CPR GuideGlove

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I. Abstract

Heart disease is the leading cause of death in the United States. Sudden cardiac arrest makes up the largest percentage of heart-related deaths, accounting for 1 in 7 deaths in America per year. With 73 percent of cardiac arrests occurring out of hospital, bystanders' ability to perform cardiopulmonary resuscitation (CPR) with proper technique is increasingly important [1]. The CPR Guide Glove provides a novel solution to support the common bystander with highly specific guidance to act in an emergency situation. The Guide Glove focuses on three main aspects of CPR technique: compression pace, compression depth, and hand placement. Through continuous real-time feedback, the Guide Glove facilitates proper compression form. The design allows those with little to no training to use this device. The Guide Glove takes on an intuitive and user-friendly design to ease the stress of emergency situations and facilitate a quick and effective response.

II. Clinical Need

Cardiac arrest is one of the leading causes of heart-associated deaths with approximately 475,000 deaths in the United States each year [1]. Cardiac arrest is the onset of a sudden arrhythmia, or irregular heartbeat. The body relies on a constant heartbeat because vital organs require continuous oxygen delivery via blood flow. When this flow is interrupted, the brain, lungs, and other organs will cease proper function and chances of survival undergo a steep decline. When cardiac arrest occurs, cardiopulmonary resuscitation (CPR) must be performed immediately to optimize chances of recovery with minimal damage. CPR is an emergency-lifesaving technique that consists of chest compressions and artificial ventilation. It is performed to maintain the blood flow and oxygenation to the brain when the heart is malfunctioning. If performed immediately, high-quality CPR can double or even triple the chance of survival for a cardiac arrest patient. Ideally, CPR should be performed within two minutes of the onset of cardiac arrest. Brain damage is likely to occur after three minutes have passed [2], which is less than half the average EMT response time of seven minutes [3].

Despite the training resources available, CPR is performed inadequately by both bystanders and first responders. In a study observing out-of-hospital CPR, 28.1 percent of patients received compressions at a rate of less than 90 beats per minute and 37.4 percent of patients received compressions that were too shallow [4]. Improper technique greatly reduces chances of survival for cardiac arrest patients. Specifically, poor technique reduces the efficacy of restoring blood flow and oxygenation. This problem becomes further exacerbated as the rescuer's fatigue sets in. According to American Heart Association (AHA) guidelines, three metrics of high-quality CPR include chest compression rate of 100 to 120 beats per minute, chest compression depth of 2 to 2.4 inches, and hand placement over the sternum [5].

The failure of immediate attention is a major contributor to the 90 percent death rate for out-of-hospital cardiac arrest patients [1]. When a cardiac arrest occurs out of the hospital, the patient's well-being lies in the nearby bystanders' ability to help. Unfortunately, only 46 percent of out-of-hospital cardiac arrest patients get the immediate help they need [1]. Studies show that

bystanders avoid performing CPR due to the worry of causing additional injuries, inadequate skills due to a lack of recent CPR training, and low confidence [6]. Due to the reluctance of bystanders to respond, many of these patients fail to receive CPR within an adequate time frame.

The majority of Americans lack a thorough and recent CPR education to safely intervene in emergency situations. These emergencies demonstrate the need for CPR assist devices that can be used by first responders as well as common bystanders. In an attempt to mitigate the situation, several CPR assist devices have been made available to the market. Two prominent products include CPR RsQ Assist and TrueCPR. CPR RsQ is designed with an ergonomic shape that allows the rescuer to compress with more ease and reduces the onset of fatigue. It relays information through audio, by telling the user to call 911 and “push” to convey the compression pace [7]. Although this product successfully aids in fatigue and provides a proper pace, it does little to help technique. The TrueCPR coaching device provides real-time feedback on chest compression depth and chest compression rate [8]. However, the inadequate design for this device makes it unsuitable and inconvenient for emergency situations. This product requires the user to place one piece underneath the patient, which may be difficult to accomplish in a timely manner. Without this piece placed appropriately, the depth feature is rendered ineffective. In addition, the range of the compression depth of the device does not take into account the subcutaneous adipose tissue (SAT) layer of obese individuals. The current products on the market attempt to aid the rescuer in compression pace, compression depth, or fatigue; however, they provide little to no feedback while the rescuer is performing CPR and lack the size setting and hand placement features altogether.

III. Project Objective Statement

As a result of the gap in the market, the CPR Guide Glove, as shown in Figure 1, is designed to address the weaknesses of existing devices and build on the strengths. This product was developed with three goals in mind: effective guidance, easy to use, and ability to set up in a timely manner. The Guide Glove addresses the goal of effective guidance by targeting three essential aspects of CPR and providing an additional feature to tailor to individuals of different sizes. The device also provides continuous feedback for the user to improve on or maintain technique throughout the duration of CPR. To increase the ease of use, Guide Glove utilizes visual and audio signals as methods for relaying information to the user. Existing CPR devices can be time-consuming to set up. To address this issue, this device is designed to allow minimal set-up time. As a whole, this device helps the user assume and maintain proper CPR technique by targeting hand placement, compression depth, and compression pace, with an additional size setting feature.

Each of the primary features is designed to be used in high-intensity situations. The hand placement feature will include a simple design that will allow the user to visually align their hands in the correct placement for effective CPR. The compression depth feature will include an effective way to convert acceleration data into a depth measurement with as little error created as possible. The device must also incorporate a feedback system to alert the user when compressions have reached the required depth. Continuous guidance and feedback encourages the user’s compression technique to follow the recommended guidelines. In addition, the device will include a size setting that will adjust compression depth requirements for larger patients. The compression pace feature will use audio to guide the user to maintain a constant pace.

The CPR Guide Glove poses a solution to the flawed devices currently on the market through its ease of use and original features. The novel design of a glove as the base structure for the device allows the user full control over the technique and force applied and requires minimal set-up time. The compact and lightweight design allows full portability and reduces any maneuvering difficulties. To further enforce effective CPR, the Guide Glove incorporates hand placement guidance and size settings, both of which are new features to the CPR assist device market.

IV. Documentation of the Design

The Guide Glove has a practical design permitting ease of use. The glove spans from the middle of the palm to the bottom of the wrist, allowing finger flexibility and maximum comfort. The fabric consists of nylon and elastic. Nylon is a durable and flame-retardant fabric, permitting use in harsh conditions. With the incorporation of elastic, the glove can be used by a person of any size. On the sleeve of the glove, below the hand, is a box that contains the circuit and all electrical components of the device. The box is contained in a casing made with acrylonitrile butadiene styrene (ABS), a durable and lightweight material that provides protection to the delicate circuit components. The box is placed on the wrist to allow the user full motion of the hand while keeping the circuit away from the area of compressions. The contents of the box include an Arduino Nano, buzzer, 9V battery, and retractable extension tool. The 9V battery is replaceable and rechargeable when the device is not in use, allowing the device to last through varied length sessions of CPR. One RGB LED is located on the top surface of the box and a rocker switch is located on the right side of the box. The MPU-9250 accelerometer is located on the back of the palm to gather acceleration measurements at a frequency of 8000 Hz. The placement of the accelerometer on the center of the hand encourages accurate measurements as it moves with the user. Despite its simple design, compression pace, compression depth, and hand placement features are fully incorporated with in-depth function.

The compression pace and hand placement features employ straightforward methods that comply with AHA guidelines. The buzzer is programmed to emit a beeping sound at 2 Hz and at a pace of 120 beats per minute. Each audible tone represents one chest compression cycle, down and up, given by the user. The hand placement feature is designed based on the human anatomy of the chest. The skeletal composition of the chest can be seen in Figure 3. The sternum is a long flat bone located in the center of the chest; the rib bones extend laterally from the sternum. The ideal position for CPR is the base of the sternum, in which a general approximation is the intersection between the midline of the chest and the nipple line. To decrease the likelihood of rib fractures and internal injuries, the bottom of the sternum should be targeted. Pressure on the xiphoid process, located directly below the base of the sternum, should be avoided during CPR because it may cause punctures or lacerations to the diaphragm and liver [9]. The nipple line provides a sufficient estimate for this positioning. After considering several intensive methods for hand placement, alignment markers were chosen for the ease and simplicity. Clear visual markers allow a position to be determined quickly in high-stress and time-sensitive situations. Each line is labeled for clear direction. The vertical line is labeled “Nipple Line” and the horizontal line is labeled “Midline of Chest” to inform the user on how the markers should be aligned. As an alternative method, the extension tool can be used for hand placement. This tool is used by first placing the device at the patient’s collarbone then extending until the device provides resistance. The resulting position of the device is the location for the suggested hand placement.

Guidance for compression technique is further supplemented by continuous depth feedback and a size setting option. The feedback mechanism utilizes the kinematics equations relating acceleration to distance. To obtain a depth value, a double integration of the acceleration data can be performed to obtain displacement measurements. Because integration can increase the impact of error, the Guide Glove is programmed to implement a windowed finite impulse response (FIR) filter to the raw acceleration data. Specifically, a low-pass filter and a Blackman window are applied to the data in the Fourier domain before the conversion from the acceleration data takes place. The data is then converted back into the time domain and a double integration is taken to obtain the displacement results. The resulting distance is compared to the ideal compression range of 2 to 2.4 inches and the LED will illuminate green or red accordingly. A green light signifies a compression depth within the range and a red light signifies a compression depth outside of the range.

When performing CPR on an obese individual, the ideal compression depth is greater than that of an average individual. This is due to a greater significant SAT layer over the chest and abdomen. This tissue creates a larger distance between the skin's surface and the vital organs beneath [10]. Currently, there are no CPR assist devices on the market that take this into consideration. The Guide Glove has an obese size setting that increases the minimum required compression depth to compensate for the SAT layer. Size selection is accomplished with the rocker switch. The switch can be moved from the **O** position to **I** for the average setting or **II** for the obese setting, depending on the size of the patient. When this setting is chosen, the device will increase the acceptable compression depth range to be 2.2 to 2.6 inches. These values were chosen because a difference of 0.2 inches will compensate for the SAT layer but will not injure an average sized person if the incorrect setting is chosen [10].

V. Documentation of Final Prototype Design

Figure 1 displays the overall design of the CPR Guide Glove. The glove is made of an elastic fabric to conform to all sizes. Alignment markers, which are two perpendicular lines that extend from the middle finger down to the wrist and across the base of the hand, are located on the backside glove. The accelerometer is located on the backside of the glove directly above the wrist. The components box sits slightly below the wrist on the arm. As shown in Figure 2(b), this box has one LED on the top surface that illuminates green or red. The contents of the box include an Arduino Nano, buzzer, extension tool, and a 9V battery. To allow sound to travel from the buzzer to the user, small holes are extruded on the surface of the box. In addition to the holes, the box is designed with a small opening on the right side to allow the user to pull the extension tool when needed. Wired to the battery is also a rocker switch, which serves as a power switch and size selection for the device.

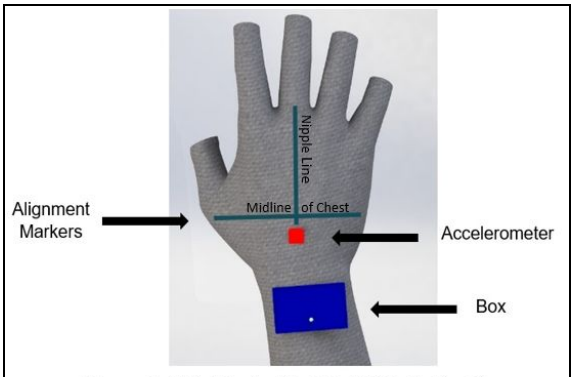
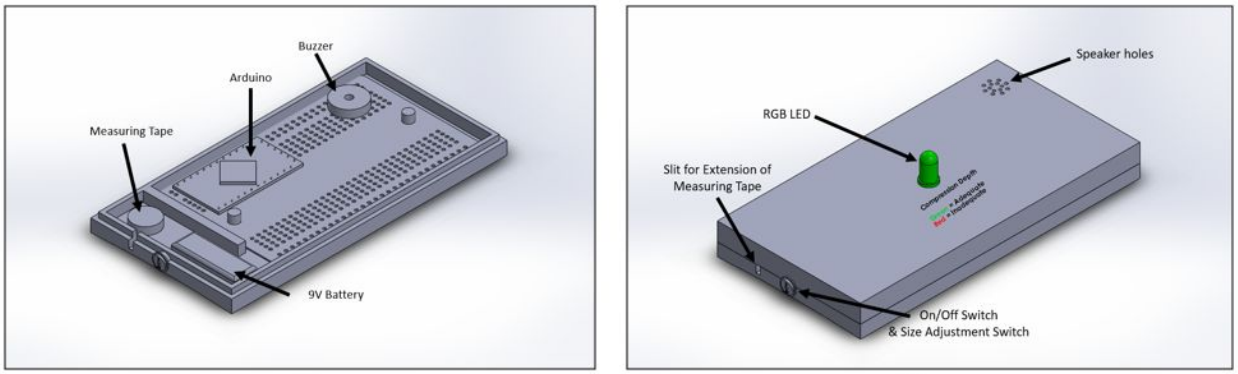


Figure 1. SolidWorks Model of CPR Guide Glove



(a) (b)

Figure 2. (a) Inside of the Components Box (b) Outside of the Components Box

VI. Proof of Functionality and Testing

The efficacy of the Guide Glove will be evaluated through testing of the main components. To assess the effectiveness of the alignment markers, two groups of participants will be utilized. The control group will work with a CPR manikin using only their hands and the experimental group will work with the manikin using the Guide Glove. Each group will consist of 50 individuals who will be asked to place their hands on the manikin as if they are about to perform CPR. The locations of their hand position will be recorded and compared to the ideal location for hand placement, shown in Figure 3. The deviance will be calculated in centimeters away from the center of the manikin's chest. The alignment markers will be considered successful when the experimental group shows a significant improvement of the hand positionings when compared to the control group. The second experiment will test for the efficacy of the device's depth-feedback mechanism. The purpose of the test is to determine if the depth-feedback system decreases the amount of time it takes a user to achieve consistent-correct form. For the experiment, consistent-correct form is defined as 5 consecutive compressions that receive a green light from the manikin, indicating proper compression depth. This test will utilize the same control and experimental groups as previously mentioned and will measure the amount of time needed to achieve consistent correct form in the units of seconds. The depth-feedback system will be considered successful when the experimental group shows a significantly shorter length of time to perform proper compressions compared to the control group. The third test will be the determinant of the accuracy and functionality of the depth-tracking system by analyzing the deviation from the desired depth while using the device. In this test, we will focus on the ability of the Guide Glove to detect a distance traveled without significant error, by dropping the device five times from five different heights (equally spaced between one and five inches) and comparing the averages of each height group with the set height. If no significant difference between the means are detected, then the depth function can be considered accurate. With the completion of these tests, the various components of the CPR Guide Glove will be considered functional and effective.

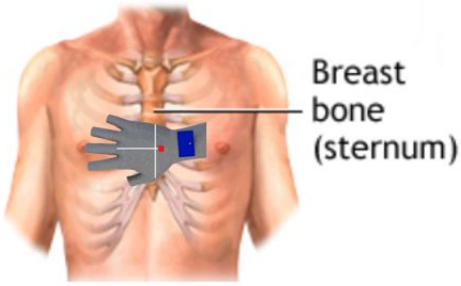


Figure 3. Optimal Position for Hand Placement [11]

Although these experiments could not be performed, the generation of mock data allowed us to perform statistical analyses and draw conclusions from the designed experiments. Because the goal of the first test was to see if the mean of the control group's deviance, or distance away from the center of the manikin's chest, is larger than the mean of the experimental group's deviance, a Welch's t-test was performed. The mean of the control group's distances was found to be significantly greater than the mean distances of the experimental group ($t(76.971) = 3.0118$, $p = .001756$). To conclude, the CPR Guide Glove increased user accuracy of proper hand placement. As done for the first experiment, the same statistical tests were performed for the second experiment to see if the average length of the control group's time is greater than that of the experimental group. The mean of the control group's times was found to be significantly greater than that of the experimental group ($t(68.917) = 14.368$, $p <$ 2.2e-16). From these results, we can infer that the CPR Guide Glove helped provide depth feedback to users in order to achieve 5 consistent and correct compressions in a shorter time than those without the CPR Guide Glove. The goal of the third test was to compare the means of each height group with their respective heights to see if there is any significant difference. Although we also decided to perform a Welch's t-test for the third test, a two-tailed hypothesis was defined instead of an upper-tailed hypothesis. The p-values found were 0.958319, 0.270259, 0.711454, 0.234929, and 0.673747 in order of increasing heights. Each p-value was well above 0.05, allowing us to conclude that the means are not significantly different from the known heights and that any error in the depth function is insignificant.

VII. Future Work

In addition to minimizing the delay of starting CPR, assessing the patient during CPR is critical. Prior to performing CPR, it is necessary to check for the patient's pulse by locating the carotid artery, a task that can be time consuming and challenging in the event of an emergency situation. To provide the user a quick method for determining the status of the patient, a future iteration of the Guide Glove will incorporate an electrocardiogram (ECG) that will monitor the patient's heart rate. CPR is only necessary if the patient's heart has stopped and unnecessary CPR will only put the patient at further risk. The CPR Guide Glove will include retractable leads inside the components box to allow the user to easily attach them to the patient. Continuous real-time feedback on heart rate will be provided to the user during CPR using a second LED. If the LED does not illuminate blue, the patient's pulse has not reached the expected threshold and the user should continue performing chest compressions. If that LED does illuminate blue, this indicates that the patient's pulse has reached the expected threshold and chest compressions are no longer necessary. The incorporation of the ECG will ultimately eliminate the need for rescuers to manually locate the carotid artery to check for a pulse before and throughout compressions.

VIII. References

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