Smart-Watch Life Saver: Smart-Watch Interactive-Feedback System for Improving Bystander CPR

Agnes Gruenerbl
DFKI GmbH
Kaiserslautern, Germany
n.n@dfki.de

Gerald Pirkl
DFKI GmbH
Kaiserslautern, Germany
n.n@dfki.de

Eloise Monger
University of Southampton
Southampton, UK

Mary Gobbi
University of Southampton
Southampton, UK

Paul Lukowicz
DFKI GmbH /TU
Kaiserslautern, Germany
n.n@dfki.de

ABSTRACT

In this work a Smart-Watch application, that is able to monitor the frequency and depth of Cardiopulmonary Resuscitation (CPR) and provide interactive corrective feedback is described. We have evaluated the system with a total of 41 subjects who had undertaken a single episode of CPR training several years previously. This training was part of a First Aid course for lay people, commonly accessed in this population. The evaluation was conducted by measuring participant CPR competence using the "gold standard" of CPR training [10], namely frequency and compression depth. The evaluation demonstrated that the Smart Watch feedback system provided a significant improvement in the participant performance. For example, it doubled the number of people who could maintain bot the parameters in the recommended range for at least 50% of the time

Author Keywords

Assistive-Technologies, Health, User-Study, Smart-Watch, Cardiopulmonary Resuscitation, Live-Feedback App, Evaluation

ACM Classification Keywords

J.3 Computer Applications. : LIFE AND MEDICAL SCIENCES

INTRODUCTION

Out of Hospital Cardiac Arrest (OHCA) is on of the leading causes of death in the western world. In the US alone more than 350,000 people die due to OHCA every year (one death every 90 seconds) and it causes approximately 40% of deaths in adults younger than 75 every year in Europe. Over 95% of those experiencing OHCA die because CPR is not commenced quickly enough [12]. Chances for survival decrease by 7-10% every minute in the absence of Cardiopulmonary Resuscitation (CPR). Unfortunately, despite relatively high numbers of people being trained (due to obligatory First Aid Courses as part of Driving License preparation in many European countries) , the reported incidence of lay bystander participation in CPR remains low. This may be due to a failure to recall the procedure or fear of causing harm. Our work aims at to improve lay bystander engagement and performance by producing a S mart-Watch based, interactive Live-Feedback System.

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Contribution

Our contribution to help improve bystander CPR engagement and performance is described in this work:

- We developed an easy to use CPR feedback application for a Smart-Watch, , designed to allow untrained people to perform CPR correctly in emergencies. As watches are worn most of the time by their owners, this application is always at hand, without the requirement for additional and expensive equipment.
- We evaluated the CPR watch application with 41 untrained testers in three modalities.
- Using the two main quantitative indicators; frequency and compression depth, the results clearly demonstrated CPR improvement using the CPR Watch.

  Thus, for example, **with the CPR watch** around half of subjects managed to stay within the recommended range for both parameters (correct frequency and compression depth) for at least 50% of the time they performed CPR. Approximately 70% of the participants managed to stay in the recommended range for both parameters for more than 30% of the time. On the other hand, **without the assistance of the watch** (even after receiving oral reminder about the CPR procedure) just 20% managed to perform CPR correctly for about 50% of the time, while only 30% performed CPR correctly (frequency and depth) for 30% of the time.

RELATED WORK

CPR Devices

Using CPR Feedback devices can help to enhance the quality of CPR. A number of such devices are commercially available. One of the most common devices is the CPR-meter (available from Laerdal, and Philips) the Laerdal CPR meter was used in this evaluation Studies similar to Buleon et al. [2] show significant improvements in CPR when using such devices. Other studies like Gonzales et al. [5] introduce alternative devices like photoelectric distance sensors, which also improve performance. In addition, Yeung et al. [16] conducted a systematic review of the literature. Their findings support the use of CPR/feedback/prompt devices for improving skills during training. These devices, however, are expensive (hundreds of Euros) and are meant for laboratory and medical training environments.They are not intended for use by the general public.

CPR support on Smartphones

There does not appear to be any iPhone App for CPR assistance in the Apple Appstore . The Google Play Store lists several apps that are intended to assist in CPR, but these mainly give information about First Aid and instructions for the performance of CPR. Only CPR Metronome provides live instruction by emitting sound at the proper frequency, yet does not provide live performance feedback.

A number of research studies have reported using Smart-Phone-apps for CPR measurement. For example [13] Song et al.used the trajectories derived by double integration of the acceleration of a smartphone for measuring compression depth. Their evaluation of the system showed only a very small error range of 1.43 mm with a standard deviation of 1mm. Chan et al. [3] evaluate a CPR Feedback application for iPhones in a controlled study (control group without IPhone app). The iPhone group reaching better compression depth than the control group.

CPR support on a Smart-watch

The idea of using a Smart-watch for assisting in CPR seems not be entirely new. A thorough literature research revealed an article in the Philadelphia Business Journal, which reported about "Lifesaver", a Smartwatch-App that was developed during the PennApps weekend hackathon [7] in January 2015. To the best of our knowledge, however, this app has not yet been published, nor have any studies been performed with it.

THE SMART WATCH LIVE SAVER CONCEPT

The Situation - Bystander CPR

In Europe, the number of people willing to actually perform First Aid and CPR is different depending upon country, the average lies at 66%.

Wissenberg et al [15] studied the rate of Out of Hospital Cardiac Arrest (OHCA) in Denmark over 10 years (2001-2010): lay bystander resuscitation was attempted in a total of 19,468 patients. The rate of bystander CPR increased over the study period from 21.1% in 2001 to 44.9% in 2010.

According to the Red Cross and ADAC, in the German speaking countries only 15-20% of people would actually perform CPR. The main reason for people not to help is because they are insecure about what to do and therefore afraid to cause harm. Grasner et al [6] report the adult OHCA incidence between 2004 and 2011 in Germany (n=11,788). Bystander CPR was initiated most often in patients between 18 and 20 years (25%), and least often in those over 80 years (12%). It was also noted that bystander CPR of a witnessed OHCA was performed significantly less often in private homes compared with public areas. These are interesting observations, from which one may surmise that being in public places makes bystanders more willing to act either because they feel it is expected by others, or that they are encouraged by their support.

Sasaki et al ([11] recorded the incidence of OHCA in Osaka Japan. As the availability of Automatic Electronic Defibrillators increased in public places, their rate of usage by lay rescuers was 0% in 2004, climbing to 11% in 2008. This demonstrates a willingness of the lay bystander to utilize technological equipment as a means of support.

The Correct Way - CPR Suggestions and Effects

CPR (Cardiopulmonary Resuscitation) was first introduced approximately 50 years ago. Ever since, scientific evidence has led to periodic changes in CPR techniques. In 2010, the European Resuscitation Council (ERC) and the American Heart Association (AHA) published the currently valid evidence based guidelines for resuscitation: They suggest to perform compressions, at least 100/min, with a compression depth of at least 2 inches/5 cm [1]. The ERC specifies the guidelines more clearly and suggests compression depth of at least 5 cm (but not exceeding 6 cm) at a rate of at least 100/min (but not exceeding 120/min) [10]. Both agencies still agree on recommending chest compressions and rescue breaths in a ratio of 30:2.

Since then, further research has further corroborated these values. It was shown [8] that CPR is in fact most effective at a frequency of 100-120 cpm (compressions per minute), while the effectiveness declines when the frequency exceeds 125 cpm. Other research indicates that compression depth of 40 mm or less results in less survival of victims than compression depth of 50 mm and more [14, 4]. Even though there appears to be no evidence that greater compression depth causes damage, the ERC that a compression depth of 60 mm should not be exceeded-even in large adults [9].

The Solution - CPR Watch

It was apparent that any tool that helped the rescuer to maintain optimal frequency and compression depth would be very beneficial. Thus, we developed an easy to understand CPR feedback application for the LG G Watch R Smart-Watch with Android Wear OS. This application has three main functionalities:

- **Frequency:** When the app is started the watch begins to vibrate and blink (black/blue - see Figure 1 A/B) with 110 cpm (average frequency of the ideal compression rate 100-120). Due to the lack of a loud speaker, audio feedback is not possible.

- **Depth:** The feedback for the compression depth is done by color (Figure 1 C-E). The center of the display stays green as long as the compression depth is within the ideal range of approx. 50-60 mm, turns yellow if the compression depth goes beyond 60 mm and turns red if the minimum compression depth is not reached.

- **Counting:** Following the ERC and AHA recommendations of a 30/2 compression/rescue breath ratio, the watch counts the compressions backwards from 30 and stops vibrating/blinking after 30 effective compressions. In case the minimal compression depth is not reached (red display) the watch stops counting backwards until a sufficient depth is reached again.

The CPR compressions are recognized using the accelerator of the Smart-Watch (see Figure 2). The magnitude of the acceleration vector allows us to estimate both CPR frequency and compression depth. By using a peak detector on the signal, we retrieve its local minima and maxima. The time differences of the peaks are used to estimate the frequency, the amplitude (the y-axis distance of max / min peaks) are used to conclude the compression quality. The derived amplitudes have been compared to the CPR-meter and adjusted accordingly.

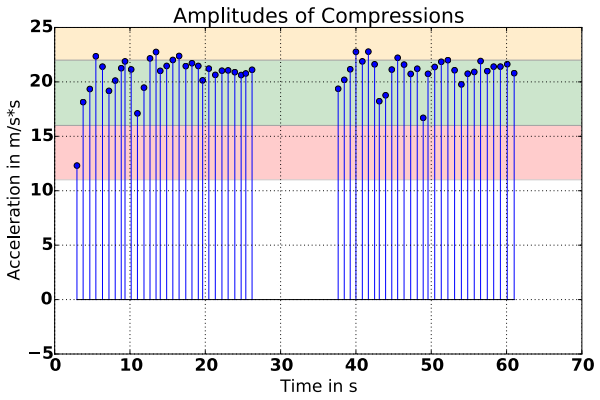

Figure 2. Amplitudes of the two compression cycles with acceleration intervals for "compression too low" - red, "compression ok" - green and "compression too strong" - yellow.

EVALUATION

Study Design

In order to test the effectiveness of our Smart-watch app we asked study participants to perform CPR on a standard CPR training manikin "Little Anne" [1]. To establish a baseline, we used a CPR-meter (QCPR[1]). This device is able to record all important aspects of CPR (compression depth, frequency, ideal zones of contact). During CPR, the app provides ongoing user feedback (which was blinded or disabled for the purpose of this study) for the key CPR elements. The parameters of this device were set to the standards currently valid in Europe (compression depth 50-60 mm and frequency 100-120 per minute).

[1] www.laerdal.com

Study Implementation

Overall every study participant was asked to perform CPR in three different modalities:

1. **without any additional information:** First every test-person was asked to perform CPR the way they remembered from their last First Aid Course.

2. **with assistance of the watch:** For the second run we explained the current CPR regulations and the functionality of the watch to the participants. Afterwards the participants performed the CPR again, but now with the assistance of the watch.

3. **with prior explanations/briefing:** After first analyses of the data it was clear that there were distinct effects and improvements visible with the assistance of the watch. As these effects might have been caused by the explanation of how CPR works we decided to repeat the measurements of CPR without the watch two weeks after the initial data recordings. So, in the third run, we asked the study participants once again to perform CPR, without the watch, but with a reminder on current CPR regulations.

Study Group

The group of participants was defined as "any lay member of the publicâĂİ (for whom the app is actually designed). The only exclusion criterion was people with medical/resuscitation background as nurses, police and and people who have undertaken frequent first aid training that included CPR. In total 41 people participated, 24 male 17 female, aged between 24-70 (average age 37, SD 13). Each study participant provided the date of their last first aid course. The most common reply was "during the course for the driverâĂŹs license", 5-35 years ago (average 16 years, SD 10). Only 5 out of 41 had refreshed their ïňĄrst aid course at least once since, and this had been between 2-25 years previously.

Data Set

In order to record a sufficient amount of data per person and for each of the 3 modalities, every test-subject was asked to perform the current standard of CPR, 30/2 (30 compressions 2 rescue breaths - the test-persons were not asked to actually perform rescue breaths on the manikin but only to make a break of 2-3 seconds), 5 times in a row. On the one hand, this could provide insights into a potential learning curve (specifically for the data-sets using the watch). On the other hand, it also allowed analysis of effects resulting from participants getting tired (specifically for the data-sets without assistance of the watch).

Therefore, in total we have:

- app. 190 recordings (5700 compressions) of CPR being performed as 30/2 the way people would perform **CPR without any additional information**,

- app. 190 recordings of CPR being performed as 30/2 **with the assistance of the watch**,

Figure 1. Smart-Watch indicates frequency of 110 cpm by a blue/black (A, B) blinking ring and the vibration motor. The center displays the number of compression necessary to complete 30 compressions, indicates the quality of the detected compression by color - green (C): compression is within the suggested interval (50 - 60 mm), yellow (D): compression too strong (beyond 60 mm, but still supports life saving feature), red (E): compression is too weak (no life saving effects), push harder.

- and app. 180 recordings (5400 compressions) of CPR being performed as 30/2 **with prior refreshing the information on how CPR should be performed according to the current standards and regulation**.

Figure 3 shows a test-subject trying to recall how CPR works without any assistance and Figure 4 shows the CPR watch in action.

Figure 3. Study-Participant trying to recall how CPR is done correctly. The CPR-meter (grey device beneath the test-subject's hands) measures the correctness.

RESULTS

Analysis of the CPR data recorded by the CPR-meter indicates that the assistance of the Smart-watch has a pronounced

Figure 4. CPR watch in action on a CPR training manikin and with the CPR-meter (grey device beneath the test-subject's hands) for analysis

positive effect on the quality of performed CPR. Table 1 provides the details: In the non intervention group, without briefing or app assistance, on average, the participants only managed to keep the ideal frequency for 19.78 % of the time (SD 33.7) and ideal depth for 48.7 % of the time (SD 25.8). Using the Smart-Watch for assistance the time spent at the ideal frequency increased by more than 200% (to 61.31%) and at the ideal compression depth by more than 30% (to 65.01%).

Analysis of the number of participants who managed to stay in the ideal range (depth and frequency) reveals that only 57,5% were able to do so. Furthermore, they only achieved this for about 20% of the time without app assistance or briefing. In contrast, with watch assistance, 95% of the participants maintained the ideal range for more than 50% of the time. For most participants the third run, without the watch but with extensive prior information about correct CPR, does slightly enhance the result in comparison with the run first without any additional information. On average the participants stay at the ideal depth (SD 41.9) 45% of the time and at ideal frequency (SD 30.2) 44.7% of the time. It can be clearly seen that even extensive prior information and two

previous sessions (one with and one without the watch) provide less improvement than the interactive feedback from the Smart Watch system. 1 (last 3 columns) shows details about enhancements of the results between "no information" to "watch", "no information" to "prior explanation", and from "prior information" to "watch".

Ideal Range

The last row of Table 1 indicates that without getting help or additional information (as it would be during a sudden incident, where getting explanations cannot be expected) only an average of 57% of all test-subjects managed to perform CPR at least for a short time in an ideal range, and those who did were only able to stay there for an average of 20% of the time! On the other hand, with assistance by the watch, only 5% of the test-subjects were not able to find the ideal range. All others reached the ideal range for an average of 50% of the time. The following subsection provides a more detailed analysis of this data.

Doing it right!

Upon further perusal, some interesting further details are revealed. These are displayed in Figures 5,6 and 7 :

Without any help, more than 70% of all test-subjects were only able to reach the ideal range (= both ideal compression depth and ideal frequency at the same time (see Figure 7) for less than 10% of the time (48% did not even manage to find the ideal range at all) and only 5% of the test-subjects were able to stay in the ideal range for more than 50% of the time!

After getting an introduction on how CPR has to be performed, this situation improved slightly. However, almost 50% the test-subjects still only managed to stay in the ideal range for less than 10% of the time (and 30% still did not manage at all). Only 14% were able to stay in the ideal range for almost 100% of the time.

With the assistance of the CPR watch, performance improved significantly. Only 15% (6 out of 41) of the test-subjects failed completely in reaching the ideal range. More than 50% managed to stay in the ideal range over 50% of the time (29% of the test-person even achieved ideal range for over 75% of the time). This amounts to an improvement of more than 45 percentage points (pp)!

Ideal Depth or Ideal Frequency

The analysis of the important aspects of compression depth and frequency demonstrates that correct depth is easier to achieve. See Figure 6.

Even without help more than 50% of participants are able to reach a depth of 50-60 mm for more than 50% of the time (only 10% stay below 50 mm 10% of the time, with 10% not reaching 50-60 mm at all). Nevertheless, usage of the watch improves performance. More than 70% of the test-subjects stay in the ideal depth for more than 50% of the time (with 50% of the test-subjects staying for more than 75% of the time, an improvement of 24 pp).

Regarding the compression frequency, most test-subjects are either too slow or too fast when they do not receive additional help. 75% of them do not even manage to stay at the ideal frequency of 100-120 cpm for more than 10% of the time . This changes significantly with the assistance of the watch. In this case, approximately 80% of the test-persons can keep the rhythm and stay at the ideal frequency for more than 50% of the time, an improvement of 60 pp. 50% even manage to stay at the ideal frequency for more than 75% of the time (36 pp improvement). See Figure 5

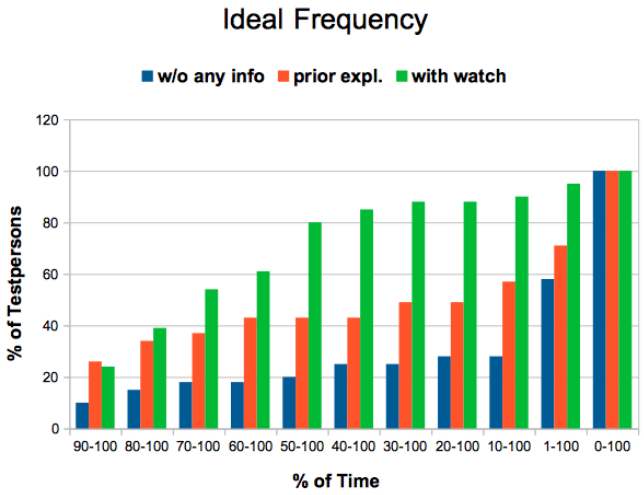

Figure 5. The percentage of test-persons managing to spend how much time in ideal compression frequency (100-120 cpm) for the three modalities "w/o any information" - blue, "with prior explanation how to do correctly"- red and "using the watch" - green

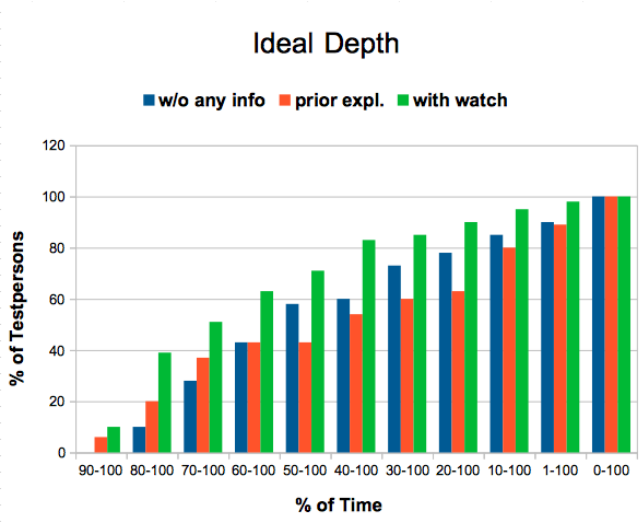

Figure 6. The percentage of test-persons managing to spend how much time in ideal compression depth (50 - 60 mm) for the three modalities "w/o any information" - blue, "with prior explanation how to do correctly"- red and "using the watch" - green

The analysis of the ideal ranges shows that the most significant benefit of the watch is helping people to find the ideal compression rhythm (60 pp improvement). Looking at Figure 8 an interesting observation related to rhythm is that participants wither performed very well, or very poorly (irrespective

		N = 40	N=35	N= 41	Improvement		
		w/o any info	**prior expl.**	**watch**	w/o info to watch	prior expl. to watch	w/o info to prior expl.
av. depth	in numbers	60.49	61.66	59.76			
	SD	9.77	8.83	7.04			
ideal Depth	**50-60mm**	**48.31%**	**45.15%**	**65.01%**	**34.56%**	**43.98%**	**-6.54%**
	SD	26.46	29.81	23.87			
too shallow	< 50 mm	*21.99%*	*12.46%*	*17.16%*	*28.15%*	*-27.41%*	*-43.35%*
	SD	30.23	29.67	25.68			
too deep	> 60 mm	*32.56%*	*42.74%*	*20.32%*	*60.22%*	*110.34%*	*31.28%*
	SD	27.80	34.59	21.34			
av. Frequ.	in numbers	102.12	107.05	104.40			
	SD	28.10	18.84	10.41			
ideal Frequ.	**100-120cpm**	**19,78%**	**43.91%**	**61.31%**	**209.96%**	**39.63%**	**121.98%**
	SD	35.33	41.81	29.79			
too slow	< 100 cpm	*51,70%*	*31.62%*	*32.13%*	*60.91%*	*-1.58%*	*-38.83%*
	SD	47.72	41.81	31.54			
too fast	> 120 cpm	*29,92%*	*26.10%*	*9.32%*	*221.03%*	*180.08%*	*-12.76%*
	SD	40.56	33.66	20.28			
ideal (depth+freq)	**50-60mm, 100-120cpm**	**18.14%**	**25.7%**	**52.14%**	**160.4%**	**80.8%**	**44.0%**
	SD	24.73	28.71	23.86			
persons in ideal	% out of total	57.5%	80%	95.1%	65.4%	18.9%	39.1%

Table 1. Total time in percent that participants were (in)correctly performing CPR, both by compression depth and frequency individually and combined (actually doing it "right") and how many participants were actually able to achieve this (columns 3-5). And improvement of of total time that participants were (in)correctly performing CPR between the three modalities "w/o any information", "with prior explanation how to do correctly" and "using the watch" for compression depth and frequency individually and combined (columns 7-9).

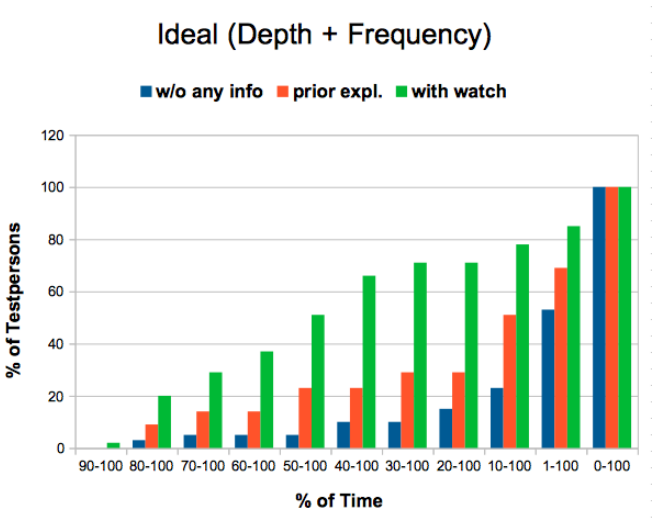

Figure 7. The percentage of test-persons managing to spend how much time doing correct CPR (ideal frequency and ideal compression depth) for the three modalities "w/o any information" - blue, "with prior explanation how to do correctly"- red and "using the watch" - green

as to whether they had a briefing/information session or not) What the watch appears to do, is to help people keep the frequency: especially those who are originally weak in this area. Thus, most of those who scored poorly without help (only around 10% of the time at ideal frequency) improve dramatically to more than 50% of the time at ideal frequency .

Deviations and Indications for a Learning Curve

One other positive effect of using the watch is that significantly less people deviate from the ideal ranges and, moreover, with less deviation. With regard to compression frequency, on average 27 persons (65%) deviated from the suggested frequency (average deviation 20 cpm, SD 12) without the watch. With assistance, only 8 persons (20%) deviated (average deviation 8 cpm, SD 6). Regarding compression depth, while without help an average of 21 (50%) people deviated from the ideal range (average deviation 4 mm, SD 4) only 15 (36%) people deviated when helped by the watch (average deviation 4 mm, SD 4).

Furthermore, the comparison of the 5 cycles (1 cycle is 30 compression 2 breaths) of each participant per modality indicated trends for a learning curve when using the watch. For both depth and frequency, during the first cycle more people deviate from the ideal range (8 frequency/16 depth) than in the last cycle (6 frequency/11 depth, with an increase at the second/third cycle). For the other modalities, the decrease of deviations is either less steep or nonexistent. See Figure 10. This could be an indication that people using the watch start to learn how to use the watch and therefore more quickly

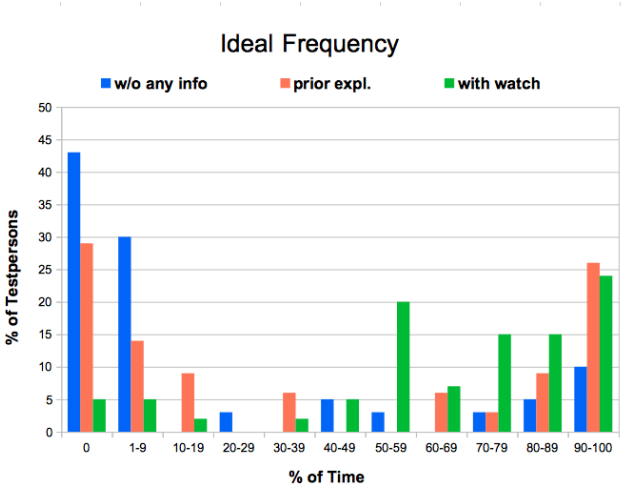

Figure 8. The percentage of test-persons managing to spend how much time in ideal compression frequency (100-120 cpm) for the three modalities "w/o any information" - blue, "with prior explanation how to do correctly"- red and "using the watch" - green

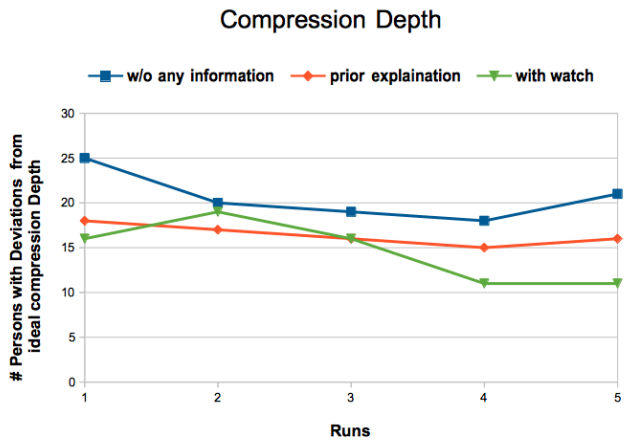

Figure 9. Number of persons deviating from the ideal depth in course of the 5 runs. In the first run the number of persons deviating are higher than in the last run. Specifically for the "with watch". This could indicate a learning curve.

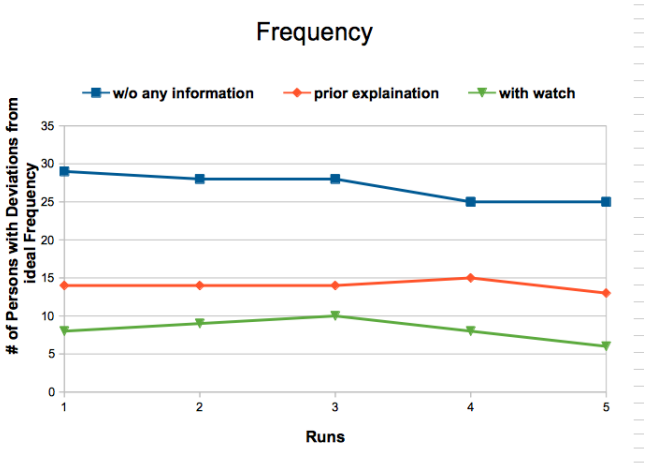

Figure 10. Number of persons deviating from the ideal frequency in course of the 5 runs. In the first run the number of persons deviating are higher than in the last run.

learn to perform CPR correctly! Nevertheless, the amount of cycles is not large enough to actually confirm the details of a learning curve. This topic is part of an ongoing study with nurse-students.

PARTICIPANTS' FEEDBACK

After the interventions, a feedback questionnaire was sent to the thirty participants who were accessible. 28 completed the survey giving a return rate of 93%, representing 68% of the initial 41 participants. 100% of the respondents stated that the topic of the study was very important or important. Furthermore, 93% were positive that a Live-Feedback System like the CPR Watch could help to save more lives (only 7% were neutral) and 83% believed that Such a system could remove the fear of doing damage whilst performing CPR. Being asked how secure they felt in their understanding of CPR before participating in our study, 35% replied "secure", 25% were "neutral" and 40% were "insecure".

Regarding our study and its outcome, the following questions were more interesting: 89 % of all study-participants stated that they felt much saver while performing CPR with the assistance of the watch than without and 92% are sure that they performed better with the assistance of the watch. 75% would immediately install such an App on their Smart-Watch if they owned one. More details are listed in Table .

CONCLUSION AND OUTLOOK

In particular Figure 7 emphasizes that a smart watch based CPR assistance has tremendous potential for improving bystander CPR and is an App that could truly save lives. Pending clarification of potential liability issues we thus intend to make it available through the App store. In terms of future work the key question is how far the impact of the system could be strengthened through more elaborate and possibly personalized feedback mechanisms. We are also currently experimenting with using a combination of Smart-Watch and Smart-Glasses. As already mentioned above, we currently have an ongoing study with nurse-students ongoing. The hypothesis of this study is, that students using the CPR-Watch while training internalize CPR faster than students training without CPR watch assistance.

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absolutely	*yes*	*neutral*	*no*	*not at all*
Is the topic of the study (bystander CPR) relevant for you personally?				
75,0	25,0	0,0	0,0	0,0
Could a Live-Feedback System help saving lives?				
32,1	60,7	7,1	0,0	0,0
Could such a system help to reduce fear of doing damage in CPR?				
35,7	53,6	3,6	7,1	0,0
How secure were you about how CPR works before the study?				
very secure	*secure*	*neutral*	*insecure*	*very insecure*
3,6	32,1	25,0	35,7	3,6
Did the watch help you to feel more secure?				
35,7	53,6	7,1	3,6	0,0
Did the watch help you to perform CPR better?				
46,4	46,4	7,1	0,0	0,0
Did the watch irritate you while performing CPR				
0,0	3,6	7,1	39,3	50,0
Would you install this App on your Smart-Watch (if you had one)?				
35,7	39,3	10,7	14,3	0,0

Table 2. Participants' Feedback. The relevance of the topic is clear to all, and in most questions the replies are quite in unison as most favor using the watch for assistance.

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