Staying Alive With Virtual Humans

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Abstract
Current at-home cardiopulmonary resuscitation (CPR) training systems are limited by the feedback they provide. Virtual trainers have the potential to enhance feedback in CPR training systems by providing real-time demonstrations. We developed CPRBuddy, a CPR training system that uses a virtual trainer to emulate a live trainer to automatically provide powerful feedback. CPRBuddy was evaluated via a user study consisting of 9 participants comparing CPR compressions both with and without feedback from CPRBuddy. We found that CPRBuddy's demonstrative feedback has potential to improve the immediate performance of CPR, e.g., compression depth, frequency, and recoil. This work contributes towards the design of avatars for training.

Author Keywords
Virtual trainer; multimodal feedback; cardiopulmonary resuscitation (CPR).

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction
Avatars enhance many applications by providing nonverbal communication (i.e., the expression of ideas and thoughts without verbalization) including improving virtual-human-based training systems (e.g., [17]) and

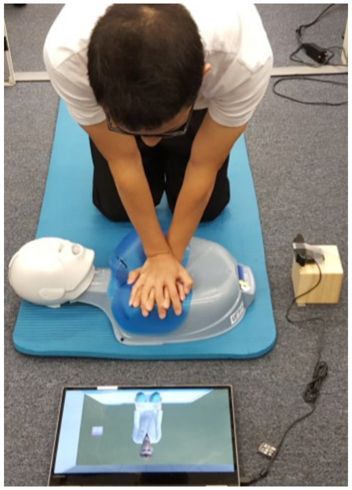


Figure 1. CPRBuddy in use.

Figure 2. CPRBuddy's components.

have the potential to enhance many new applications (e.g., cardiopulmonary resuscitation (CPR) training systems). Virtual humans have been used as viable alternatives to real humans in the medical field, for applications ranging from teaching communication skills [17] to coaching physical exercises [19]. These virtual trainers often communicate multimodally to emulate a range of real human behaviors, providing expressive verbal and gestural feedback to users in real-time.

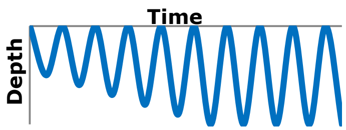
Our goal was to develop a virtual trainer that emulates real tutors during CPR training scenarios, removing the need for an actual human. To do this, we developed CPRBuddy (Figure 1), a vision-based training system that automatically provides audio and gestural feedback using an avatar to train lay people in hands-only CPR. We focused our efforts on hands-only CPR training because of its potential for saving lives. Out-of-hospital cardiac arrests are responsible for the deaths of more than 350,000 people in the United States [3] and 40% of deaths in adults younger than 75 in Europe [14] every year. CPR performed by bystanders saved thousands experiencing out-of-hospital cardiac arrests in 2015 [6]. CPR is also effective when performed using hands-only [12]. Thus, training everyone to perform hands-only CPR is vital. There are advantages to the use of a virtual trainer for CPR: a real trainer may not be able to judge compression quality as accurately as a CPR measurement device [8] and simulations are beneficial for psychomotor-cognitive tasks [15]. Also, use of a virtual trainer facilitates training large amounts of people with minimal supervision.

Several CPR training systems (e.g., [1,5,7,13]) have been created that provide rich audio and visual feedback to the user. Audio feedback consists of corrective voice messages that instruct the user in how to improve the way they are performing CPR as well as messages that notify the user that they are performing CPR correctly [1,5,7,13]. Visual feedback includes LED lights [1,5], black bars that show chest compression depth [13], and a graphical display that "fills" as compression quality is optimal and remains optimal [7]. These studies reported positive outcomes with regards to improving CPR skills (e.g., chest compressions [1,5,7,13] and hand position [13]).

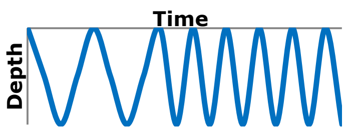
Existing virtual reality and augmented reality systems for CPR training have either focused on alternative methods for presenting the same type of feedback provided by physical systems [10,18] or simple displays of the patient's cardiac rhythm [20]. Thus, current systems lack the demonstrative feedback that a live trainer provides by only illustrating the user's performance without demonstrating correct technique and providing little guidance on how to improve compressions to reach the proper technique.

In contrast, CPRBuddy uses demonstrative gestures, which are shown to be beneficial in human-human interactions [9], during periodic feedback to both emulate the user's actual performance and guide the user toward the correct technique [3], with the goal to facilitate learning. This visual feedback is accompanied by corrective audio feedback.

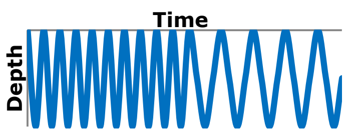
We investigated CPRBuddy as a training tool by conducting a user study with 9 adults. We assessed learning hands-only CPR by evaluating performance (e.g., chest compression depth, rate, and recoil—the distance the chest rose after compression) both before (without feedback) and after training with an avatar



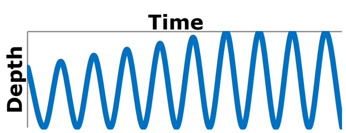
(a) Too Shallow



(b) Too Slow



(c) Too Fast



(d) Insufficient Recoil

Figure 3. Compression motion, i.e., the up-and-down motion that the avatar's hands make while performing compression gestures.

giving demonstrative gestures. Findings from our evaluation show that the feedback provided by CPRBuddy improved the immediate performance of CPR. Thus, the primary contribution of our work is the design of a virtual trainer for training CPR.

Designing CPRBuddy

We designed our feedback to meet the following goals:
(G1) Diagnose errors in CPR performance.
(G2) Mimic feedback performed by human trainers.

Concept

To address our goals, we developed a concept focused on real-time feedback, which allowed users to correct their technique while performing hands-only CPR on a Actar D-Fib CPR/AED Manikin (Fig. 1) and contained a reference that users could compare their chest compressions to. This reference consisted of the avatar using gestures to demonstrate correct compression (rate, recoil, and depth) in mid-air (Fig. 4). Every 5 seconds CPRBuddy used computer vision techniques and a tracking sticker to evaluate the user's hands-only CPR performance and categorize this 5-second window into one of five different states. These are listed in order of priority: too shallow, too slow, too fast, insufficient recoil, correct. Like Wik et al [21], we focus on correcting depth first, before rate or recoil. Warnings regarding compressions that are too deep were omitted due to lack of evidence that they cause damage [14]. Thresholds for correct chest compression technique were determined by the American Heart Association's (AHA) official guidelines [3]. CPRBuddy's margins for error are comparable to those of CPRmeter [16], an accepted CPR feedback device.

Since too much feedback can exceed a user's ability to understand and react [11], CPRBuddy's feedback was designed to be minimal. Feedback was limited to a short speech clip that informed the user how to correct their problem simultaneously given while an avatar performed gestures. Incorrect compressions resulted in the avatar mimicking the user's incorrect action and then smoothly transitioning to a correct example, which highlighted what the user needed to do differently to improve. If CPRBuddy only displayed correct compressions, it would be difficult for the user to gauge the actual depth, as the avatar would need to be scaled up and calibrated to real-world dimensions. Correct compressions resulted in a "thumbs up" gesture. Each state is described below and the corresponding feedback shown in Fig. 3:

- **Too Shallow.** When the average compression depth was < 1.95 in. (2 in. recommended depth with a margin of error of 0.05 in.). The avatar said *"Push harder to around 2 inches into the chest"* while gesturing.
- **Too Slow.** When the average compression rate was < 95 compressions per minute (CPM) (100 CPM recommended minimum rate – 5 CPM margin of error). The avatar said *"Speed up to a rate of 100 beats per minute"* while gesturing.
- **Too Fast.** When the average compression rate was > 125 CPM (120 CPM recommended maximum rate + 5 CPM margin of error). The avatar said *"Slow down to a rate of 100 beats per minute"* while gesturing.
- **Insufficient Recoil.** When the chest did not return to < 0.3 in. from the origin between compressions (0 in recommended recoil depth – 0.3 in margin of

Figure 4. Avatar's posture while giving compression feedback.

Figure 5. Thumbs up gesture.

error). The avatar said *"Let the chest rise all the way between compressions"* while gesturing.

- **Correct.** When compressions had the correct depth, rate and recoil. The avatar said *"Correct"* or *"Good"* while performing the "thumbs-up" gesture.

CPRBuddy's avatar was developed using Unity3D, with the vision tracking component developed in Python and utilizing OpenCV. CPRBuddy tracks the movement of a sticker placed on the side of a user's wrist and uses this to determine how far down they press on the manikin's chest and how much time elapses between each compression. More implementation details and videos are available at https://github.com/Isaac-W/cpr-vision-measurement. See Fig. 2 for CPRBuddy's components.

Evaluating CPRBuddy

CPRBuddy's feedback on CPR performance was evaluated via a lab-based study. Nine participants aged 19–26 years old (μ=21.78, SD=2.44, four female) were recruited from a local university. Participants were fluent in English, the language in which the feedback was provided. No participants had CPR certification, had taken a CPR course within the last 2 years, or had ever performed CPR in an emergency. Our protocol was approved by our Institutional Review Board.

First, each participant completed all portions of a AHA Heartsaver® CPR AED Online training course that pertained to hands-only CPR [2], as they would in a real at-home training scenario. After an in-person demonstration of hand placement (as specified by the AHA, but with all participants placing their left hand on the bottom to assist with tracking), participants practiced performing hands-only CPR on a manikin for two minutes without feedback for one session of chest compressions. This was done to establish a baseline for comparing their improvement. After a 2-minute break, participants then performed two sessions of chest compressions for two minutes with feedback, each followed by 2 minutes of rest. This mimicked an optimal real-world situation where bystanders take turns performing CPR for two minutes [3]. CPRBuddy ran on a Lenovo Yoga 720 laptop in tablet mode, which was placed on the floor directly in the user's field of view. We recorded the participant's average compression depth, recoil, rate, and correct compression percent.

We asked participants to evaluate CPRBuddy using questions (e.g., questions regarding helpfulness were rated on a scale from "extremely unhelpful" to "extremely helpful") on a visual analog scale that were then quantified on a scale from 0 to 10. We asked participants to evaluate CPRBuddy with regards to: helpfulness; willingness to interact with an avatar again for CPR or for learning a different skill; and likelihood of recommending the system to a friend. We also asked participants to rate their confidence that they would remember the feedback in an emergency. All participants were given verbal feedback at the end of the study based on CPRBuddy's evaluation of their CPR performance. For example, participants were advised to remember the song "Staying Alive" by the Bee Gees when performing chest compressions as the song's beat matches the recommended CPM tempo.

Results and Discussion

Compression Correctness

We computed the percent of correct compressions (PCC) by dividing the number of correct compressions by the total number of compressions. Each participant completed three sessions of chest compressions—the

Session	μ	SD
Baseline	5.77	5.96
Feedback	69.81	22.52

Table 1. Percent of correct compressions for baseline and feedback sessions.

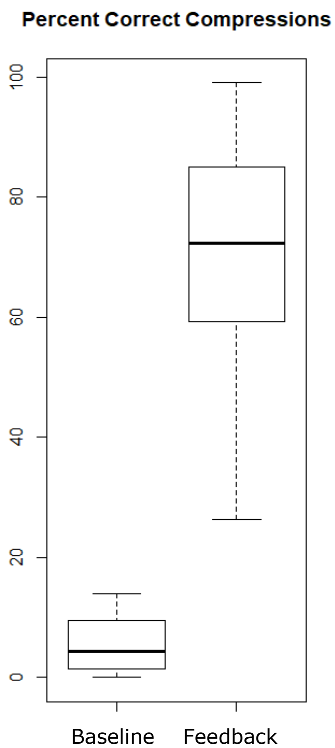


Figure 6. Boxplot of percent of correct compressions for baseline and feedback sessions.

first session without feedback (baseline) and two sessions with feedback. PCC was computed for baseline and both feedback sessions combined. Outliers, as determined by ±1.5 IQR from the median for each session, were removed (6 sessions, for a total of 21 sessions used in analysis). The mean proportion of correct compressions and standard deviations across baseline and feedback sessions is shown in Table 1. Figure 6 contains boxplots of data (PCC) for both baseline and combined feedback sessions. These results show a significant difference between the sessions (One –way ANOVA, $p < 0.001$) indicating that CPRBuddy has potential to drastically improve CPR performance.

Qualitative Results

Participants reported that CPRBuddy was fairly helpful (μ=8.53, SD=1.02) and that they would be likely recommend CPRBuddy to a friend (μ=7.52, SD=1.64). This indicates that a virtual trainer could be considered an acceptable training solution by the general public. They also believed that they were likely to remember CPRBuddy's feedback in an emergency (μ=7.69, SD=2.00), indicating CPRBuddy's effectiveness.

Participants also expressed willingness to use CPRBuddy again for practicing CPR (μ=7.38, SD=1.39) or a similar system for another (unspecified) skill (μ=6.28, SD=2.0). One participant (P2) who gave a low rating for their willingness to use CPRBuddy for another skill indicated that their willingness "depends on the specific skill." This has implications for research that seeks to use virtual trainers for teaching practical skills insomuch that it is clearly vital that designers of such systems carefully determine whether the skill they are attempting to teach is appropriate for use of a virtual trainer.

Conclusion and Future Work

In this abstract, we presented results from a study exploring the use of demonstrative gestural feedback and how it can be utilized as an effective tool in designing virtual-human-based teaching/educational systems in the domain of teaching bystanders hands-only CPR. Future work will include evaluating the effect of CPRBuddy use on CPR skill retention with a larger sample size and compare performance against someone taking instruction from a human trainer. This may include the addition of feedback for more complex skills such as hand placement, communication during a cardiac arrest, and bag-valve-mask ventilation. Finally, further evaluation and development will be done to ensure that CPRBuddy has the most potential societal impact by investigating special populations using the system (e.g., the elderly and people of lower socioeconomic status [4]).

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