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Development of an Accessible CPR Device to Improve Outcomes for Out-of-Hospital Cardiac Arrest

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Introduction

One of the leading causes of death within adults in the US is cardiac arrest with 470,000 lives taken each year. Unfortunately, 350,000 people suffer an OHCA with an abysmally low 12% survival rate. Out of OHCA incidents, 74% happened at the home while 15% happened in a public setting (Newman, 2021). At the onset of cardiac arrest, the patient may only have a few minutes before succumbing to it unless interventions are taken-for every minute gone without any aid, chances of survival deteriorate quickly. Until emergency medical services (EMS) can arrive, the only effective method available to save the patient's life is through CPR, in which a bystander would have to resuscitate the patient.

Unfortunately, the help that the patient receives is also largely dependent on socioeconomic factors. High-income areas with plentiful resources will be more equipped and well connected to get the appropriate medical attention, while impoverished areas are not only less-equipped, but also more susceptible to cardiovascular issues. When administered, CPR is the only effective measure for the average layperson to substantially increase an OHCA victim's survival rate. This paper will first review the limitations in the prevention of cardiac risk and in administration of lifesaving CPR techniques. Above all, this study aims to consider the societal and on-site issues pertaining to CPR in order to improve upon its low success rate and develop one of the most accessible, effective, and economically sound solutions possible.

Socioeconomic Factors and Cardiac Risk

The incidence of OHCA is largely dependent on the cardiac health of the individual. Sudden cardiac arrest is closely related to coronary artery disease and is dependent on many genetic and environmental factors. Many of these include a family history of coronary artery disease, smoking, high blood pressure, high blood cholesterol, obesity, diabetes, and an inactive lifestyle (Mayo Clinic, 2021).. These problems are prevalent in older populations, and those over the age of 60 constitute approximately 60% of the incidence of cardiac arrest (Mayo Clinic, 2021). However, age is only one aspect to the complicated web of factors that affect cardiovascular health. A significant and complex indicator of poor cardiac health and higher incidence of cardiac arrest is SES. Observing four major markers for socioeconomic status (income level, educational attainment, employment status, and environmental factors), researchers found strong links between poor cardiovascular health and lower socioeconomic status.

A study analyzing urban populations in North America found that those within the impoverished demographic were disproportionately affected by the incidence of sudden cardiac arrests; at six of the seven metropolitan sites, sudden cardiac arrest was shown to occur at a significantly higher rate in the lowest socioeconomic quartile than in the highest one (Reiner et al, 2011). Additionally, those with lower socioeconomic status tended to have a greater risk for cardiovascular disease, poorer control over their risk factors, and longer delays in seeking hospital care for cardiovascular issues (Reiner et al, 2011). The lack of lower-income patients' compliance with medications or access to more expensive procedures/quality care (i.e. fewer yearly medical check-ups, less propensity to use aspirin) may account for higher risks for cardiovascular events and increased heart failure (Shultz et al, 2018). This issue may be further explained by the lack of basic health care funding, which is not guaranteed for these groups; the aforementioned correlation of cardiac arrest in lower socioeconomic groups was stronger in sites in the United States than in Canada (Reiner et al, 2011), where universal health care is provided. In fact, although a substantial proportion of patients who have sudden cardiac arrest have preceding symptoms such as angina, dyspnea, nausea, and syncope, many victims ignore these symptoms or avoid the hospital entirely, especially if they are afraid of the significant and uncovered costs of attending emergency services. This potentially heavy financial burden may account for the higher occurrence of sudden cardiac arrests, along with delays in seeking emergency help, in underprivileged populations (Shultz et al, 2018).

Cumulative socioeconomic backgrounds of the neighborhood have also shown increased risk factors and mortality rates; neighborhood disadvantages, such as accessibility of transportation, recreational space, cost of healthy foods, along with social factors, such as safety, lack of social support, and a sense of community, have influenced the availability of the proper resources needed to lead a healthy lifestyle. Meanwhile, lower education and unemployment are both attributable to behavioral risk factors, such as smoking and physical inactivity, while dietary and lifestyle mediators (most commonly alcohol and smoking) only exacerbate the risk for cardiovascular events (Shultz et al, 2018).

Considering the lack of stability in one's life, it becomes difficult for impoverished people to care for their families, causing them to lack medical support (i.e. prescriptions, medical appointments), and experience a greater likelihood of falling victim to drug addiction. Thus, drug abuse and overdoses are more concentrated in economically disadvantaged zip codes (Grinspoon, 2021). Especially because recreational drug use is cited as a cause of cardiac arrest (*Causes of cardiac arrest* 2021), these factors, in conjunction with the other, already-prevalent risks, only further predispose those of poorer demographics to fall victim to cardiac arrest.

Other psychosocial issues, such as stress and depression, not only increase the risk of cardiac arrest, but also disproportionately impact poorer individuals. Long-term stress resulting from poverty can increase inflammation in the arteries, as people with higher levels of stress were found to have higher risks of having a major cardiovascular event: those earning less than $35,000, annually reporting stress and depressive symptoms, were found to have a 48% increased risk for developing cardiovascular disease, an association nowhere near as present in those earning a greater salary (Schultz et al., 2018).

Ultimately, the occurrence of bystander CPR was also found to be lower in low SES communities. If the members of the community are educated or familiar with proper medical practice and infrastructure, bystander CPR will be more successful, and survival rates will improve. For these complex perspectives, economically disadvantaged areas should be targeted with CPR training and education in order to best combat the low survival rates, along with the occurrence of such incidents in said demographics. There are numerous long term solutions that may improve the health of people at risk for cardiac arrest. One proposed intervention to improve health behaviors and risk factors would be to focus on targeting traditional risk factors of cardiovascular diseases heavily linked with lower SES. Methods such as behavioral counseling have proven effective in including the reduction of blood pressure, diabetes melitus, and cholesterol levels. Another proposal would be an increase in physical activity in communities with lower SES, especially given its widespread benefits and inexpensive nature. Yet, factors such as physical insecurity (i.e. crime rates), lack of proper infrastructures (i.e. sidewalks, bicycle paths) in one's neighborhood makes it extremely difficult to maintain sustainable habits of physical activity (Shultz et al, 2018).

Though these solutions are effective ways to improve the health of the whole populace, implementing these solutions on a wide scale is resource intensive and will take years to see the initial reform. Preventative measures such as the ones mentioned above should certainly be pursued, but there must exist a better means of improving survival rates when a patient is undergoing cardiac arrest. Therefore, focusing on responsive measures such as CPR is imperative to save the lives of those who are in immediate risk of cardiac arrest.

On-Site Responses to OHCA: CPR and the AED

CPR is a technique that is used in a medical emergency in which the patient's hearts or lungs have slowed or stopped. When the heart has slowed down to a ventricular fibrillation rhythm that is incompatible to life, the only other recourse to save the patient is to defibrillate the heart with a device such as the automated external defibrillator (AED) to restore normal cardiac functioning. For every minute that CPR is not performed after a cardiac event, survival rate decreases by 7-10% (Ibrahim, 2007). Therefore, the actions of bystanders during the first few minutes after the onset of OHCA is crucial for the survival of the patient. During an OHCA, the best recourse for bystanders or first responders is to start CPR with hard and fast chest compressions. CPR allows oxygen-rich blood to flow to the brain and other vital organs until medical services can arrive at the scene and use more advanced techniques and medical devices to resuscitate and transport the patient (Mayo Clinic, 2022).

For CPR to be performed successfully, there are three important processes to keep in mind:

1. Compression: Perform compressions to restore air flow. The hands should be placed palms down stacked on top of each other on top of the person's chest. Then quick, shallow compressions with a depth of at least 2 inches (5 centimeters) and less than 2.4 inches (6 centimeters) should be administered at 100-120 beats per minute. The depth and timing are crucial to the successful administration of CPR.
2. Airway: Open the patient's airway. When at least 30 chest compressions have been performed, lift the chin and head in a specific position until the patient's airway is open.
3. Breathing: Rescue breathing must be performed to help restore breathing. Mouth-to-mouth breathing or mouth-to-nose breathing (in the case that the mouth is not accessible due to injury or another obstruction) must be applied.

These three steps are to be repeated until EMS workers arrive (Mayo Clinic, 2022). Unfortunately, seven out of ten cases of cardiac arrest occur inside one's own home (*Three Things You May Not Know About CPR*, 2021), where victims may not have access to care before an ambulance arrives, compounded by the fact that, in America, EMS units average 7 minutes from the receipt of a 911 call to arrive on-scene, with a median of 14.5 minutes in rural areas (Mell et al., 2017). Within this interval, it is essential that the bystander takes action so as to prevent the victim from undergoing irreversible neurological damage or death.

A critical device that can be used either by bystanders or first responders to resuscitate OHCA patients is the automated external defibrillator (AED). These portable devices range from $1,275 to up to $2,875 and can be placed in non-hospital settings such as schools and public buildings (Cardio Medical Partners, 2022). After analyzing the pulse of the patient, AEDs deliver a shock to their body in an attempt to restore the heart's rhythm to a regular one (typically from shockable irregular rhythms, such as by ventricular fibrillation) and can be administered by lay bystanders. However, it is highly recommended that people with access to an AED be trained regularly and extensively. Additionally, there are certain issues that arise from AED usage, such as cost, access, and portability that will later be addressed, especially given this study's objective of improving CPR accessibility and outcomes, including for those of lower SES.

Accessibility and Availability of CPR Training and AEDs

Timely CPR performed by a bystander has been shown to double or triple the chances of survival from witnessed cardiac arrest at many different intervals to defibrillation (Ibrahim, 2007). Intuitively, the more people are trained in CPR in a given community, the more frequently it is performed. For instance, Los Angeles, with a relatively small percentage of citizens trained in CPR, saw only a small percentage of bystanders performing CPR, and just 1.4% OHCA victims survived. Seattle, with one of the highest frequencies of bystander-performed CPR in the USA, saw 10 times more success in survival rates (>15%) (Roppolo & Pepe, 2009): improvements in survival were not linear, but potentially logarithmic. Thus, increasing the opportunities of CPR education for all individuals across the nation could serve as one of the possible solutions to increase OHCA survival rate.

However, in addition to the slow return on the investment, CPR training for the general masses faces one too many hurdles to be a practical solution. First, CPR training is simply not prevalent throughout the country. Although CPR training courses are readily available, only 2.4% of the population have undergone CPR education of any kind (Brown & Halperin, 2018). According to a cross-sectional, nationally representative survey, factors such as older age, poor education, and lower income were associated with reduced likelihood of CPR training, further dooming victims in lower SES areas, and, despite many efforts to increase the interest in CPR courses, they have been largely unsuccessful (Brown & Halperin, 2018).

One way to ensure access to CPR education for the general population is to implement training into schools' curricula as a graduation requirement across the nation. In fact, the majority of states in the US have passed laws incorporating CPR education into the educational curriculum. However, there exists variability in the extent of implementation, especially as there is no one standard of teaching CPR with different courses provided by different organizations (such as the American Heart Association (AHA) and American Red Cross). Without clear parameters and regulations, this endeavor is currently ineffective. The only recommendations for schools by the AHA include recognizing the need to initiate CPR, physically practicing CPR, and learning about the utility of defibrillators. However, to ensure the best CPR quality, stricter standards should be upheld, including, in addition to all of the aforementioned recommendations taught by a qualified instructor, the use of non-inflatable mannequins in lessons, and actual instruction on defibrillator use. Only 23% of schools responding to a recent survey meet these standards, indicating a waste of time and financial resources for schools (Brown & Halperin, 2018). Legislation alone, while it may promote CPR education, is not enough to improve the outcome of CPR.

Soon, all 50 states will have passed legislation requiring CPR training in high school (Brown & Halperin, 2018), making it imperative to evaluate and improve upon current CPR training methods. Especially since poorer areas receive less CPR training and high-quality education, it may be seen as a waste of resources to incorporate regulations introducing CPR to lower SES environments, with minimal improvements in CPR outcomes. Yet, previous experience in training increases bystanders' confidence and willingness to perform CPR, so creating the most cost-effective means of education would allow the government to improve CPR performance, reach more laypersons, and save more lives while eliminating conflicting financial interests hindering this goal.

Still, even for those that are trained, CPR skill retention is a prevalent issue for bystanders and healthcare professionals alike – repeated training correlates with better retention of skills. Data suggest that rolling refresher courses that provide short, frequent exposures to hands-on CPR practice improve skill retention (Brown & Halperin, 2018); thus, it would be ideal for high schools to implement recurring lessons in addition to initial training.

Even if the skill is retained, another serious issue that arises from CPR performance is that during the actual administration of CPR, there is no method that allows bystanders or even EMS personnel to check whether the chest compressions have successfully been delivered following the guideline depths. Many fail to realize that the ability to compress the chest to guideline standards does not rely on strength, but rather, factors such as the stiffness of the victim's chest, the weight distribution of the rescuer, and the delivery of compressions (Trenkamp & Perez, 2016). Critical mistakes have been prevalent in emergency medical technicians (EMT) and paramedics, who are certified and frequently refreshed with CPR training. In one experiment that tested the medical professionals in the effectiveness of their chest compressions, four out of five test subjects failed to perform successful CPR due to excessive rate, while five-eighths of the subjects applied excessive force on the sternum that would cause further damage to the patient (Trenkamp & Perez, 2016). In addition to the obvious need to educate and refresh the public about CPR, this difficulty demonstrates the need to aid the CPR performer in action, especially those who have little to no experience.

In addition to the lack of CPR training, there are also troubling statistics on the racial and socioeconomic disparities in the prevalence of bystander CPR and use of AEDs. In a Texas study published in 2020, results revealed that the Black community has experienced the worst survival rates; cardiac arrest incidences are normally higher in Black communities, but AED use was an abysmal 3.2% compared to 11.2% in white neighborhoods. While the Latino communities had a 4.9% of AED use, there was a significantly lower rate of CPR administration of 38% compared to that of white neighborhoods at 47.5% (Huebinger, 2020). Socioeconomic barriers were also a strong determinant of the quality of care received after an OHCA. Lower income areas have an 8.4% of AED use compared to high income areas that have a 11.9% use of AEDs (Huebinger, 2020). In low SES areas, access to AEDs are also limited because the devices are cost prohibitive and need extensive training for effective use. This creates substantial geographic variation in the rates of bystander CPR (10-65%) and resultant survival (3-22%) in the country (Brown & Halperin, 2018).

The majority of the time, bystanders report OHCA to emergency dispatchers but do not perform CPR and await the arrival of medical professionals on site (Kurz et al., 2020). This is likely due to the fact that most bystanders would have minimal experience. Thus, the use of telecommunicator CPR (T-CPR), which stems from dispatchers assisting bystanders in performing CPR, has been recommended by AHA guidelines to improve upon OHCA response. With the implementation and proper training in every emergency response unit, not only would dispatchers help identify if a patient is in cardiac arrest, but they would also provide CPR instructions to the inexperienced while quickly sending EMS on-site (Kurz et al., 2020). This holds potential to greatly increase effectiveness of CPR, and thus improve survival rates, especially in low SES areas.

An Accessible Device to Increase the Efficiency of Bystander CPR

The AED is an effective but expensive method to resuscitate victims of OHCA, and it provides instructions to bystanders as to how to perform CPR. The AED, composed of the electrode pads, battery, capacitor, and the processor, is highly priced due to its components which have to deliver a powerful shock to the patient's body (and for that reason, is not commercially available). Additionally, due to their large size and weight, AEDs are typically placed in cabinets mounted on walls, lacking true mobility and, thus, accessibility at all times. A further deficiency of AEDs is the additional cost of maintenance; batteries and pads are required to be replaced every 2-3 years, which cost an extra $150-$400 for each replacement (Avive Solutions, 2021). This paper proposes an alternative device which will be much cheaper and will focus on educating the bystander to perform the most effective CPR until EMS arrives with a defibrillator. While it may not replace the AED, the device will be able to monitor the victim's chest to provide feedback to the bystander, and can even be used in conjunction with an AED to optimize the quality of CPR. Especially given its size and substantially lower cost, it has potential to develop widespread availability and improve the quality of administered CPR and accessibility of quality care. The device will have 3 main components.

Implementation of a metronome to keep track of rhythm and timing of chest compressions

An essential guideline to consider for the optimal survival of OHCA victims is administering the proper rhythm of 100-120 beats per minute for resuscitation. Compression rate is associated with ROSC at a cubic spline curve that peaks at a compression rate of 125 beats per minute: those receiving <75 delivered compressions per minute and/or frequent interruptions are less likely to achieve ROSC, though it also suggests a decline with compression rates >125 per minute (Nolan et al., 2012). Compression at a rate too fast and/or with too much residual weight on the victim's sternum does not allow for the victim's chest to properly recoil, and the root cause is an inability to self-regulate the rhythm in most EMTs and paramedics alike (Trenkamp & Perez, 2016).

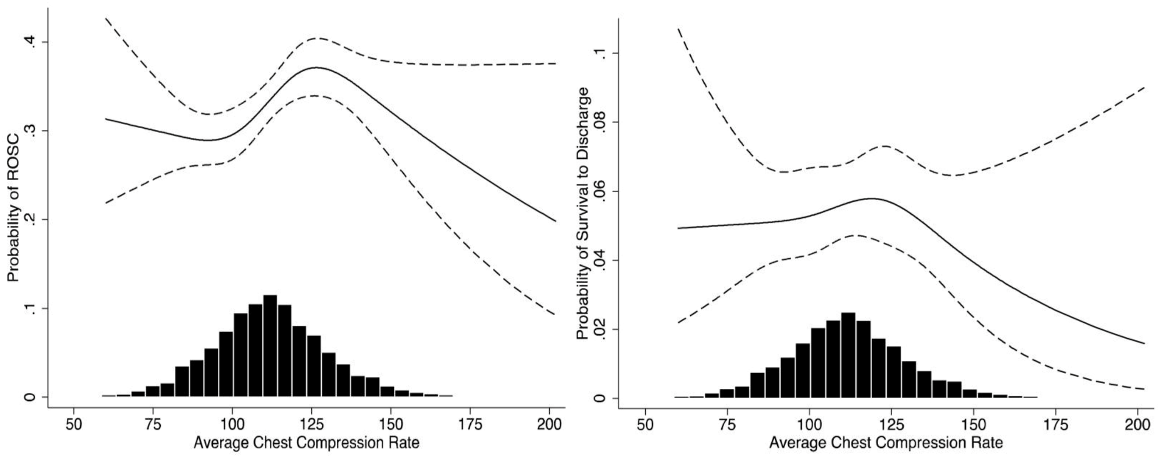
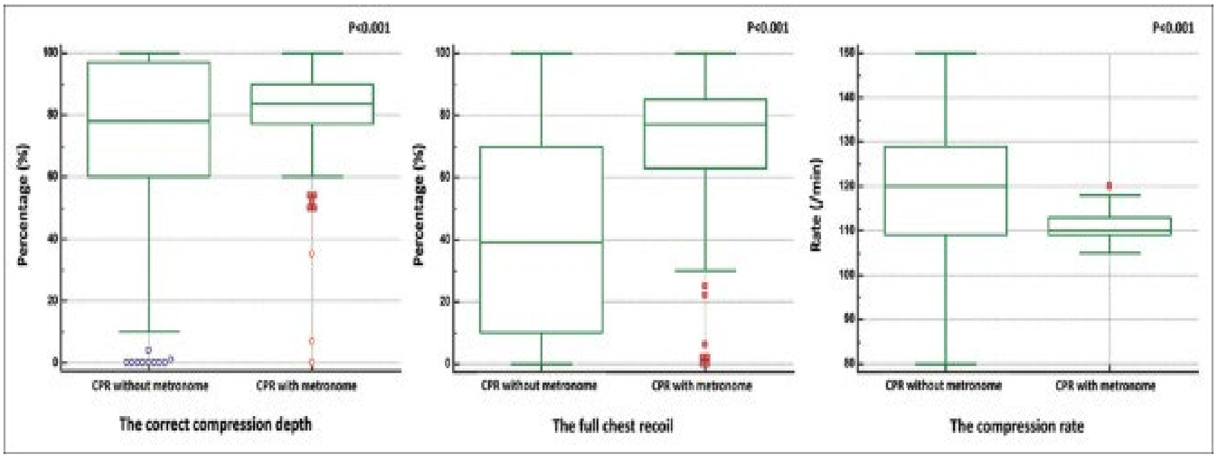


Figure 1. The relationship between CPR compression rate and ROSC and subsequent survival, based on 3,098 analyzable cases recorded via monitor-defibrillators. Cubic spline graph, accounting for error and adjusted for factors such as age, location, and CPR attempted by bystanders V.S. EMS– as modeled by a logistic regression, probability of ROSC gradually increases along a curve before peaking at 125 BPM and rapidly declining afterwards, yet probability of survival to discharge seems to peak at around 115 BPM. Additionally, both histograms depict how most patients were resuscitated at a rate of 110 BPM. Thus, it seems as though a compression rate of 110-125 BPM would be ideal (Idris et al., 2012).

Although CPR training courses recommend the use of popular songs such as "Staying Alive" by the Bee Gees, which provide the ideal tempo to administer CPR, the bystander may not keep a steady rhythm on their own when undergoing a stressful situation (arising from a so-called "performance anxiety"). Currently, AEDs replay instructions as to how to perform CPR and emit a rhythm to help the bystander perform the compressions at the correct rate. Thus, it would be ideal for those untrained to receive an audio guide to keep track of their pace. For a more accessible device, a more economical way of implementing a steady pulse rate would be the incorporation of a metronome. A metronome is a device that emits a sound at a regular speed, measured in beats per minute. Traditionally used to keep time for musicians, the metronome is a cost-effective and simple method to help bystanders keep time for their chest compressions. Given that the heart beats rhymically, and so does a metronome, the use of metronome during CPR as a guide has shown to improve its quality by 22% (Neighmond, 2015). In other words, a metronome would serve as a feedback mechanism for rescuers to know they are providing compressions at the appropriate rate. A device that provides active feedback would allow bystanders performing CPR (regardless of skill-level) to benefit both psychologically and in terms of quality; improved confidence in performance during a high-pressure situation can also work to negate anxiety, and hence, reduce errors (i.e. dragging/rushing), especially if the performer feels as though he/she would be able to receive assistance and depend on the consistent, correct instruction of a metronome.

In fact, a survey indicated that 94.1% of of medical professionals and participants were either receptive or neutral towards the idea that metronome usage had a positive effect on their CPR performance (70.6% in agreement and 23.5% neutral), with 97.1% receptive or neutral towards incorporating metronome use during CPR routines (66.7% in agreement and 30.4% neutral) (Çalışkan et al., 2021). With a metronome set to 110 BPM, resident physicians achieved not only complete recoil with 77% efficiency, as compared with 39% without one, but also an increase in optimal chest compression depth with 83% efficiency (as compared with 77% without one). The variation in the compression is also significantly closer to normal guidelines (interquartile range of 109–113) with metronome use than without (IQR pf 109–129) (Çalışkan et al., 2021). With the overwhelming majority not only improving with the help of a metronome, but also welcoming it in their CPR regimen, its incorporation should expect little resistance. Based on these data and the current guidelines, it seems



as though a range of 110-125 BPM emitted by the metronome would be ideal.

Figure 2. The efficacy of CPR with the use of a metronome; as can be seen, not only do compression depth and rate become closer to established guidelines, but consistency also increases. Based on the data and standard deviation/error, variability and the interquartile range with a metronome is much smaller than that of CPR performed without one (Çalışkan et al., 2021).

Measurement of patient’s chest dimensions for proper administration of chest compressions

Ineffective chest compressions may be fatal to the OHCA patient in the first few minutes after the onset of cardiac arrest. According to the official guidelines of CPR, chest compressions have to be between 2 inches (50 millimeters) and less than 2.4 inches (60 millimeters) (AHA, n.d). This narrow margin may be difficult to follow in high stress environments and lack of training: laypersons may not provide compressions of adequate depth which creates less blood flow, diminishing survival rates and the chance of ROSC. As previously mentioned, multiple studies have already established that chest compressions are widely varied even among medical professionals. Especially because compression depth tends to decline with increasing rate in chest compression, bystanders will need a method to track their chest compressions to ensure optimal compression depth, and hence, increase the survival rate of the patient. Additionally, excessive depth and force applied often does not allow for the full or proper recoil of the chest, in which it must return to full expansion in order to maximize refilling of the heart leading to less blood flow which reduces rates of ROSC and survival. Compressions at an excessive depth also hold potential to break the sternum or surrounding ribs, causing further damage to the victim (Barger, 2014).

To ensure that the correct depth of CPR is performed, the proposed device will track the movement of the chest cavity using accelerometers. The device is to be placed on the victim's chest, and, as it measures the rate and force at which it rises and falls, it would be able to determine the distance traveled. In conjunction with a microcomputer such as RaspberryPi, it would analyze the chest compressions in real-time to evaluate the efficacy of the bystander's actions. A thick rubber plate on the bottom would be incorporated so as to prevent sliding and serve as a resistor to withstand the shocks provided by a defibrillator. It would analyze compressions from a starting point to determine not only the depth of the compression, but also if full recoil occurs.

The use of accelerometers have already been used in methods for CPR feedback, in which they can detect the chest's acceleration during compressions and double integrate the acceleration in order to calculate the instantaneous chest displacement (González-Otero et al., 2018). More specifically, a triaxial accelerometer can record the acceleration values of the x-, y-, and z-axes, accounting for gravitational influence, to determine the overall direction of the device. Yet, there are certain limitations to this method of data processing: for instance, cumulative integration errors may result from variable environments, chest elasticity, etc., affecting the accelerometer's calculations (Lu et al., 2018). Additionally, the initial value of the device's velocity/position would be essential to determining recoil and distance traveled but would not be available simply using integration. Similarly, integration drift would accumulate from baseline offsets of the device, such as instability of the device and calibration errors, which are often unavoidable and create significant errors when double integration is used (Lu et al., 2018). Thus, algorithms have been established in which the magnitude of maximal acceleration is determined from the data recorded within time intervals during each chest compression, in which the value and its change in direction is determined and related to the acceleration at the proximal point (Lu et al., 2018). The algorithm would be modeled by acceleration squared divided by the number of time points recorded within an interval (Lu et al., 2018), based on the "respite" periods in between each chest acceleration and displacement (González-Otero et al., 2018). To account for varying environments and individual's chests during compression, the device would utilize a "machine learning" technique of sorts, testing sample inputs and predicting future data to determine accurate compression depths.

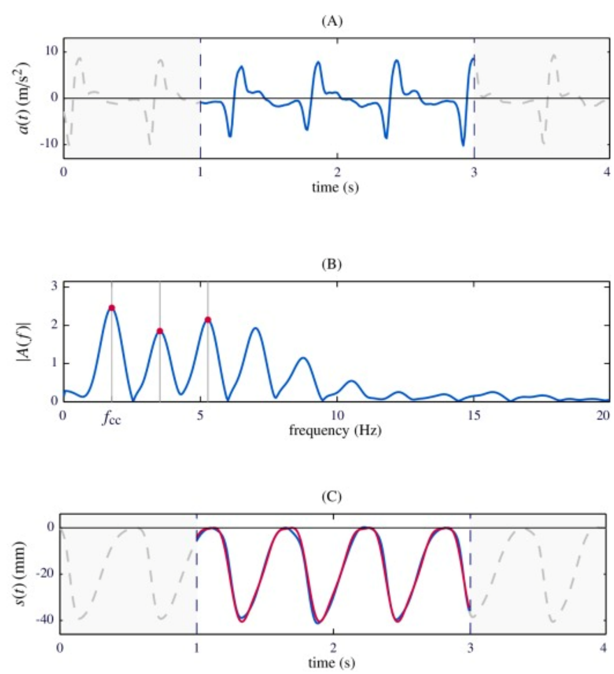


Figure 3. After selecting a given time interval, the algorithm detects compression activity based on power, reconstructing compression signals, depicted in red, which calculates feedback rate and depth values in millimeters (provided in the bottom-most graph). A similar algorithm for the device would be used, in which for each compression and time interval, the device would model the acceleration over each time point within the interval, detect the maximum acceleration (and proximal point), and compute the compression depth and rate for feedback (González-Otero et al., 2018).

To ensure that full recoil is achieved, force sensitive resistors have been used to account for residual weight (Jacob et al., 2019), and would be placed on the top of the device to detect any pressure. Thus, an algorithm utilizing accelerometers, along with force sensors, could be used to detect the force applied to the patient's chest, which may be especially important during the recoil upwards (so as to allow for full recoil and the elimination of residual force). It would provide real-time, visual feedback to ensure adjustment of compressions.

Easily accessible graphics user interface (GUI) to provide real-time visual feedback

It is well established that the quality of CPR administration even after initial education is difficult to uphold. A study assessing the quality of CPR education proved that even health-care professionals who frequently undergo refresher courses for CPR every two years (in order to maintain certification) were only able to perform optimal CPR 28% of the time without CPR quality feedback (Brown & Halperin, 2018). CPR outcomes improved greatly when instruction was displayed on a screen in front of a group of laypersons, with 13.6% better depth and 20.5% better rate of recoil than those of a control group (Tanaka, et al., 2019). The proposed device will have a screen with a simple user interface to provide the bystander with real-time visual feedback of their performance. Based on the accelerometer and force sensor's readings and algorithm, the programmed device would be able to process said data in real time to evaluate each individual compression to determine if it is the correct depth and at the correct pace. With the program instructing the bystander to adjust their implementation of CPR in real time, the CPR performer can constantly adjust the pace and the pressure of compression to achieve the maximum outcome given the education.

The use of LEDs would allow the device to provide feedback pertaining to the compression rate: similar to certain manikins that provide light feedback based on the rate of compression, the device would have different colored lights that would light up pertaining to the rate of compression. To ensure a detailed, yet straightforward feedback system, the lights would indicate as follows: the bottom-most light, which would be red, would light up when CPR is performed below the guideline's minimum recommended rate of 100 BPM; the first of the green LEDs above that would light up when CPR is performed within the recommended rate of 100-125 BPM (based on both established guidelines and aforementioned data); both green LEDs would light up when CPR is performed at a rate of 110-120 BPM (based on the data indicating the most optimal BPM correlated with survival to discharge); the top-most, yellow LED would light up when CPR is performed above the optimal rate of compression (>125 BPM). This would allow for the responder to adjust the rate of their compressions, improving their quality of CPR. Accelerometer-based feedback devices are said to result in slower compression rate due to the increased consciousness and accuracy of each compression (Kornegay et al., 2018), so to account for this, the metronome would likely play at a slower compression rate, though the ideal rate and depth combination would have to be tested for via the experimentation and application of the device.

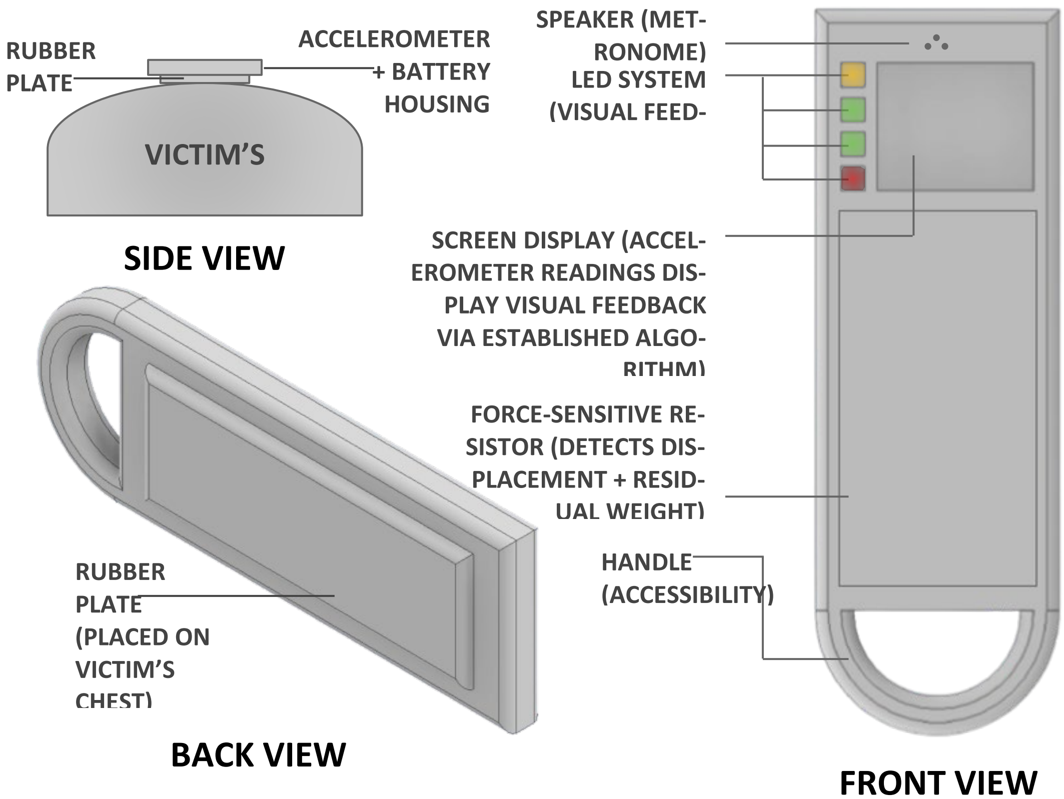


Figure 4. The design of the accessible CPR device will be lightweight and compact, and to be placed on the victim's chest. Based on the feedback algorithm developed, accelerometer readings will be able to detect vertical displacement, determine if the rate of compressions administered is accurate, and provide visual feedback to aid the layperson. Not to scale; dimensions of the device should be determined based on tests for optimal size and surveys for perceived comfort when utilizing the device.

Limitations

Although an accessible device for CPR administration may be effective for immediate survival rate, the utility of this device will only increase when more of the population is educated on the nature of OHCA (likely arising from the aforementioned policy-based proposals, such as providing access to effective training for everybody). Currently, there is not a single government or private entity in the US that has provided an endorsement or standardization of CPR training courses (Brown & Halperin, 2018). The creation of an independent accrediting body that oversees the quality and effectiveness of CPR training will greatly improve the standard for CPR training. At the current moment, dispatcher instruction and the use of telecommunicator CPR seems to be the best means of combating this issue. Given the link between OHCA and the initial 911 call to a dispatcher, the AHA has highly recommended dispatcher-assisted CPR over the phone in order to improve survival for OHCA, even including it in its guidelines (Kurz et al., 2020). Especially because in the majority of cases, laypersons make the initial call to 911, but do not perform CPR (Kurz et al., 2020), it is evident that most would stand to benefit from further instruction as to how to perform CPR until emergency medical service is able to arrive with a defibrillator. This would likely make for one of the best means of improving upon CPR performance, quality, and survival rates in that even those with no experience would be able to perform CPR with the instruction of a dispatcher and the feedback of an accessible, non-invasive, and straightforward device.

Another issue with the device is that it cannot fully replace an AED- the AED provides defibrillation, in which immediate therapy with defibrillation has been shown to be by far the most effective treatment when performed within the first five minutes of collapse (Ibrahim, 2007). However, immediate CPR is able to provide a critical amount of blood to the heart and brain while waiting for a defibrillator to arrive. With the arrival of a defibrillator CPR increases the likelihood that a shock successfully terminates irregular heartbeats such as ventricular fibrillation, and especially important if a shock is unable to be delivered within five minutes of collapse (Ibrahim, 2007). Many victims of sudden cardiac arrest, therefore, can survive if bystanders act immediately, with quality compressions, without the immediate use of an AED. The ultimate goal of this device would be to be manufactured and disseminated at a fraction of the cost of an AED, and most AEDs' costs derive from the cost of incorporating defibrillators while concurrently becoming FDA approved, creating a lack of widespread availability. Given that its main goal is to target those who cannot typically afford quality care and an AED, the incorporation of this device into the regimen of bystander/layperson. Until an affordable defibrillator becomes widely available, this device would currently stand as one of the cheapest, best means to combat OHCA deaths. Additionally, because it provides feedback with compression depth, a feature even the AED lacks, it could potentially even be used in conjunction with the AED to provide the most quality CPR, and thus, improve survival outcomes.

Conclusion

The causes and outcomes of cardiac arrest are complex and have multiple societal factors that will require greater policy and institutional changes to be able to increase the survival rate of those who experience an OHCA. Improvements in education are certainly beneficial, but will be cost-intensive. However, a low-cost solution must be available to all those with a higher risk of cardiac disease and cardiac arrest. With a low-cost device to instruct and guide lay bystanders to administer CPR, survival rate of patients after an OHCA may increase. Additionally, due to the fact that the device's features have been implemented based on the demonstrated benefits they provide to medical professionals, it is highly probable that professionals would stand to benefit from this device as well. Especially because the device would be used in concert with the AED. Future research should be focused on implementing the design of the proposed device and evaluate the ability of the device to educate untrained or minimally trained bystanders to follow instructions and administer the proper depth and timing of chest compressions on human dummies or replicas. Different variables, such as optimal chest compression depth, metronome's BPM emitted, size of the device, and battery used (voltage, longevity, and rechargeability), should be accounted for in order to adjust the device for optimal instruction and feedback. Perceived user experience pertaining to wieldiness and receptivity to the device are also factors that should be considered in improving upon the device. The device would first be tested by people in different groups based on experience (no experience, certified, or medical professional) and socioeconomic background (impoverished, middle class, and high-class) on manikins against a control group, and after its making appropriate adjustments, on a sample of humans before becoming commercially available. Then will the device, through its wide-spread use, hold applications to truly improve upon CPR quality and overall survival rates.

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