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Simulation and education

Using a smartwatch with real-time feedback improves the delivery of high-quality cardiopulmonary resuscitation by healthcare professionals

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Abstract

Aim: Cardiopulmonary resuscitation (CPR) quality affects survival after cardiac arrest. We aimed to investigate if a smartwatch with real-time feedback can improve CPR quality by healthcare professionals.

Methods: An app providing real-time audiovisual feedback was developed for a smartwatch. Emergency Department (ED) professionals were recruited and randomly allocated to either the intervention group wearing a smartwatch with the preinstalled app, or to a control group. All participants were asked to perform a two-minute CPR on a manikin at a 30:2 compression-ventilation ratio. Primary outcomes were the mean CCR and CCD measured on the manikin. A secondary outcome was the percentage of chest compressions meeting both the guideline-recommended rate (100–120 min^{-1}) and depth (50–60 mm) of high-quality CPR during a 2-min period. Differences between groups were evaluated with t-test, Chi-Square test, or Mann–Whitney U test depending on the distribution.

Results: Eighty participants were recruited. 40 people were assigned to the intervention and 40 to the control group. The compression rates (mean ± SD, min^{-1}) were significantly faster (but above the guideline recommendation, $P < 0.001$) in the control (129.1 ± 14.9) than in the intervention group (112.0 ± 3.5). The compression depths (mean ± SD, mm) were significantly deeper ($P < 0.001$) in the intervention (50.9 ± 6.6) than in the control group (39.0 ± 8.7). The percentage (%) of high-quality CPR was significantly higher ($P < 0.001$) in the intervention (median 39.4, IQR 27.1–50.1) than in the control group (median 0.0, IQR 0.0–0.0).

Conclusion: Without real-time feedback, chest compressions tend to be too fast and too shallow. CPR quality can be improved with the assistance of a smartwatch providing real-time feedback.

Keywords: Smartwatch, Cardiopulmonary resuscitation, Chest compression, Feedback device, Cardiac arrest, Wearable device

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Introduction

Despite the advancement of medical research and clinical practices, survival rate from cardiac arrest remains poor worldwide.[1–3] Previous studies have shown that prompt delivery of high-quality Cardiopulmonary Resuscitation (CPR) affects survival from cardiac arrest, whether CPR is initiated by a layperson in the prehospital environment, an emergency physician in the Emergency Department (ED), or a clinician in the inpatient ward.[4–6] In 2005, the American Heart Association (AHA) Guidelines for CPR and Emergency Cardiovascular Care (ECC) were revised and high-quality CPR was first introduced.[7] In the most updated 2015 AHA and European Resuscitation Council (ERC) guidelines, the emphasis on high-quality CPR remains the same. To fulfil the standard of high-quality CPR, rescuers should aim to perform compressions at a rate of 100–120/min and a depth of 5 cm (2 in.) to 6 cm (2.4 in.), allow full chest recoil after each compression, minimize pauses in compressions, and avoid excessive ventilation.[8]

To improve CPR quality, researchers have sought to develop prompt devices, or methods for providing feedback during CPR training or in clinical practice. In a recent review that included 42 studies with interventions to improve CPR quality, feedback or prompt devices were used as the main intervention in 7 studies and CPR experiments were all performed on manikins.[9] To date, there are only a few randomised trials that investigated the effect of feedback or prompt devices using real patients. In a cluster-randomised trial, Hostler et al. showed that real-time audio visual feedback provided by the monitor-defibrillator during CPR altered performance to more closely conform to guidelines in prehospital settings.[10] Another randomised study conducted by Bohn et al. reviewed the influence of different feedback configurations on survival and compression quality for patients with out-of-hospital cardiac arrest (OHCA), and found that the addition of voice prompts had only limited effect on CPR quality.[11] Although the studies to date are limited; the 2015 guidelines still recommend that it may be reasonable to use audiovisual feedback devices during CPR for real-time optimization of CPR performance, and feedback on compression technique can be considered as part of a broader system of care.[12,13]

To help rescuers in performing high-quality CPR and improve adherence to guidelines, various medical device companies have developed and marketed potential solutions to advance emergency care.[14–16] These devices, which incorporate sophisticated computational algorithms, are expensive, impractically large, and too complex to be used by bystanders in the pre-hospital environment. Although these devices can be used for training or clinical practice, they are used primarily by professionals. Currently, wearable devices are used for a variety of medical applications.[17] A wearable device can be broadly defined as a mobile electronic device that can be unobtrusively embedded in the user's outfit as part of the clothing or an accessory.[18] With the functionality of biosensors capable of wireless communication, these devices are considered to have the potential to transform the healthcare system and improve quality of care.[19] One of the wearable technologies gaining widespread popularity in the healthcare sector is the smartwatch. With its miniaturized design and intelligent computing technology, a smartwatch can be worn continuously without interrupting the user's daily activity. Although smartwatches have been used as a platform for a variety of healthcare applications, their applications in emergency settings have just begun.[20,21] To facilitate the delivery of high quality CPR, two different research groups have developed smartwatch apps with visual feedback to improve CPR quality on manikins.[22,23] The results varied in terms of CPR quality and the applications focused mainly on laypersons or medical students. Furthermore, these studies provided only on-screen reminders without audio feedback. Until recently, there have been no randomised control studies with professional healthcare providers that examined the impact of smartwatches on CPR quality. Our study sought to test a smartwatch app with real-time audiovisual feedback on the delivery of high-quality CPR by healthcare providers for patients with cardiac arrest in a simulated emergency setting. We hypothesized that a smartwatch-based chest compression feedback app would improve the quality of CPR on a sensorized manikin.

Methods

Study design

We conducted a randomised controlled simulation study during a study period from April 1st 2018 to June 30th 2018 at the ED of National Taiwan University Hospital (NTUH), a 2400-bed university-affiliated tertiary teaching hospital with daily service of about 8000 outpatients and 300 emergency visits. A smartwatch app capable of estimating CCD and CCR was developed for use in a smartwatch (ASUS ZenWatch 2 model WI501Q, Taipei, Taiwan), one of the major commercially available smartwatches of Android Wear with a built-in accelerometer and speaker. In this app, we introduced a novel algorithm for real-time CCD estimation based on the sensor data collected from the 3-axis accelerometer in the smartwatch. The validation study has been reported elsewhere.[24] User-Centred Design (UCD) was utilized during the design phase and a brief usability test was performed before the implementation of this app.[25,26] This part of the study has been completed and will be submitted in a future paper. ED professionals, who are Advanced Cardiovascular Life Support (ACLS)-certified doctors and nurses, were recruited and randomly allocated to either the intervention group wearing a smartwatch with the preinstalled app, or to a control group without the smartwatch. All participants were asked to perform a two-minute CPR on a Resusci Anne QCPR training manikin using the 30:2 compression-ventilation ratio. The quality of CPR performed on a sensorized manikin (simulated an adult cardiac arrest victim) by healthcare providers was compared between groups. The study protocol was reviewed by the Research Ethics Committee of NTUH and was considered IRB exempt in accordance with the governmental laws and regulations (NTUH-REC No.: 201803090W). This study was also reviewed and determined IRB exempt by the University of Washington Human Subjects Division (IRB ID: STUDY00001681).

The display feedback module of this app shows the estimated values of CCR and CCD in real-time on the smartwatch screen at a 5-Hz refresh rate. It displays a turquoise background of circular light if both the CCR and CCD match the standard of high-quality CPR or a red background if they do not (Fig. 1). The audio feedback module is comprised of two parts. The first part uses verbal commands to help rescuers better adhere to the guideline-recommended rate (100–120 min^{-1}) and depth (50–60 mm) of high-quality CPR. When activated, rescuers hear “Push faster”, “Push slower”, “Push harder”, or “Push softer” in response to the estimated values of CCR and CCD determined by the algorithm implemented on the smartwatch, with the CCR being on the first input for decision in the audio feedback flowchart (Fig. 2). Since too much verbal feedback may disturb the

Fig. 1 – The smartwatch screen displays a different color of circular background in response to both the estimated chest compression depth (CCD) and rate (CCR). Circular turquoise light indicates the current chest compression is meeting both the guideline-recommended rate (100-120 min^{-1}) and depth (50-60 mm) of high-quality CPR, and red indicates it is not.

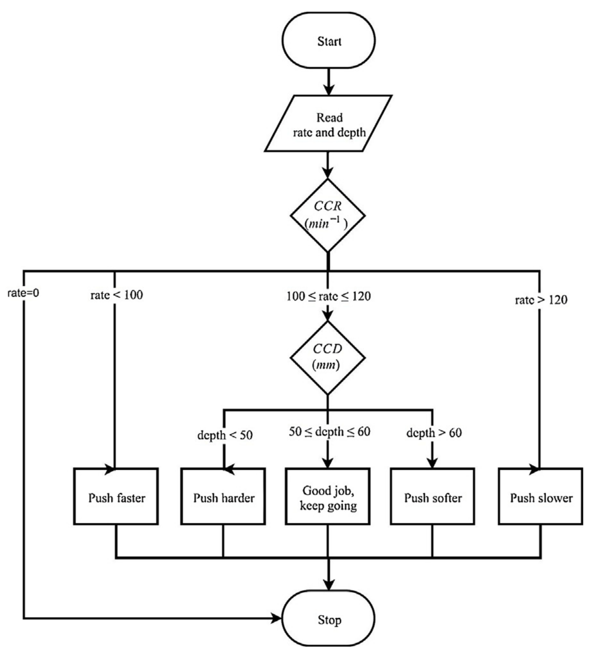

Fig. 2 – The audio feedback flowchart, where chest compression rate (CCR) was designed as the first input for decision in the feedback algorithm, and chest compression depth (CCD) the second.

rescuers, we set the feedback interval to be 3 s in this study according to our UCD and usability testing, but it can be adjusted to 5 s or 10 s according to users' preference. For encouragement, rescuers hear "Good job, keep going" if their chest compressions are judged to be fulfilling the standard of high-quality CPR. The second part of the audio feedback is the use of metronome-like sound to guide the tempo during chest compressions. The rate can be set between the frequencies of 100–120 beats per minute, and was set as 110 for this study based on our pre-implementation UCD and usability test.

Although this study focused mainly on healthcare providers who should perform chest compressions and ventilation at a 30:2 ratio, the app can also be utilized by laypersons to perform chest compression-only CPR by adjusting it to "hands-only" mode. In our study, the app was set to "professional" mode. Rescuers (allocated to the intervention group) heard "Please open airway and give two rescue breaths, first breath, second breath" after approximately 30 consecutive compressions during the CPR attempt.

Inclusion and exclusion criteria

Participants were recruited through the use of flyers distributed via hospital intranet and by word of mouth from current researchers. Informed consent was obtained and participants were apprised of the nature of the research and participation. All subjects were told that their CPR performance would be evaluated, and participant identifiers to be collected included only profession, years of working experience in their current position, age, and gender. Participants eligible for enrolment included those healthcare providers who were 20–65 years old, currently held a clinical license to practice nursing or medicine and board-certification at an acute care facility, currently involved in caring for adult patients at an acute care facility, and currently held a valid certificate of ACLS issued by recognizable organizations such as AHA or other relevant authorities. Individuals who were medical students, younger than 20 or older than 65 years old, without an active ACLS certificate, or individuals who were primarily involved with taking care of paediatric patients were excluded from the study.

Data collection

Participants were recruited and eligibility was assessed. All enrolled participants received a two-minute demonstration of the feedback features of the smartwatch by one of our researchers before the experiment. The standard of high-quality CPR for healthcare providers was also reviewed during the demonstration. Afterwards, participants were randomly allocated to either the intervention group or the control group by simple randomization using a coin toss.[27] Without any trial attempt, all participants were asked to perform CPR for two minutes, with chest compression and ventilation at a 30:2 ratio. They performed CPR on a Resusci Anne QCPR training manikin (Laerdal Medical, Stavanger, Norway) placed on the floor in one of our ED observation units (Fig. 3). A standardized Bag-Valve-Mask was ready to be used beside the manikin. Participants

Fig. 3 – A participant allocated to the intervention group wearing a smartwatch (ASUS ZenWatch 2) with pre-installed app performed chest compression on the manikin.

received instant reminding by an investigator if they forgot to perform ventilation in response to the audio command alerted by the watch in the intervention group or by the supervision of the investigator in the control group after about 30 consecutive chest compressions, and were labelled as failure to be adherent to the 30:2 compression-ventilation guideline (no matter how many times they were reminded during a 2-min CPR). Beat-to-beat CCR and CCD in each compression were recorded using Laerdal PC SkillReporting software (Laerdal Medical, Stavanger, Norway).

Data analysis

The collected data were processed using Microsoft Excel 2007 (Microsoft, Redmond, Washington, USA) and analysed using SPSS statistical software for Windows (Release 17.0, SPSS Inc., Chicago, IL, USA) or MedCalc for Windows (version 15.2.2, MedCalc software, Mariakerke, Belgium). The corresponding real-time sensor data generated by the accelerometer on the smartwatch were also collected using SensorsApi (Google, Menlo Park, California), but not utilized in this study.

Primary outcomes were the episode mean values of beat-to-beat CCR and CCD measured on the manikin by each participant during the 2-min period.[28] A secondary outcome was the percentage of beat-to-beat chest compressions meeting both the guideline-recommended rate (100–120 min^{-1}) and depth (50–60 mm) of high-quality CPR by each participant during the 2-min period. The tertiary outcome was the number of participants receiving at least one reminder from the investigator for forgetting to perform ventilation after about 30 consecutive chest compressions during CPR in each group. Differences between groups were evaluated with the t-test, Chi-Square test, or Mann–Whitney U test depending on the distribution.

Results

In this randomised controlled simulation study, 80 ED professionals were recruited. No one was excluded due to ineligibility. Of the enrolled participants, 40 people were assigned to the intervention group and 40 to the control group. A total of 11,737 compressions were collected, 5775 (49%) of which were performed by the intervention group. Participant demographics are shown in Table 1. There were no differences between the intervention and the control groups in terms of participant profession, years of working experience in their current position, age, and gender.

The compression rates (episode mean ± SD, min^{-1}) were significantly faster (but above the guideline recommendation, $P < 0.001$) in the control group (129.1 ± 14.9) than in the intervention group (112.0 ± 3.5). The compression depths (episode mean ± SD, mm) were significantly deeper ($P < 0.001$) in the intervention group (50.9 ± 6.6) than in the control group (39.0 ± 8.7). Data comparison graphs on the chest compression distributions are shown in Fig.4. The percentage (%) of high-quality CPR was significantly higher ($P < 0.001$) in the intervention group (median 39.4, IQR 27.1–50.1) than in the control group (median 0.0, IQR 0.0−0.0). The percentage distribution of high-quality CPR is shown in Fig. 5. The number of participants who received the investigator reminders for forgetting to perform ventilation after about 30 consecutive chest compressions was significantly higher ($P < 0.01$) in the control group (11 over 40) than in the intervention group (1 over 40).

Table 1 – Participant demographics.

	Control (n = 40)	Intervention (n = 40)	P value
Age, years			
Mean (SD)	29.7 (4.7)	30.2 (4.7)	0.618
Gender (n, %)			
Male	5 (12.5)	7 (17.5)	0.531
Female	35 (87.5)	33 (82.5)	
Profession (n, %)			
Physician	3 (7.5)	2 (5.0)	0.644
Registered nurse	37 (92.5)	38 (95.0)	
Working experience, years			
Mean (SD)	5.7 (3.9)	6.2 (4.4)	0.531

Discussion

This study evaluated the impact of a smartwatch app capable of detecting CCD and CCR while also providing real-time feedback on CPR quality for cardiac arrest. It compared the quality of CPR performed by healthcare providers on a sensorized manikin (simulated cardiac arrest) with or without the smartwatch app. The results showed that CPR quality could be significantly improved by using a smartwatch with real-time feedback.

As opposed to smartwatch, a smartphone has been an indispensable device for everyone during our daily activities. There have been various smartphone applications that provided feedback on CPR quality, but these applications mainly focused on CPR training .[29,30] Although smartphones might be considered to be wearable, they most often reside in a pocket or purse and could be difficult for use during CPR, since rescuers would have to hold a smartphone in one hand while performing chest compression with the other hand. In terms of using a commercially available electronic device to assist during CPR, researchers have utilized the Microsoft Kinect with motion sensing ability to track hand position and provide real-time feedback during CPR.[31,32] Although the results are promising in terms of CPR quality, their applications are limited due to the size and lack of portability of the device. Our study is a great example of using modern information technology as an assistive device in improving the quality of healthcare. Although it is a simulation study performed on a manikin, it has great potential to be utilized in clinical settings.

For clinical practice in Taiwan, healthcare providers working in acute care settings have to pass ACLS training classes offered by recognizable organizations every three years. This ensures that they have sufficient knowledge and experiential skills to practice in clinical settings where cardiac arrests may happen unexpectedly. Based on this simulation study performed on a manikin, we found that participants in the control group tended to deliver chest compressions at a faster rate and more shallow depth than the recommended guideline standards. The percentage of high quality chest compressions remained poor in the control group without feedback. In addition, the adherence to the 30:2 compression-ventilation ratio was significantly better in the intervention group than in the control group. With a smartwatch that provides real-time feedback in the intervention group, compression depth and rate were within the range recommended in the guidelines. The overall performance in the smartwatch group was superior to the control group.

Previous reports suggested that, even for healthcare providers, CPR quality was often suboptimal and associated with poor outcomes.[33–35] With newer technology capable of monitoring CPR quality, it is now possible to receive real-time feedback to improve resuscitation

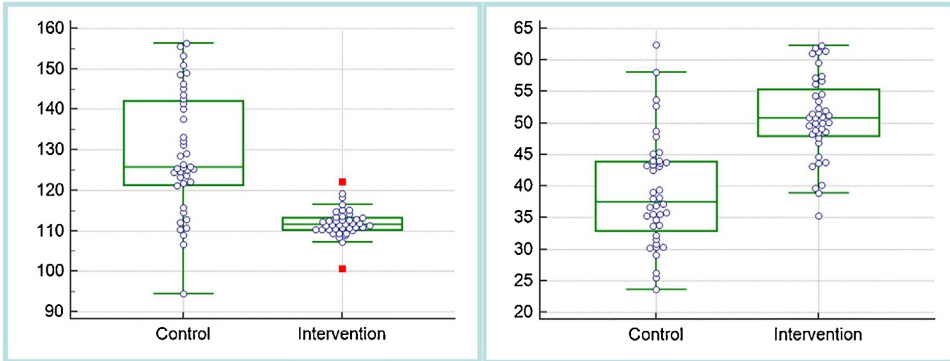

Fig. 4 – Data comparison graphs on chest compression distribution in chest compression rate (min^{-1}, left figure) and chest compression depth (mm, right figure) using box-and-whisker plots. The far out values (or outer fences, defined as a value that is smaller than the lower quartile minus 3 times the interquartile range, or larger than the upper quartile plus 3 times the interquartile range) are marked as red squares.

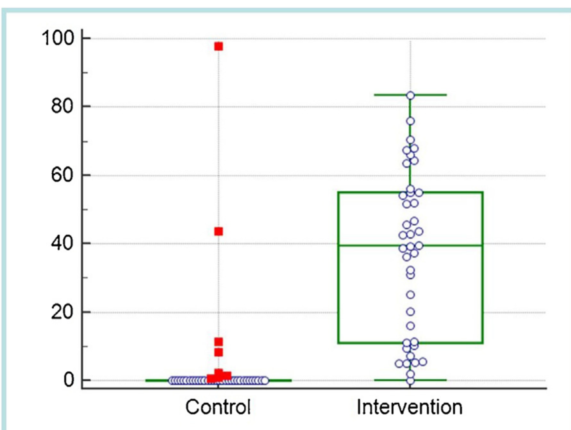

Fig. 5 – The percentage (%) distribution plots (box-and-whisker plots) of high-quality CPR in the control (left) and the intervention group (right). The far out values (or outer fences, defined as a value that is smaller than the lower quartile minus 3 times the interquartile range, or larger than the upper quartile plus 3 times the interquartile range) are marked as red squares.

performance. This study demonstrates how a readily available, off-the-shelf consumer electronic device can facilitate the delivery of high-quality CPR. A smartwatch can be easily worn on the wrist without interrupting daily activity, making it a particularly valuable assistive device. Although this study aims to evaluate CPR quality with focus on healthcare providers in the ED, its applications can also be extended to the prehospital setting to be used by laypersons for bystander CPR. The smartwatch app in this study provides three different feedback mechanisms: visual feedback on the screen, audio feedback from the speakers, and metronome guidance that was set as 110 min^{-1}. While we found differences between the intervention and control groups, based on the study design we cannot tell whether one feedback mechanism was responsible for these differences. Further study will be needed to compare the effect of the individual feedback mechanisms.

There are limitations in this study. First, this study was conducted in our ED observation unit instead of a real resuscitation unit. Background noise may influence the effect of audio feedback and thus the CPR quality when in real-world clinical practice. Second, allowing full chest recoil after each compression is recommended by the guidelines but was not measured in this study. Leaning can hinder chest recoil and should be avoided due to its effect on preventing the return of blood flow to the circulation.[8] Such deficiency in detection of leaning has been a major drawback of any attempt to derive complete feedback from the accelerometer-based devices.[36] Third, participants performed chest compression on a manikin that was placed on hard ground. The estimated CCD may be inaccurate when CPR is applied on a patient lying on a bed or on a soft surface.[37] Fourth, this study was designed for healthcare providers who should perform compression to ventilation at 30:2 ratio. We evaluated participants' adherence to the guideline, but we did not evaluate hand position on the chest or measure the ventilation quality. Fifth, we sought to compare CCD and CCR on the same basis during the two-minute CPR attempt (participants without delivering ventilation tend to perform more chest compressions than those with ventilation), so participants received instant reminding of ventilation since CPR quality decreased significantly faster when performing continuous chest compression compared to 30:2 ratio.[38] Sixth, in this study most of the recruited participants were nurses, young, and female. The lack of diversity in professions and working experience may have affected the overall performance in this study. Lastly, data on participant demographics were recorded and compared, but we did not collect participants' weight, body mass index, or physical fitness, which may have influenced CPR quality.[39,40]

Conclusions

Without real-time feedback, chest compressions even when performed by trained medical professionals tend to be too fast and too shallow. CPR quality, in terms of rate and depth of compressions, was improved with the assistance and feedback through a smartwatch providing real-time instructions in a simulated environment.

Conflicts of interest

None.

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