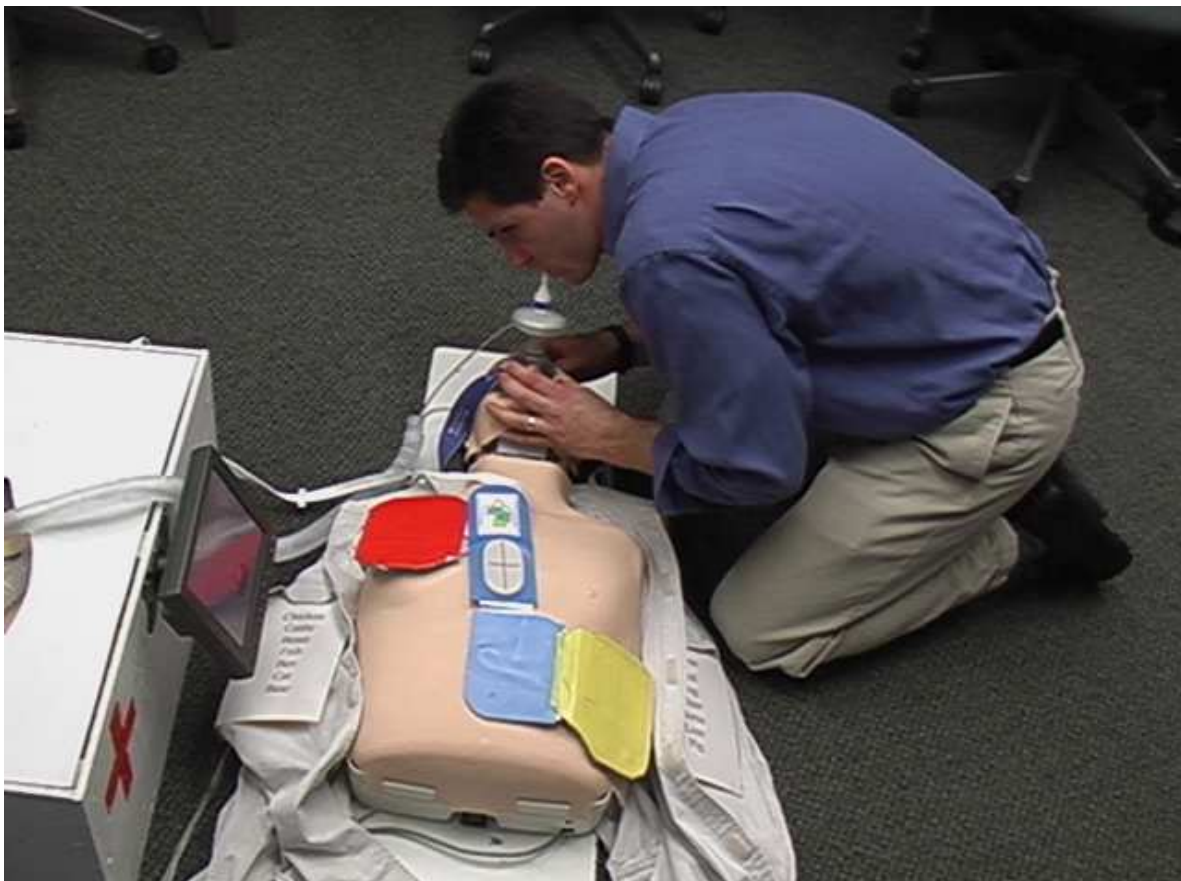

Fig. 3. Components of the device.

2.4 Procedure

Training sessions were offered at various times and locations for a period of 90 days. Participants were blinded to the type of training they would undergo. After the group

training session, each individual was to schedule a testing date a minimum of fourteen days to a maximum of twenty-one days after training. Participants' self selection of training and experimental times contributed to the randomization process.

Upon returning for the experimental session the experimenter ensured consent forms were completed, verified previous training, and read the participant the appropriate instructions. All participants were informed that they would enter a room with an unconscious victim (no breathing, no pulse). Their task was to perform CPR until help arrived (the victim would remain unconsciousness for the entire scenario).

The groups that were not utilizing the device were informed that "tools" would be available adjacent to the victim. These included a mask for ventilating the victim as well as pads associated with the defibrillator. The components were identical to those available in the device condition.

The device group had the added benefit of the headrest and of course, the protocol, audio and visual cues and feedback presented by the device. Pre-experiment instructions encouraged device-group participants "…to follow the instructions of the device as closely as possible". A still frame of the video instruction to place the headrest is displayed in *Figure 4*.

Fig. 4. Screenshot of video instruction "place headrest".

After completing the scenario, the researcher praised the efforts of the participants and reassured them it was simply a simulation with an inanimate object. The debriefing also included a survey to assess actions and a number of variables that based on COCOM should be sensitive to differences between groups. Finally participants were thanked for their time and paid $30.

2.5 Coder training

Research assistants coded participant behavior based on a number of categories for each of the steps of performing the task of providing CPR. Participant activities were coded as falling into one of the categories based on Hollnagel's COCOM model.

	Control mode (COCOM)		
	Scrambled	Opportunistic	Tactical
Mask	no two hand use of mask	Two hand use, with effective seal	Two hand use (anesthesia based) with effective seal
Breaths	audible leak	give when system commands	look for chest rise while giving
Chest compressions	One handed; wrong grip	Chest compressions with beeps	15 consistent chest compressions (despite beeps)
Body	excessive move (waist shoulders)	looks @ screen	little movement to accomplish
Verbal comments by participants	"what"/"how to do ….?"; expression of frustration	Comments expressing insights e.g., "Oh", "Ahh"	count out loud; articulate plan
Start/Stop	begin action- without finish (correct)	system interrupt; follow system	ignore system to perform correct
Tools	fail to use; explore; search; can't find immediately	used on command	use correct without prompt anticipate
Pads	don't use pads at all	watch screen for placement of pads	place pads without looking at screen; correct placement before or without cue or feedback

Table 5. Coding of performance based on COCOM.

2.6 Post experimental questionnaire

To identify group based differences on subjective measures like action selection, utilization of cues and feedback, determination of outcomes, goal setting, and time pressure a post-experimental questionnaire was applied. For example, to assess the perception of feedback in the scenario participants were asked to rate on a 10 point scale how effective feedback was ranging from a value of 1 – I did not receive feedback to a value of 10 – feedback was helpful. The basic assumption is that participants in the different experimental conditions should be sensitive to differences in manipulation based on predictions from COCOM and these differences should be reflected in measures like action selection, utilization of feedback, determination of outcomes, goal setting and subjective time-pressure since they are sensitive to the level of control of a participant.

3. Results

3.1 Control modes

Four trained coders who were blinded to the hypotheses of the study performed the control mode analyses. After each coder succeeded in a 4 hour training that familiarized them with the categories and their definitions, they were tested on example videos that represented samples of the observation study. Each coder was trained until they reached 95% accuracy of detecting and coding behavior as specified in the definitions. Next, in a different session they were instructed on how to review the video recordings and who to record their observations to the data sheet. Inter-rater reliability was assessed with Cohen's Kappa (Kappa = 0.899). This kappa value is well above the commonly accepted 0.70 level threshold validating the use of the coding results.

Table 2 summarizes the proportion of actions by mode for each participant group. A multivariate analysis of the control mode data resulted in a significant difference for experimental group (Wilks'Lambda = 0.049, approximate $F(12, 246.3) = 43.6$, $p < 0.001$). Next univariate and post-hoc Scheffe tests were conducted to analyze the overall finding in more detail. The results of these analyses are discussed in the sections below.

Group	%Scrambled	%Opportunistic	%Tactical
GRE-NO	90(12)	4(7)	5(7)
GRE-DEV	30(15)	66(15)	4(8)
CPR-NO	19(22)	16(7)	64(25)
CPR-DEV	17(12)	62(16)	21(17)
DEV-DEV	15(9)	60(10)	24(12)

Table 6. Group means for COCOM classification (in percent). Standard deviations in parentheses.

In a comprehensive analysis that categorized participants as being in a particular mode of control based on the median of their actions falling within one of the three control modes, all of the participants in the *GRE-NO* group were classified as performing in the scrambled control mode at the aggregated level. A more detailed analysis of the average percentage of actions across the group and not based on individuals falling into one of the three control modes revealed that almost all of the actions of participants in this condition were classified as displaying scrambled behavior (M = 90%, SD = 12%). Post-hoc comparisons revealed the 90% mean for *GRE-NO* was significantly higher compared to scrambled mode scores for all other groups ($p < 0.001$) (see Figure 5).
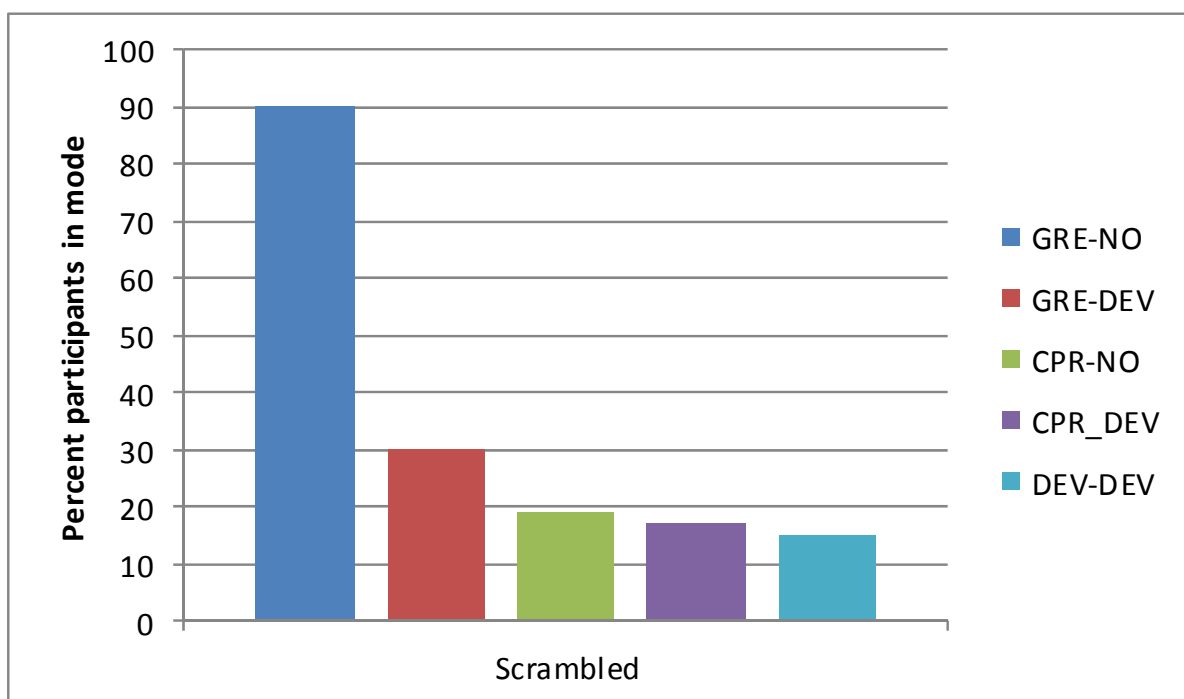

Fig. 5. Scrambled control mode for all experimental conditions.

In contrast to the *GRE-NO* group of participants, participants in the *GRE-DEV* condition benefited from the provisions of plans, cues, and feedback and demonstrated an opportunistic control mode. Overall, only two participants (10%) in this group were classified as acting at the scrambled level of behavior, while all other participants in this group performed in an opportunistic mode of control. In a more detailed analysis focusing on individual actions, the *GRE-DEV* group posted the highest proportion of opportunistic behaviors (M = 66%, SD =15%) (see *Figure 6*). Post-hoc tests demonstrated that this percentage was significantly higher than the two non-device groups ($p < 0.001$) but not statistically different from the other two device groups ($p \geq 0.658$). Most of *GRE-DEV*'s remaining actions (M = 30%, SD = 15%) resembled a scrambled mode of control (see *Figure 5*).
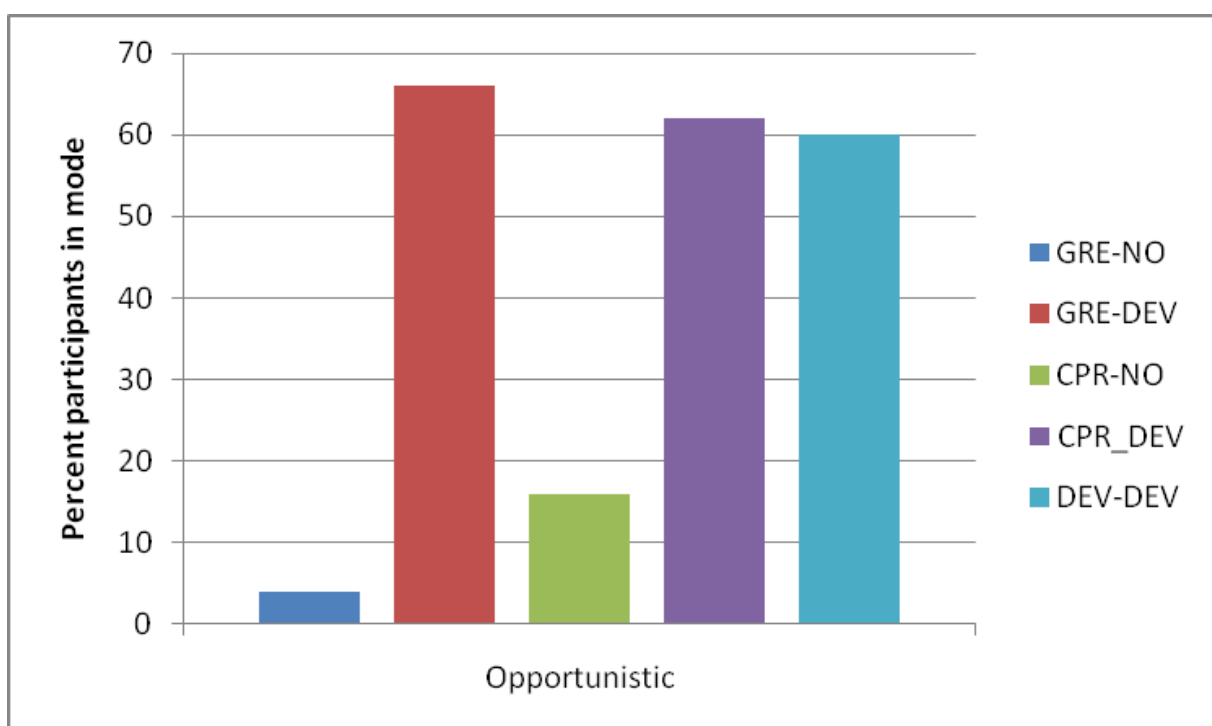
Fig. 6. Opportunistic control mode for all experimental conditions.

The *CPR-NO* group consisted of well trained but unsupported (no plan, cues, or feedback) participants, relying on knowledge retrieval based on their previous training to perform the task. Adequate performance given the background of participants should facilitate a tactical control mode, which is supported by the data (*Figure 7*). Overall of the twenty participants in the *CPR-NO* group, eighteen were classified as acting at the tactical level, and only two participants were coded as performing at the scrambled level of control. When analyzing individual actions at the group level, actions that were classified as being representative for tactical control accounted for the majority (M = 64%, SD = 25%) of their activity, which is significantly higher than any other group ($p < 0.001$). In addition, this group's opportunistic control mode score (M = 16%, SD = 7%) was significantly lower than the three device groups ($p < 0.001$), and the *CPR-NO's* scrambled score (M = 19%, SD = 22%) was comparable to the three device groups and reveals that participants in all groups made some errors when performing the task.

The device clearly captured participant's attention in the *CPR-DEV* group where 16 participants' actions were classified as falling into the opportunistic mode of control, three participants were classified as acting in the tactical control mode, and one participant was performing in the scrambled control mode. Again, the three device groups did not differ significantly in their opportunistic scores (p $\geq$ 0.658), nor scrambled scores (p $\geq$ 0.074), but *GRE-DEV* did lag the other two groups in tactical actions (p $\leq$ 0.026).

Finally, analyzing the performance in the *DEV-DEV* group revealed that at the aggregated level, all 20 participants in *DEV-DEV* group were classified as performing at the opportunistic mode of control. This overall performance is also reflected in the fact that the analysis of individual actions revealed that the majority of actions were performed at the opportunistic control mode, approximately 20 % of the actions were performed in the tactical control mode, and the fewest number of all actions of all groups was performed in the scrambled mode of control.
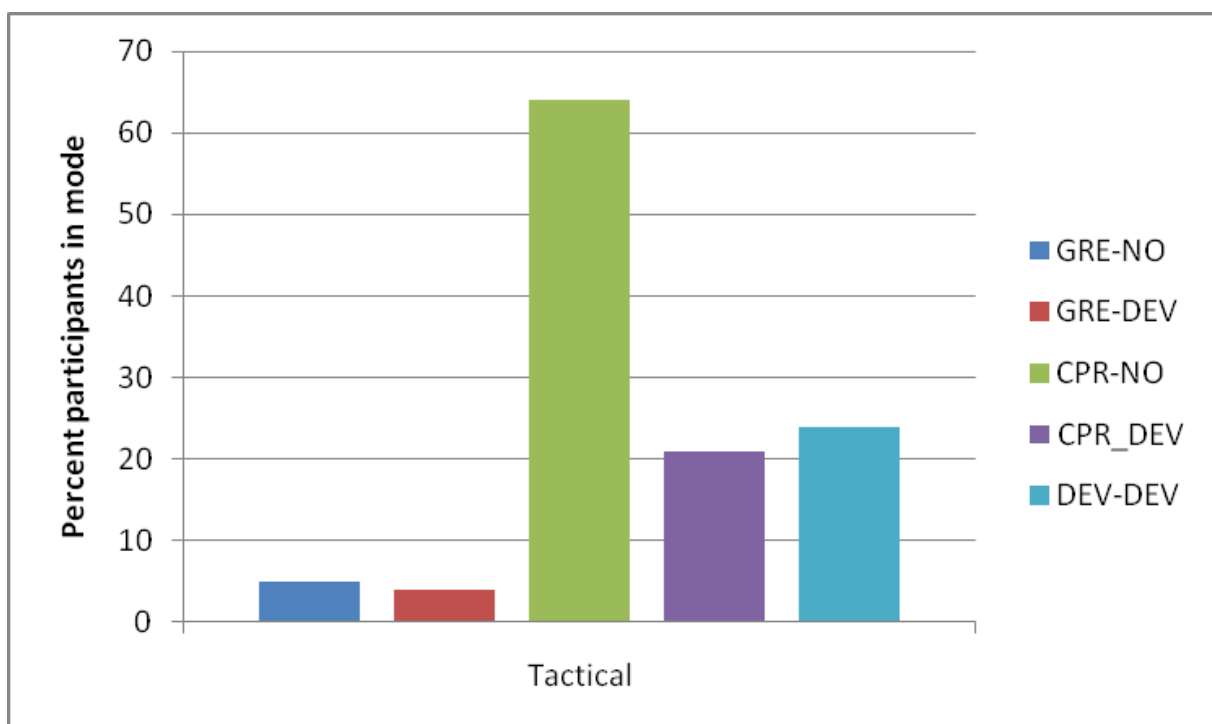
Fig. 7. Tactical control mode for all experimental conditions.

3.2 Protocol compliance

Another analysis focused specifically at the subtasks that were classified as necessary to comply with the American Heart Association's CPR protocol. Specific comparisons between each experimental condition were performed to identify the degree of compliance with these steps. For this purpose, the number of correctly completed steps achieved by each participant was recorded. The analysis was confined to only the first cycle of providing CPR since one of the constraints of these tasks is that all tasks must be completed the first time through the procedure. For example, if the pads are placed in the first cycle, there is no need to complete that step in each cycle. Subsequently, only a subset of the tasks was repeated.

Again, two trained coders (same training procedure as described above applied) independently evaluated each action on the video recordings and determined if participants

correctly completed the required nine activities. Of the 900 judgments, only 19 discrepancies between the coders emerged resulting in high concurrence between the raters (agreement exceeded 97.8%). *Table 7* contains the number of protocol steps each group performed correctly.

Experimental group	GRE-NO (GRE training – no device)	GRE-DEV (GRE training – device)	CPR-NO (CPR training – no device)	CPR-DEV (CPR training – device)	DEV-DEV (device training – device)
MEAN	1.6 (1.46)	7.80 (1.05)	7.85 (1.49)	8.45 (0.88)	8.65 (0.49)

Table 7. Mean number of protocol steps executed correctly (9 max) standard deviation in parentheses.
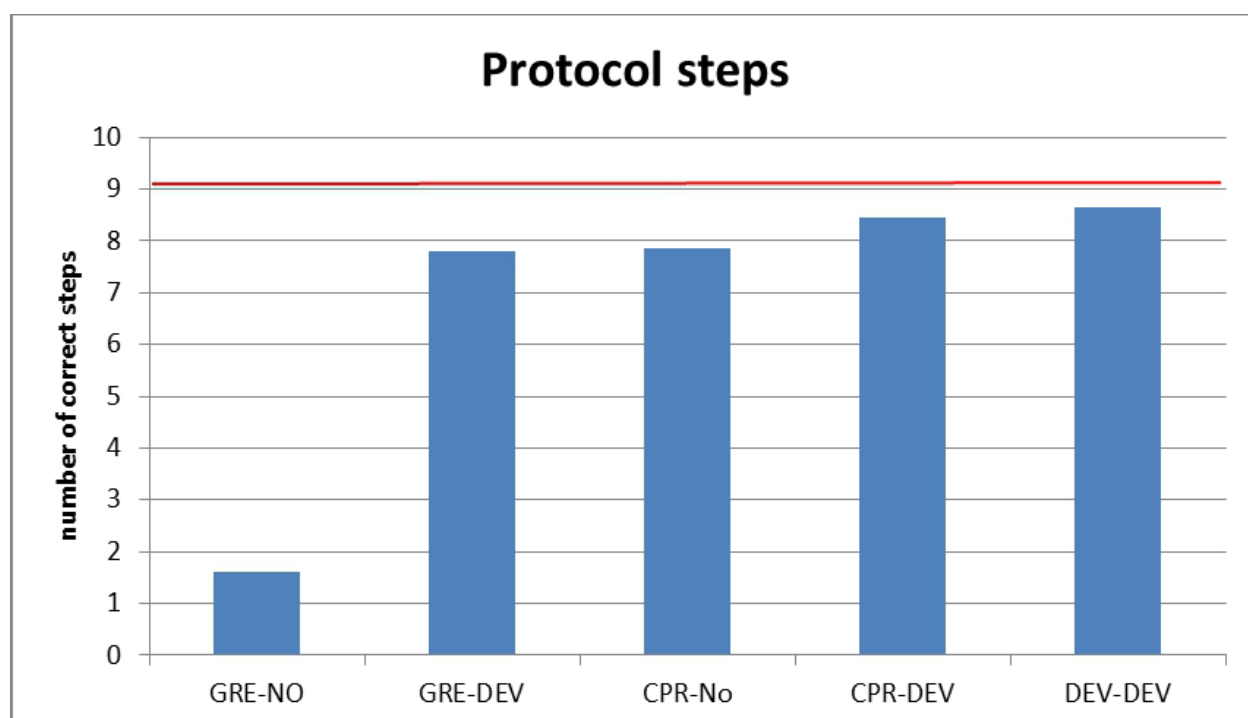
Fig. 8. Average number of correctly performed steps in accordance with the AHA protocol for each experimental condition. The red line indicates perfect performance.

Statistical analyses revealed that the group means were significantly different ($F_{(4,95)} = 135$, $p < 0.001$) overall (see Figure 8). Post-hoc comparisons indicated that the *GRE-NO* was unable to accomplish most subtasks that are critical to CPR and defibrillation ($p < 0.001$). Interestingly, there was no difference in performance between any of the other four experimental groups. All of these groups were able to complete the required steps at a level of performance that is statistically not different. Finally, inspection of the standard deviation for each group indicates that the DEV-DEV had the smallest level of variation, where GRE-NO and CPR-NO had high levels of performance related variability between participants within each group. Overall, this descriptive finding indicates that external guidance in the DEV-DEV supported standardization of performance, where the two groups that had no such guidance available were more heterogeneous in terms of compliance with the AHA required steps.

3.3 Post experimental survey data

The post-experimental questionnaire served as yet another instrument employed to assess the bounds of control mode categories and provided converging evidence for the hypothesis that the different experimental conditions lead to differences in control mode. The survey instrument utilized multiple scales to represent different COCOM parameters. Specifically, scales represented action selection, utilization of cues and feedback, determination of outcomes, for goal setting, and time pressure. The inquiries concerning action drivers (includes cues), feedback utilization, and outcome determination yielded results consistent with hypotheses

In general, participants in the *GRE-NO* condition exhibited a scrambled control mode as they reported no use of *feedback* and minimal determination of the *outcome*. Participants in the *GRE-DEV* condition showed a high reliance on *cues* and *feedback* where participants in the *CPR-NO* condition ranked *feedback* very low and recorded the highest *action* score avowing their use of a memorized plan to drive their actions. All of these findings are consistent with predictions based on COCOM. However, inconsistent with COCOM predictions the survey results concerning subjective time pressure were not supportive of COCOM predictions. According to the COCOM, operators in scrambled mode have a proclivity to perceive an enormous limit of the time for action available, however, there was no difference between groups (F<1). The lack of a difference between groups can potentially be attributed to the fact that the scenario length was relatively high (more than 5 minutes). Thus the available time may have subjectively felt as being sufficient and superseded any time pressure participants may have experienced at the start of the scenario.

4. Discussion

4.1 COCOM and JITS

The vision of the JITS framework is to provide guidance for the development of systems that are capable of enhancing user performance as operators confront unfamiliar tasks that require immediate intervention by a task novice. Based on the findings of the present study there is support for the idea that the JITS accomplishes this challenge by providing adaptive plans, cues, and feedback tailored to the user's understanding. System flexibility is required to adapt to dynamic contextual conditions as well as user behavior.

The basis for the COCOM-derived dependent measures reside in Hollnagel's mode characteristics. Each of the subtasks when providing CPR (i.e. holding mask, placing pads, delivering compressions) provided subtleties for control mode classification. For example, one technique for holding the mask was the anesthesia-style hold taught in training. This grip exemplified tactical control as it demonstrated knowledge retention and skill.

Overall, the *GRE-NO group* performed 90% of their actions in scrambled mode. All 20 participants coded as scrambled overall for the scenario. Based on the fact that they had neither skills nor knowledge to employ, there was little probability they could perform in any other manner. The *CPR-NO* group demonstrated tactical control a majority of the time (64%). However, their erroneous behavior was highlighted by 20% of their actions being coded as scrambled and 60% of the responders failing to properly sequence the subtasks. Examining the device groups, *GRE-DEV* was hypothesized to demonstrate opportunistic control and the data of this study support that claim. Sixty-six percent of the actions of

participants in this group were coded as opportunistic. Participants also made some mistakes as evidenced by 30% of their actions classified as scrambled. Observation of their performance indicated that many of the mistakes occurred early in the scenario. Anecdotal examples include some confusion while searching for the mask, and giving compressions with the wrong grip and compressing much more slowly than the required pace. Most device-aided participants corrected their actions in the subsequent CPR cycles after receiving feedback.

Trained groups using the device also demonstrated control profiles easily adapted to the COCOM paradigm. At first glance, their training should have enabled them to demonstrate some tactical mode characteristics. Nonetheless, the presence of the system would likely drive their actions in the direction of opportunistic control. The question to be determined empirically was related to the proportion of opportunistic to tactical methods. Each *trained-device* group performed roughly 20% - 25% of their actions in tactical mode and more than 60% in opportunistic. Two factors are most plausible for generating this distribution. First, the system was explicitly designed to seize attention and engage the operator throughout the scenario. Second, with what can be considered limited training and practice, most operators would likely defer to the system for expertise.

In general, *GRE-NO* exhibited a scrambled control mode as they reported no use of *feedback* and minimal determination of the *outcome*. *GRE-DEV* showed a high reliance on *cues* and *feedback*. *CPR-NO* ranked *feedback* very low and recorded the highest *action* score avowing their use of a memorized plan to drive their actions. One disappointment in the survey results came from the *time pressure* scale. According to the COCOM, operators in scrambled mode have a proclivity to perceive an enormous limit of the time available. However, due to the length of the scenario and lack of purposeful activity, five minutes probably felt like a long time superseding any time pressure they may have experienced at the start of the scenario (it did to the researchers watching them struggle).

To conclude, there are many advantages to widespread deployment of such a system. The delay in getting professional responders to the scene is well documented. Precious moments are lost in transport. Additionally, it has been shown that even when they arrive, they are not performing optimally. Based on the results of the present study, it clearly is possible to develop novice supportive technology that is based on Human Factors principles. Such technology not only will be user friendly, for example support users to use defibrillators more effectively, but ultimately save lives.

The leading question of this work was, is it possible to identify indicators of performance that help understand how to better design systems that provide instructions at the time when need is greatest. Thus, after describing COCOM, we outlined the Just-in-Time Support framework, described an implementation of this framework in the context of providing CPR, and provided data in support of the hypothesis that human factors driven implementation of just in time support technology can guide performance of novices.

In addition, the present work represents one of the earliest applications of COCOM to generate dependent measures sufficiently robust for quantitative analysis. Very few researchers attempted to test COCOM predictions in such a manner largely due to the inchoate bounds of control modes and an inability to derive cogent measures. Stanton, Ashleigh, Roberts, and Xu, (2001) provided the first empirical support for COCOM hypotheses. However, the process of coding behavior was lacking some of the necessary rigor to allow generalizable inferences based on this work.

4.2 Conclusions

This work demonstrates in the context of a complex task that it is possible to develop Just-in-Time Systems that are capable of instructing a task novice in performing a task at a level that suffices in terms of outcomes. Clearly, this needs to be the main goal when the alternative is scrambled behaviour of a person without instruction or knowledge, that is likely to do more harm than good. In addition, there are a number of contexts where systems that follow the guidance of COCOM in determining how to effectively guide an operator can be of use. Among those context is certainly the use of defibrillators, and especially systems where guidance needs to be tailored to users who due to a number of factors (e.g., age) are not performing at the highest possible cognitive level and are in need of support.

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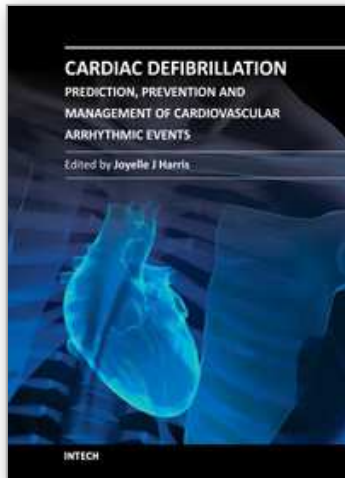
Cardiac Defibrillation - Prediction, Prevention and Management of Cardiovascular Arrhythmic Events

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Millions of people throughout the world currently depend on appropriate, timely shocks from implantable cardioverter defibrillators (ICDs) to avoid sudden death due to cardiovascular malfunctions. Therefore, information regarding the use, applications, and clinical relevance of ICDs is imperative for expanding the body of knowledge used to prevent and manage fatal cardiovascular behavior. As such, the apt and timely research contained in this book will prove both relevant to current ICD usage and valuable in helping advance ICD technology. This book is divided into three comprehensive sections in order to cover several areas of ICD research. The first section introduces defibrillator technology, discusses determinants for successful defibrillation, and explores assessments of patients who receive defibrillation. The next section talks about predicting, preventing, and managing near catastrophic cardiovascular events, and research presented in the final section examine special cases in ICD patients and explore information that can be learned through clinical trial examinations of patients with defibrillators. Each chapter of this book will help answer critical questions about ICDs.

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