BreathEZ: Using Smartwatches to Improve Choking First Aid

Amanda Watson, Gang Zhou

Computer Science Department, College of William and Mary, United States

Abstract

Choking first aid is an important tool for all individuals as choking is the cause of nearly 5,000 deaths per year in the US. Normally for incidents like this, the local emergency medical services (EMS) could be relied up on to respond and provide necessary lifesaving aid. The average EMS response time is almost eight minutes and someone choking only has four to six minutes before permanent brain damage occurs. Cardiopulmonary resuscitation (CPR) trained individuals are often also trained in choking first aid for this very reason, though relying on bystanders presents its own problem. Many individuals assume others will be more qualified to help and therefore will not involve themselves, a psychological phenomenon known as the bystander effect. In order to combat this problem, we present BreathEZ, a smartwatch application that provides both choking first aid instruction and real-time tactile and visual feedback on the quality of the abdominal thrust compressions. To the best of our knowledge, prior to this there has been no feedback device developed that targets choking first aid. BreathEZ uses the onboard accelerometer on an Android smartwatch to identify an abdominal thrust and measure the peak acceleration. It then analyzes the data collected and provides feedback on the quality of the thrust to the user.

Keywords: healthcare, smartwatch, choking first aid, first aid

1. Introduction

According to the National Safety Council, choking is the fourth most likely cause of unintentional injury death accounting for 5,051 deaths in 2017 [1]. Choking incidents cause a medical condition known as cerebral hypoxia and is characterized by a lack of oxygen to the brain and causes tissue damage and cell death in as little as four to six minutes [2]. Since the average emergency medical service (EMS) response time in the US is 7.51 minutes, EMS services cannot be fully relied upon in choking incidents. The quickest possible response would be from a bystander that has been trained in choking first aid.

The rate of cardiopulmonary resuscitation (CPR) trained individuals in US counties ranges from zero to fifteen percent [3] and standard CPR courses often include choking first aid training. Even among those trained in CPR and choking first aid, many individuals will not attempt to intervene during a choking incident due to a phenomenon colloquially called the "bystander effect". The bystander effect occurs when individuals in a group believe that another onlooker must be more qualified than themselves to offer aid and so they refuse to intervene which often results in no aid being provided at all [4]. To help combat this effect, we hypothesize that many would be more comfortable and willing to perform a life saving first aid procedure if they were to receive real-time guidance and encouragement.

Ubiquitous computing devices such as the smartphone and smartwatch may provide an ideal medium for delivering real-time first aid coaching to improve bystander assistance. Current smart devices are equipped with an array of sensors (e.g. accelerometer, gyroscope, etc.) which can be exploited to determine the quality of a bystander's performance of a particular first aid technique in order to provide instant feedback to help and encourage them. Because smartwatches are unobtrusive, easy to use, and readily available on the wrist, they may be particularly effective tools to help bystanders perform choking first aid. Our approach uses only the smartwatch but future work could utilize a network of sensors [5] [6].

We answer the following research questions in this paper:

Email addresses: aawatson@cs.wm.edu (Amanda Watson), gzhou@cs.wm.edu (Gang Zhou)

- How accurately can we classify abdominal thrusts?
- Does the assistance of a smartwatch application that provides live feedback to the user increase the performance of the abdominal thrust portion of choking first aid?
- Does the assistance of a smartwatch application that provides live feedback to the user increase an individual's willingness to perform choking first aid?

To determine how accurately abdominal thrusts can be classified, we collected choking first aid data and used a random forest to classify each abdominal thrust. We collected data by performing three separate user studies, one of which consists of data collected from only those with formal training in choking first aid. We then analyzed the data using the Weka toolkit [7] and found that by using a random forest we could accurately classify abdominal thrusts at a rate of 94.6%.

To understand if a smartwatch application that provides live feedback to the user increases the performance of the abdominal thrust portion of choking first aid, we compared the performance of our participants based on whether they were given a smartwatch application that provides feedback on choking first aid or shown a choking first aid tutorial prior to being asked to perform choking first aid. To accomplish this we develop BreathEZ, a smartwatch application that not only provides real time feedback to a user on choking first aid, but also attempts to combat the bystander effect and provide timely assistance to an individual who is choking. To begin we asked each participant to give their best effort performing choking first aid. Then we split the participants of our final user study into two groups, group 1 was given BreathEZ while group 2 was shown a video tutorial.

To quantify whether people are more willing to perform choking first aid with the use of a smartwatch and decrease their fear of injuring the choking victim, we add questionnaires to our user study. In these questionnaires we ask each participant to quantify their comfort and willingness on a scale of one to five by administering a questionnaire before and after they perform choking first aid. We compared how each group improved and found that while both groups improved, group 1 saw greater improvement in their comfort, willingness, and performance of choking first aid.

To date, a system that monitors and provides feedback on choking first aid has not been developed. Abdominal thrusts combined with back blows is the recommended treatment if someone is choking [8]. Zoll Medical corporation designed a handheld device for first aid training using several accelerometers to monitor abdominal thrusts [9]. To improve the performance of a CPR, Gruernerbl et al [10] developed a smartwatch application that provides live user feedback. Our BreathEZ smartwatch application combines these two approaches by providing live feedback on the abdominal thrust portion of choking first aid. It also goes beyond and provides recommended instructions for choking first aid. Other types of first aid have also been improved with the use of smartwatches, smartphones, and newly developed devices [11] [12][13][14]. An approach of using games to help improve the performance of first aid has also been taken [15] [16].

Our contributions may be summarized as follows:

- We introduce BreathEZ, a smartwatch application that improves choking first aid by providing auditory and tactile feedback to the user and improves bystander performance of abdominal thrusts as part of choking first aid.
- We conducted two user studies with the first comprised of 135 abdominal thrusts from 13 individuals and the second comprised of 100 abdominal thrusts from 10 individuals. Short surveys were administered to gain insight on the viability of using BreathEZ in real world scenarios.
- We present a model describing abdominal thrust performance using number and quality of the abdominal thrusts which are used to coach the user while they are performing choking first aid.

The remainder of this paper is divided into seven sections. We begin with a background of choking first aid, a discussion of our pre-user study, and the feasibility of using a smartwatch to assist in the performance of choking first aid. Following that we detail our system design and the evaluation of that system, then continue on to our BreathEZ application and the results of a user study in which it was used. Finally we discuss related work, future work, and summarize with our conclusion.

2. Pre-User Study

To evaluate the usefulness and effectiveness of our application, we performed a pre-user study in which participants were asked to perform abdominal thrusts on a CPR training manikin while wearing a Motorola 360 smartwatch. The CPR training manikin known as the "Annie" training manikin [17], shown in Figure 1, is the standard training manikin used in First Aid Training courses.

2.1. *Choking First Aid Background*

To prevent complications from choking incidents such as cerebral hypoxia, choking first aid should be administered immediately after the victim is confirmed to be choking and consent to administer aid is given. From here we refer to the individual receiving choking first aid as the victim and the individual administering choking first aid as the first aid provider. The American Red Cross recommends this treatment [8], which we quoted in the following bullets, for choking victims who are conscious and either standing or sitting :

- "After checking the scene and the victim, have someone call 911 and get consent to perform first aid."
- "Bend the victim forward at the waist and give five back blows between the shoulder blades with the heel of one hand."
- "Place a fist with the thumb side against the middle of the victim's abdomen, just above the navel. Cover your fist with your other hand. Give five quick, upward abdominal thrusts."
- "Continue sets of five back blows and five abdominal thrusts until the, object is forced out, the victim can cough forcefully, breathe, or the person becomes unconscious."

Figure 1: The "Annie" CPR training manikin used in our study.

In this paper, we focus on the abdominal thrust portion of choking first and discuss back blows in the future work section. Abdominal thrusts are also known to many as the "Heimlich Maneuver". The "Heimlich Maneuver" was developed by Dr. Henry Heimlich and was first published in 1979 [18].

The above recommended choking treatment is for adults and children large enough that you can stand or kneel behind them. We do not address choking first aid for infants in our solution. We discuss the recommended treatment for infants in the related work and how we can add this to our solution in discussion and future work.

2.2. *Study Design*

The study group participants were students recruited from the College of William and Mary. No incentives were garnered by our participants for their participation in our study. In total, we collected 105 recordings of abdominal thrusts from seven participants, three female and four male. The average participant age was 21 with a standard deviation of 6. Prior to this study, four participants had completed choking first aid training.

Pre-Study Questionnaire First, each user was asked to fill out a questionnaire with the following questions:

1. Have you had abdominal thrust or Heimlich maneuver training? Yes or No. If yes, why?
2. On a scale of 1-5, how comfortable are you performing abdominal thrusts?
3. Is the topic of the study (bystander abdominal thrusts) relevant for you personally? Yes or No. If yes, why?
4. On a scale of 1-5, how willing are you to perform abdominal thrusts?
5. On a scale of 1-5, how familiar are you with a smartwatch?

We asked these questions to assess each participant's previous experience with abdominal thrust training and their willingness to perform abdominal thrusts.

Three Scenarios for Abdominal Thrusts Next, each study participant was asked to perform abdominal thrust first aid in three different scenarios. We designed our scenarios to test our users basic knowledge of abdominal thrusts and determine if their performance and confidence improved when given instructions to follow. First we test their untrained knowledge of abdominal thrusts. Following this, we show them a tutorial and test their performance again. Then we test their retention of the knowledge gained from the tutorial. It takes each participant no more than ten minutes to complete the three scenarios. Each participant performs five abdominal thrusts per scenario for a total of 15 abdominal thrusts per individual per study.

1. Without training: In the first scenario, each participant was asked to perform abdominal thrusts to the best of their ability without help from a video tutorial.
2. With the video tutorial: In the second scenario, each participant was shown a video tutorial on the correct way to perform abdominal thrusts and was then asked to perform abdominal thrusts.
3. With knowledge gained from training: In the third and final scenario, each participant was again asked to perform abdominal thrusts without the aid of the video tutorial.

Data Recording For our study, we chose to use a smartwatch as it is a consumer available device that allows the wearer to be hands free when performing first aid and will also provide us with the ability to convey feedback to the user through the screen. We recorded the accelerometer and gyroscope data from the smartwatch during the study using WristSensors[19], an Android smartwatch application. The data was written to a CSV file and stored on a connected Android smartphone. The average file size was 107 MB.

Post-Study Questionnaire Following these scenarios, the participant was asked to fill out the following questionnaire:

1. Did the smartwatch irritate you? Yes or No. If yes, why?
2. On a scale of 1-5, how willing are you to perform abdominal thrusts using a smartwatch with our app?
3. Did you feel that you performed abdominal thrusts better with the smartwatch? Yes or No. If yes, why?
4. Would using the smartwatch with our app reduce your fear of injuring the person you are performing abdominal thrust on? Yes or No. If yes, why?
5. If you had a smartwatch, would you install our app? Yes or No. If yes, why?

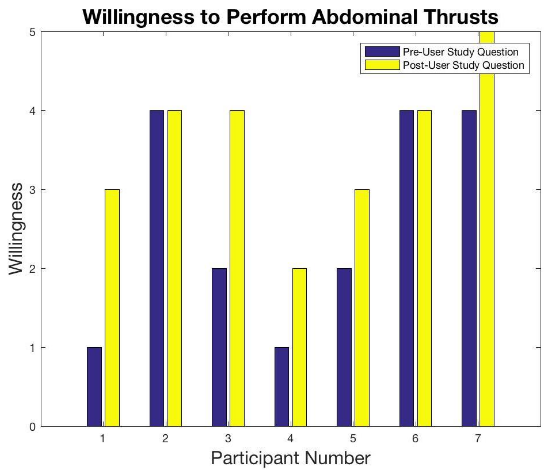

Figure 2: Participant willingness to perform abdominal thrusts.

We use these questions to assess any changes in their comfort level and likelihood of performing first aid on choking victims as well as their familiarity with smartwatches.

2.3. Results

With this user study, we gauge the effectiveness of a smartwatch as a tool for assisting in the performance of abdominal thrusts, if a smartwatch application would combat the bystander effect, and finally if it will increase a participant's willingness to perform choking first aid. Of our seven participants, six had no experience with smartwatches. After performing abdominal thrusts we surveyed all participants to determine if the smartwatch was a cause for irritation. None of the participants reported irritation because of the smartwatch and six of the seven participants would install a smartwatch application that provided real time feedback during their performance of choking first aid if they owned a smartwatch.

We evaluated each participant's comfort and willingness to perform abdominal thrusts both with and without the aid of an instructional video and show the results in Figure 2. Here we see that no matter what level of training the participant came in with, no participant was less willing to perform choking first aid and the mean level of willingness increased by one. From this user study, we see that our participants are not only comfortable with using a smartwatch while performing choking first aid but also are more willing to perform it. This shows that it is possible that a smartwatch application could help to combat the bystander effect and provide an individual with the knowledge and confidence required to help save a life.

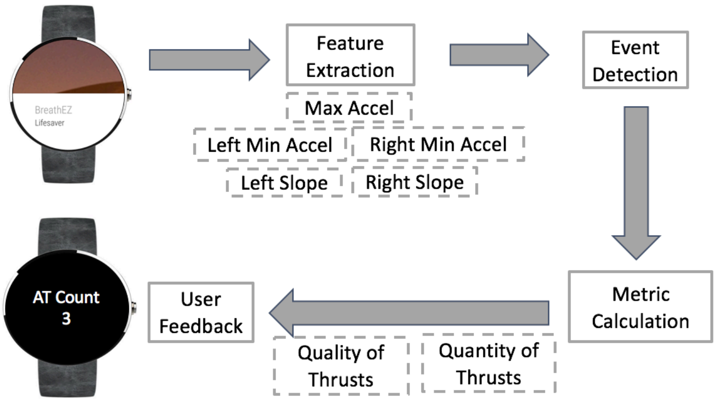

Figure 3: System Architecture for BreathEZ

3. System Design

In this section, we describe the design of BreathEZ. BreathEZ is a smartwatch application that assists users in the performance of choking first aid by providing instructions and feedback on abdominal thrusts. First, we discuss the System architecture. Then we discuss each of the features we extract to detect an abdominal thrust event. Following this we describe the metrics used to quantify how well our users performed each abdominal thrust.

3.1. System Architecture

In order for BreathEZ to classify abdominal thrusts and provide feedback on choking first aid, it must perform several tasks. First, BreathEZ must acquire data from the smartwatch accelerometer. Next, the application extracts five features that will be used to detect an abdominal thrust event. To detect this event, the features will be fed into a random forest classifier and it will classify the event as either Abdominal Thrust (AT) or Not Abdominal Thrust (NAT). Following this, for events classified as AT we calculate two metrics: quality of thrusts and quantity of thrusts. These metrics allow us to provide feedback to the user.

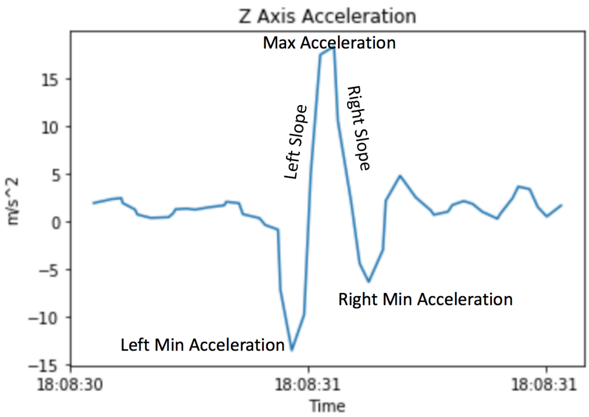

Figure 4: Extracted Features from Y Axis Accelerometer Data

3.2. Feature Extraction

We classify abdominal thrusts using accelerometer data from the Y axis. To do this, we use a sliding window with a size of 1500 milliseconds that moves right by 750 milliseconds each time. We set the size to be 1500 milliseconds by calculating the maximum length of an abdominal thrust from our expert data to be 1000 millisecond and adding 50% to give our non-experts some buffer room. Abdominal thrusts have a very distinct shape due to the high maximum acceleration needed when performing a thrust. To model the abdominal thrust we focus on this. An example of a single abdominal thrust with our features labeled is shown in Figure 4.

To calculate our features, we define,

$$arg(x_i) \triangleq i \tag{1}$$

Then, on each sliding window, $Input = [x_1 ... x_n]$, we calculate 5 features:

$$MaxAccel = \max_i(x_i) \tag{2}$$

$$MinLeft = \max_{x_i \in [x_1, MaxAccel]}(-x_i) \tag{3}$$

$$MinRight = \max_{x_i \in (MaxAccel, x_n]}(-x_i) \tag{4}$$

$$SlopeLeft = \frac{MaxAccel + MinLeft}{arg(MaxAccel) - arg(MinLeft)} \tag{5}$$

$$SlopeRight = \frac{MaxAccel + MinRight}{arg(MinRight) - arg(MaxAccel)} \tag{6}$$

3.3. Event Detection

We leveraged Weka Data Mining Software provided by the University of Waikato [7]. We fed the five features described above into the five standard data mining classifiers. We evaluated these classifiers on three metrics: precision, recall, and f-measure. The results of the evaluation of these classifiers are shown in Table 1. From the results, we saw that the random forest classifier outperformed the rest in all the metrics.

We evaluated our classifier using a data set combining both the expert and the pre-user study data. Within this data set, we had a total of 105 abdominal thrust events. After we partitioned the data we had a total of 853 windows to be classified as AT or NAT. Since the data was partitioned into 1500 millisecond windows and we moved our sliding window by 750 milliseconds, it is possible that a single abdominal thrust could fall in two different windows. This caused some abdominal thrust events to be classified twice. Because of this, we had a total of 194 windows whose ground truth is AT even though there were only 105 abdominal thrust events recorded. We discuss how we handle the abdominal thrusts that are repeated in two windows in the Quantity of Thrusts portion of the Metric Calculation subsection.

Classifier	Precision	Recall	F-Measure
Random Forest	94.5	94.5	94.5
Random Tree	92.9	92.7	92.8
SMO	87.5	87.9	87.1
Nearest Neighbor	91.2	91.4	91.2
Logistic	88.8	89.1	88.6

Table 1: Evaluation of multiple classifiers on our data set.

3.4. Metric Calculation

To provide feedback to the user, we must calculate two metrics. First, we determined the quality of abdominal thrusts by calculating a maximum acceleration from expert data. Second, we counted the number of abdominal thrusts performed. This allowed us to provide feedback to the user on their maximum acceleration after five abdominal thrusts were performed.

3.4.1. Quality of Thrusts

To the best of our knowledge, there is no known standard for the maximum acceleration when performing abdominal thrusts. The goal of performing abdominal thrusts is to expel the foreign object from the victims airway while attempting to prevent further injury to the victim. Abdominal thrusts that have too low a maximum acceleration will not expel the foreign object while those that have too high a maximum can cause injuries including damage to internal organs and ribs [20][21][22]. Due to the lack of availability of a recommended maximum acceleration, it can be difficult for a first aid provider to gauge these metrics and so to combat this, we asked six experts to perform abdominal thrusts on the "Annie" [17] CPR manikin while we recorded their accelerometer data. The six experts consisted of four CPR certified lifeguards and two CPR certified trainers. We instructed each expert to perform five abdominal thrusts for a total training set of thirty abdominal thrusts. The mean maximum acceleration for expert abdominal thrusts was 11.302 m/s^2 with a standard deviation of 4.437 m/s^2.

3.4.2. Quantity of Thrusts

For each window, we classified if an abdominal thrust had occurred. In the Event Detection subsection, we discussed that a single abdominal thrust can appear in two adjoining windows. To ensure that we did not count the same abdominal thrust twice, we only count the abdominal thrusts such that

$$max(AT_n)! = max(AT_{n-1}) \tag{7}$$

This allowed us to get an accurate count of abdominal thrusts so that we could provide feedback after each fifth abdominal thrust.

4. BreathEZ Application

We accomplish two goals with our BreathEZ application. First, we offer easy to follow instructions for choking first aid and second, we provide feedback to the user on their performance of the abdominal thrust portion of choking first aid. BreathEZ is implemented on Android 8.0 Oreo. The smartphone application is approximately 3.5 MB and the smartwatch application is about 9.5 MB. To make certain that feedback is provided to the user in a timely manner, the functions that run the display, data processing, and data logging are implemented in their own threads. When in use, BreathEZ samples the accelerometer at 5 Hz.

We displayed the instructions for choking first aid in a manner that is both user friendly and intuitive. We designed our smartwatch screens to show both a summary of the current screen's instruction and a more detailed explanation below that can be scrolled through. These screens are shown in Figure 5.

Figure 5: Instructional screens from BreathEZ.

Once the user gets to the "5 Abdominal Thrusts" screen as shown in Figure 5, we start to give the user feedback on their performance of abdominal thrusts. The user is given tactile and auditory feedback as the smartwatch counts five abdominal thrusts to let the user know that each abdominal thrust is classified and logged. Once the user has completed their 5 thrusts and they swipe to the following screen, the user is given feedback on the performance of their abdominal thrusts by providing textual feedback and changing the background color of the screen. The different feedback screens are shown in Figure 6.

5. Post-User Study

In order to evaluate BreathEZ, we performed a post-user study in which participants were asked to answer two questionnaires and perform abdominal thrusts on a CPR training manikin [17], shown in Figure 1 while wearing a Motorola 360 smartwatch.

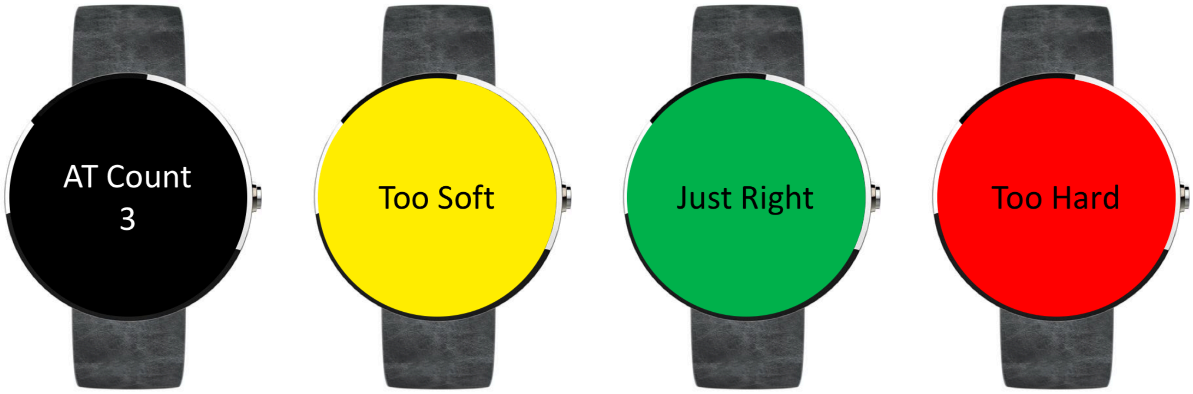

Figure 6: Screens that provided feedback for abdominal thrusts in BreathEZ.

5.1. Study Design

The study group consisted of participants recruited from the College of William and Mary and surrounding area. No incentives were given for participation in our study. Overall, we collected 229 recordings of abdominal thrusts from ten total participants, eight female and two male. The average participant age was 35.4 with a standard deviation of 14.6. Prior to this study, four participants had completed choking first aid training.

Pre-Study Questionnaire First, we ask each participant to answer the following questions:

1. Have you had choking first aid and/or Heimlich maneuver training? Yes or No. If yes, why?
2. On a scale of 1-5, how comfortable are you performing the choking first aid?
3. Is the topic of the study (choking first aid) relevant for you personally? Yes or No. Why?
4. On a scale of 1-5, how willing are you to perform choking first aid?
5. On a scale of 1-5, how familiar are you with smartwatches?
6. Which is your dominant hand? Right, Left, Ambidextrous

Two Scenarios for Choking First Aid We designed our two post-user study scenarios to complement the pre-user study scenarios. These scenarios again tested the participants' basic knowledge of abdominal thrusts and determined if their performance and confidence improved. First, we tested their untrained knowledge of abdominal thrusts. We did not instruct them on any aspects of choking first aid, just handed them the CPR manikin and allowed them to give it their best effort. Following this, we divided the participants into two groups. Group 1 was shown a Red Cross tutorial video [23] and then asked to once again perform choking first aid. Group 2 was instructed to use BreathEZ app. It took each participant no more than ten minutes to complete the two scenarios. Each participant performed a minimum of five abdominal thrusts per scenario for a minimum of ten abdominal thrusts per individual per study.

1. Without training: In the first scenario, each participant was asked to perform abdominal thrusts to the best of their ability without any help.
2. With the video tutorial or BreathEZ: In the second scenario, each participant was either shown a Red Cross video tutorial [23] on the correct way to perform choking first aid or instructed to use the BreathEZ app. If the participant was shown the Red Cross video tutorial, they were asked to once again perform choking first aid. If the user was instructed to use the BreathEZ app, they were asked to follow the in app instructions.

Data Recording We recorded the accelerometer and gyroscope data from the smartwatch during the study using our BreathEZ application. The data recording service was run in the background on the smartwatch and did not effect the performance of the user facing BreathEZ app. The data was written to a CSV file and stored on a connected Android smartphone. The average file size was 237 MB.

Post-Study Questionnaire

After performing abdominal thrusts, the participant was asked to answer the following questions:

1. Did the smartwatch irritate you? Yes or No. If yes, why?
2. (a) On a scale of 1-5, how willing are you to perform choking first aid using a smartwatch with our app?
   (b) On a scale of 1-5, how willing are you to perform choking first aid after watching the Red Cross Video Tutorial?
3. (a) Did you feel that you performed choking first aid better with BreathEZ? Yes or No. Why?
   (b) Did you feel that you performed choking first aid better after watching the Red Cross Tutorial Video? Yes or No. Why?
4. (a) Would using the smartwatch with our BreathEZ app reduce your fear of injuring the person you are performing choking first aid on? Yes or No. Why?
   (b) Did watching the Red Cross video tutorial reduce your fear of injuring the person you are performing choking first aid on? Yes or No. Why?
5. If you had a smartwatch, would you install our app? Yes or No. Why?
6. Any other comments?

Questions two through four are modified depending on which group the participant is in. Group 1 received questions 2a, 3a, and 4a. Group 2 received questions 2b, 3b, and 4b. Question five is only given to group 1.

5.2. Results

In this subsection we discuss the results of the user study and the questionnaires. First we quantify the two main objectives of BreathEZ: to classify abdominal thrusts in real time and provide feedback to the user. Following that we discuss how our participants willingness and fear to perform choking first aid changed after using BreathEZ.

5.2.1. Classification of Abdominal Thrusts

The five participants in group 1 used the BreathEZ app in their user study. BreathEZ classified each participant's abdominal thrusts in real time and then gave them feedback on how well they performed them. Each abdominal thrust classification was monitored by the individual giving the study. On each possible classification of an abdominal thrust, the individual would mark whether or not the application correctly classified the abdominal thrust. Among the five participants there were 55 possible abdominal thrusts classifications and BreathEZ correctly classified 50 of them in real time.So BreathEZ correctly classifies abdominal thrusts in real time 90.9% of the time. When BreathEZ did not classify an abdominal thrust correctly, it did not register an abdominal thrust. When this happened, the participant had to perform an extra abdominal thrust to get to the feedback screen of the application. This is an issue that should be resolved in later versions of the BreathEZ app. We will discuss this more in the Discussion and Future Work Section.

5.2.2. Abdominal Thrust Performance Feedback

We recorded the feedback that each of our participants received after performing abdominal thrusts while using the BreathEZ app. We show this feedback in Table 2. From Table 2, we saw that four of the five participants improved from their first performance of abdominal thrusts to their second. Of the four participants that improved their performance, we saw three that received the feedback, "Too Soft", after performing their first set of abdominal thrusts. Participants 4 and 5 were able to increase their feedback to "Just Right". Participant 3 again received the feedback "Too Soft" but was able to raise their max acceleration and get closer to the "Just Right" feedback. The final participant who showed improvement was able to better his feedback from "Too Hard" to "Just Right". From this study we saw that after being given feedback, most of our participants were able to improve their performance in abdominal thrusts.

The participant who did not improve their BreathEZ feedback, participant 5, began with a "Just Right" feedback and moved to "Too Soft". It is worth noting that this participant was trained as an EMT-Basic and found the "CPR specific manakin is painful to do abdominal thrusts at the appropriate force". We used the CPR specific manakin for our study, since after contacting two local fire stations, one hospital, and two CPR training facilities in the nearby area we found that they only used the CPR specific manakin.

To understand how our users felt about their improvement in their performance we included a question in the questionnaire for all ten participants. Of the five participants that were shown a tutorial video, we saw that three of five believe their performance improved after being shown the tutorial video. A summary of their comments showed that they found the instructions helpful but they still could not tell if they were performing choking first aid correctly. More specifically their comments consisted of "instructions helped, I had never heard of back blows", "its good to know what to do", and "I still don't know if I'm doing it right". Of the five participants that were allowed to use BreathEZ, we saw that all five found believed their performance improved. Their comments were centered around the feedback they received saying that it was "helpful to have feedback", "it tells you what to do and that you are doing it right", and "it helped to know how well I was doing". One participant even commented on their personal improvement by saying "it told me to thrust harder and I was able to get a just right the second time".

Participant #	1st Feedback	2nd Feedback
1	Just Right	Too Soft
2	Too Hard	Just Right
3	Too Soft	Too Soft
4	Too Soft	Just Right
5	Too Soft	Just Right

Table 2: This table shows the feedback each participant in group 1 received after their first and second round of abdominal thrusts.

5.2.3. Willingness and Fear

To combat the bystander effect, we focus on two factors. The first is our participants' perceived willingness to perform choking first aid. The second is the fear of injuring the victim of choking while performing choking first aid. To gauge this, we asked three questions relating to this in our pre and post questionnaires.

We began by asking all participants to rate their willingness to perform choking first aid on a scale of one to five before and after training was given. These results are shown in Figure 7. On average, before any training was given, the average willingness was 2.4 out of 5.0. After each participant performed choking first aid, we questioned them again to understand any changes. Those who were asked to watch a tutorial video, participants 2-6, had an average willingness of 2.8. Those who were asked to use BreathEZ, participants 1 and 7-10, had an average willingness of 4.2. From this we can clearly see that while each average willingness increased, those who were asked to use BreathEZ had a much higher increase in willingness.

After performing choking first aid, we asked participants if their fear of injuring a choking victim had decreased. Of those who were asked to watch a video tutorial, three of five said that their fear had not been reduced, citing that they were not sure that they could perform choking first aid correctly. More specifically the commented "I feel slightly better now that I know what I'm doing", "I don't want to hurt anyone", and "What if I do it wrong". Of those who were asked to use BreathEZ, all five participants responded that their fear had been lessened. A summary of their comments is as follows: "I would be less scared because it would tell me if I was thrusting too hard", "it told me I was in the just right zone", and "it made me more confident in my skills".

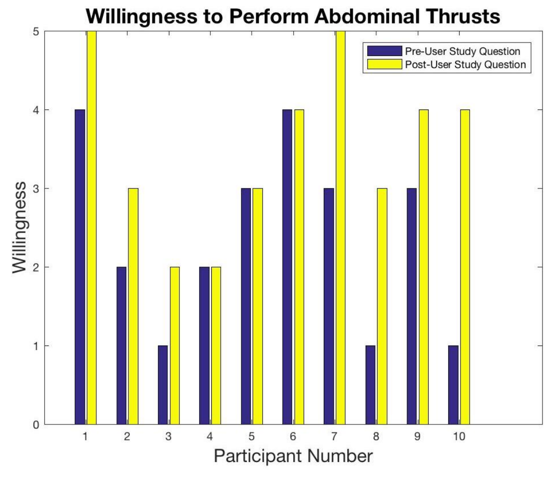

Figure 7: Willingness to perform abdominal thrusts in the post-user study.

6. Discussion and Future Work

6.1. Angle of Abdominal Thrusts

To create a better abdominal thrust feedback system for the user, the angle of the abdominal thrust can be measured. This is essential because the angle of the abdominal thrust contributes to the expulsion of the foreign object [24]. This feedback should be given before the user begins administering the abdominal thrusts to ensure that the best care is provided. The BreathEZ app should incorporate this by guiding the user to the correct angle with either verbal or tactile feedback. This will allow for a more complete BreathEZ system.

6.2. *Feedback After Each Abdominal Thrust*

In the current implementation of the BreathEZ application, the user only receives feedback after all five abdominal thrusts are complete. For a more complete user experience, two factors should be considered. First, it can be beneficial to the user to receive feedback on their abdominal thrusts performance after each abdominal thrust. This can be implemented by developing a training mode and/or giving the user access to analytics after performing choking first aid. Second, it may not take all five abdominal thrusts to expel the foreign object. If this is the case the user should be able to either manually move on from the abdominal thrusts portion of BreathEZ and/or BreathEZ should time out after a set threshold of time if it has not registered the performance of any abdominal thrusts.

6.3. *Back Blows*

Choking first aid requires the first aid provider to be able to perform two maneuvers: back blows and abdominal thrusts. In our solution, we only address abdominal thrusts. ”Back blows are given with the heel of your hand between the victim’s shoulder blades” [8]. If the first aid provider wears a smartwatch on the wrist of the hand that they are delivering back blows, it is possible that we can also detect, classify, and give feedback on these motions. Kautz et al [25] are able to detect sports motions based on sensing an impact between a sports ball and a hand or arm by having the subject wear an accelerometer on their wrist. Here we will be tackling a similar challenge by attempting to sense the impact between a subject’s hand and the back of a manikin. To provide feedback on the back blows portion of choking first aid, we can measure the max acceleration to determine if the first aid provider is within a range of the average max acceleration data collected from experts.

6.4. *Choking First Aid for Infants*

We focus on choking first aid for adults but choking first aid procedures for infants should also be addressed. The American red cross recommends this treatment [26], which we quoted in the following bullets, for infants who cannot cough, cry, or breathe:

- “After checking the scene and the victim, have someone call 911 and get consent to perform first aid.”
- “Give firm back blows with the heel of one hand between the infant’s shoulder blades.”
- “Give five chest thrusts. Place two or three fingers in the center of the infant’s chest just below the nipple line and compress the breastbone about one and half inches. Make sure to support the head and neck securely when giving back blows and chest thrusts. Keep the head lower than the chest.”
- “Continue sets of five back blows and five chest thrusts until the object is forced out, infant can cough forcefully, cry or breathe, infant becomes unconscious.”

A complete choking first aid application should also address this scenario. At this point, our app does not address this scenario but the movements described can be monitored. Back blows can be monitored as described above but the max acceleration should be set by expert data where back blows are performed on an infant manakin. To monitor the chest thrusts, we look to Gruenerbl et al [10] as chest thrusts for infants are similar to measuring the depth and frequency of CPR chest compression.

7. Related Work

7.1. *Choking First Aid Devices*

The first related work is a patent on a method to measure abdominal thrusts for general use and training in a clinical setting by Totman at Zoll Medical Corporation [9]. The authors designed their own hardware device using accelerometers which is held by the first aid provider performing abdominal thrusts. They plan to be able to determine the appropriate depth and speed of the abdominal thrusts. They indicate it could be used for first aid training, but they do not have any extensive evaluation on how such a system could improve user performance. In contrast, our system provides in situ instruction and real-time feedback on the quality of each set of abdominal thrusts.

7.2. First Aid on Smartwatches

Gruernerbl et al [10] developed a smartwatch application that provides live user feedback for CPR. Their system measures the frequency and depth of CPR chest compressions on a first aid manikin. They performed their evaluation as a large scale user study and demonstrated that their system not only improves CPR technique, but improves user likelihood of performing it. Our work takes the same approach but with the abdominal thrust portion of choking first aid. Ultimately, BreathEZ is meant to complement their work by providing a more complete first aid training suite.

7.3. First Aid on Other Smart Devices

A number of systems and applications focus on healthcare. Some are relatively simple applications such that display standard American Heart Association's or American Red Cross' First Aid Protocol information for the user. Shah et al [11] documents the benefits and shortcomings of these applications and indicates that they are insufficient. Others such as Jaeger et al [12] develop their own hardware device to be used during a medical emergency that measures a victim's pulse and other respiratory features. Lockman et al [13] developed their own wrist-worn accelerometer and provided an algorithm to accurately detect wrist motions associated with an epileptic seizure in order to pave the way for quick reporting.

Carvalho et al [15] introduced an Android application video game first aid training tool in which users score points by performing first aid actions. They argue that such a system familiarizes users with first aid scenarios and as such could improve performance. Urturi et al [16] similarly created an Android application game for teaching first aid, but specifically for users with autism. Although game-based incentives could raise awareness about the necessary protocols for bystanders, it is not proven that game based incentives improve the quality of the bystander first aid performance.

Pande et al [14] created a smartphone framework for automating first aid for burn victims. Their system offloads much of the assessment from the user by having the user send images of the burn victim to a cloud hosted database. From these images, experts can determine the severity of the burn, provide personalized instructions, and use the phone's GPS location to send an ambulance. This system sets aside the user entirely in favor of as much automation as possible. Such a framework may be possible in some aspects of healthcare, but for choking victims the protocol requires bystanders to perform abdominal thrusts in all choking scenarios. Thus, users need guidance to perform the action well and our real time sensor feedback framework is a better solution for our problem than a cloud based one.

8. Conclusion

In this paper we presented BreathEZ, the first smartwatch application that classifies and provides feedback in real time on choking first aid. BreathEZ identifies abdominal thrusts, measures the peak acceleration, and provides feedback on the quality of the abdominal thrust to the user. This application is shown to not only increase the user's performance of choking first aid, but to also combat the bystander effect by increasing a user's willingness to perform choking first aid and decreasing their fear of injuring a choking victim. This is important because choking leads to nearly 5,000 deaths per year in the US. While EMS response is optimal for the victim, it does not always occur in less than six minutes and within that time frame brain damage can occur. Using BreathEZ to help combat the bystander effect and increase the quality of performance of choking first aid can help to bring the number deaths due to choking down.

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