

# Training CPR with a Wearable Real Time Feedback System

**Agnes Gruenerbl**  
DFKI GmbH  
Kaiserslautern, Germany  
agnes.gruenerbl@dfki.de

**Hamraz Javaheri**  
DFKI GmbH  
Kaiserslautern, Germany  
hamraz.javaheri@dfki.de

**Eloise Monger**  
University of Southampton  
Southampton, UK  
e.monger@soton.ac.uk

**Mary Gobbi**  
University of Southampton  
Southampton, UK  
m.gobbi@soton.ac.uk

**Paul Lukowicz**  
DFKI GmbH /TU  
Kaiserslautern, Germany  
paul.lukowicz@dfki.de

## ABSTRACT

We present a study comparing the effect of real-time wearable feedback with traditional training methods for cardiopulmonary resuscitation (CPR). The aim is to ensure that the students can deliver CPR with the right compression speed and depth. On the wearable side, we test two systems: one based on a combination of visual feedback and tactile information on a smart-watch and one based on visual feedback and audio information on a Google Glass. In a trial with 50 subjects (23 trainee nurses and 27 novices,) we compare those modalities to standard human teaching that is used in nurse training. While a single traditional teaching session tends to improve only the percentage of correct depth, it has less effect on the percentage of effective CPR (depth and speed correct at the same time). By contrast, in a training session with the wearable feedback device, the average percentage of time when CPR is effective improves by up to almost 25%.

## Author Keywords

Assistive-Technology; Instant Feedback; Teaching; User-Study; Smart-Device; CPR; Evaluation

## ACM Classification Keywords

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## INTRODUCTION

Wearable personal trainers recently have gained popularity in many areas: from classical fitness trackers and sensors for golf, tennis, and table tennis [3] through shoe based systems for running and soccer [15] to sensor networks in professional sports such as Olympic ski jumping [2]. What most today's system have in common is the focus on off-line analysis. Thus, the sensor data is used after the actual training session to show the user where and how they can improve and take the feedback into account when doing the activity next time. While such "postmortem" analysis certainly has

benefits, within training skills that involve complex motor coordination it is suboptimal. Acquiring motor skills involves moving beyond conscious control towards an automatic execution of the motions ("muscle memory"). However, learning from postmortem analysis can only be accomplished through conscious control as the insights from seeing the results of the previous training session have to be translated into a modified execution of the next one. To avoid (or minimize) the conscious control aspect, real-time "online" feedback that corrects the execution as it happens is much better suited. Thus, experienced coaches often take their trainees by the hand and executed the motions together with them rather than explain it in abstract terms. While real-time wearable feedback is well established in applications such as maintenance support, today there is much less work on real-time feedback in wearable personal training systems for motor skills (see related work).

In this paper, we present the design and evaluation of such a real-time feedback system for training cardiopulmonary resuscitation (CPR). CPR is a life-saving procedure as means of keeping a person in cardiac arrest alive until further measures can be applied [8]. For effective CPR two parameters are essential according to ERC [4]: the compression speed (100-120 compressions per minute), and the compression depth (min. 5cm to ensure heart stimulation). While the general concept is easy to grasp, maintaining the right speed and depth over extended periods of time is a non-trivial motor coordination problem which only a few people can achieve without proper training. In previous work [5] a smart-watch based real-time feedback system that helped users with no or little CPR skills to perform the procedure correctly was presented. In this paper, we build on this work to investigate the effect such a feedback system can have beyond supporting immediate execution towards training the person to do it correctly in the future.

## Related Work

An overview of various general approaches to real-time feedback in motor training can be found in [11]. This includes in particular augmented/virtual reality and different "classical" modalities such as screens and audio. In the wearable domain in specific tactile feedback (e.g., for music teaching) has been investigated [7]. Recently, EMS muscle stimulation has also generated significant interest [6]. Concerning specifically CPR training, different approaches have been tried [13]. In the traditional approach, a professional instructor leads the trainee through the CPR steps, while in self-directed learn-

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ing, an assisting device is used to teach the CPR procedure. Rasmussen et al. [10] showed that participants with the assistance of a new dispatcher protocol performed CPR with a higher quality score and had higher motivation. Alongside dispatcher based teaching approaches, some well-known self-learning methods for resuscitation are computer-based video training and application based methods conducted for smartphones [9, 14]. Alonso et al. [1] demonstrated improved success rate and completion times in CPR, using telematics support by an expert through head mounted glass. Wang et al. [12] introduced a feedback system using optical sensing that enhanced the chest compression quality in the paramedic's training. Furthermore, as we have shown previously [5], the use of a smart-watch feedback system significantly increased the participant's performance in compression depth and speed.

#### Paper Contributions

This paper compares the effect of traditional teaching of CPR (teaching) with the effect of training with wearable instant feedback devices (training) in a study with 50 test persons (23 nurse students, 27 novices) where for both, the order of training or teaching first and which device (smart-watch or smart-glass) to be used were randomly selected. The results, indicating the clear superiority of the device training, are evaluated with an ANOVA analysis.

#### BACKGROUND

A typical standard CPR teaching session that nurse students will attend repetitively during their training looks as follows: A teacher will first, with the help of a training manikin, provide the theory of what CPR means and the effects CPR has, to a group of 10-15 students. After receiving all the information and some demo by the teacher, the students will perform CPR themselves, individually or in small groups, on training manikins. Meanwhile, the teacher will observe the students and give hints and feedback if necessary. Alternatively, each student might perform CPR while the rest of the group is watching and thus profiting from the direct feedback, the experienced teacher is providing.

#### CPR Assistant Devices

Based on the work of [5] we implemented instant feedback applications on two different smart-devices. The calculation of speed and depth for both devices is based on real-time peak-detection of the magnitude of the acceleration signal.

**Smart-Watch Instant Feedback Application:** The instant feedback application combines tactile speed instructions (vibration) and visual cues (figure 1 left). On start, the Watch begins to vibrate and blink (black/blue) with 110 vibrations per minute (vibration-length 225ms), which denote the average speed of the recommended compression rate of 100-120. While performing CPR, the actual compression speed is shown in the center of the display. The compression depth feedback is provided in color. The center square in the display is green for good compression depth (50-60 mm), yellow for compressions beyond 60 mm and red if the compression depth is not deep enough. An LG G Watch R Smart-Watch with AndroidWear OS was used.

**Google Glass Instant Feedback Application:** The feedback application of the smart-glass combines audio output and

numeric visual feedback (see figure 1, right). On start, the Glass begins to click in an audible sound with an average required speed for CPR. While performing CPR, the display of the Glass provides the current compression speed, and also (if necessary) prompts the user to slow down or speed up with arrows next to the compression frequency. The compression depth is also shown in the display.



Figure 1. CPR Assistant Devices: Watch (left) and Glass (right) providing instant feedback on compr. depth and speed while performing CPR

Both devices are intuitive and straightforward to use. Short explanations about the meaning of color (Watch) and of numbers (Glass) suffice for a user to be able to use them effectively.

#### EXPERIMENT

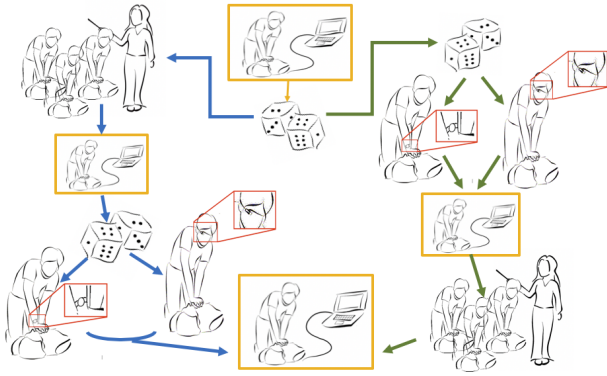
A randomized, prospective simulation study was designed to assess the effect of a CPR human teaching lesson vs. the impact of CPR training with the instant feedback devices.

**Study Group:** Out of the 50 volunteer participants, 23 were chosen among first-year nurse students at the University of Southampton. These had a basic understanding of CPR but had not had teaching lessons. The other 27 participants had no CPR experience and were recruited in the TU-KL and DFKI.

**Study Implementation:** In the course of the study, the participants were randomly distributed into two groups. The first group would get a CPR teaching lesson first and afterward train with one of the devices. The second group would first train with one of the devices and receive a thorough CPR lesson afterward. Figure 2 graphically explains the study procedure. For both groups, it was also randomly determined which participant would use which device (thus the groups are not entirely even in the number of test-persons).

To capture the CPR performance of each participant and their improvement (or worsening) over time baseline recordings (measurement points) were done in the beginning, after each session, and at the end of the study (see figure 2). The measurement points were obtained by using a standard CPR training manikin, which was equipped with a pressure sensor beneath the "chest skin" of the manikin's chest (not visible from outside). The pressure recorded on the chest of the manikin was calibrated with a professional CPR recording device (laerdal.com).

**Data Set :** During each measurement point, every participant performed three cycles of 30 compressions with a few seconds break in-between. The 30 compressions cycle was chosen since current regulations for nurses in Southampton teach a 30/2 (30 compressions, two breaths) rhythm. Therefore, overall we recorded a data-set with 90 compressions per person per measurement (13500 compr. in total).



**Figure 2. Study design:** after baseline recording it is rand. decided if teach. or train. is first. For train. the device to be used is also rand. picked. After teach. or train. another baseline is recorded (w/o device) and the modality is switched. At the end, the third baseline is recorded.

## RESULTS

The comparison of the overall effect of a teaching lesson onto the performance of effective CPR (depth + speed correctly) vs. device training (regardless of which was applied first) is shown in Table 1. Improvement of teaching is less than nine percentage points (pp), while the improvement of training is almost 25pp, which is clearly in favor of device training. The only aspect, teaching overall has an improving impact of more than 10pp in the compression depth. In all other aspects, specifically speed but also the effectiveness of CPR, the training has a far greater impact (around 24pp). To evaluate the quality of the improvement, a single-factor ANOVA was performed on each before and after dataset of teaching and training. The results of the ANOVA clearly confirm that the effect of training is significant, while the effect of teaching does not reach the 95% confidence level.

	before	after	impr.	p-val.	f-val.	f-crit
<b>TEACHING</b>	N = 50					95%
% effect. CPR	34.95	42.59	7.64	0.26	1.30	
% corr. depth	54.03	68.00	13.97	0.08	3.10	3.94
% corr. speed	52.94	62.83	9.35	0.19	1.71	
<b>TRAINING</b>	N = 50					
% effect. CPR	30.43	55.37	24.94	0.00	14.85	
% corr. depth	58.30	74.90	16.60	0.03	4.80	3.94
% corr. speed	47.81	71.37	23.57	0.00	11.93	

**Table 1. A comparison of the overall effect of a teaching lesson and of a training session with any device on the CPR performance.**

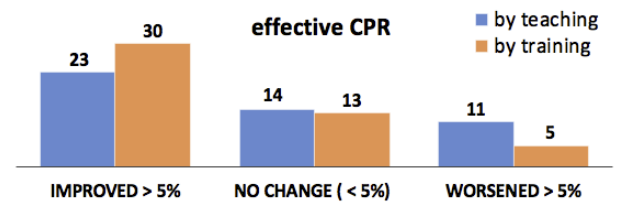
However, the above analysis compares the overall effect of teaching versus train regardless of which learning method was applied first. To better understand whether the order of teaching/training has an impact, we also analyzed each group individually. See table 2. For this analysis, we split the results according to whether traditional teaching or training with the device was done first, as it influences the start condition. Table 2 also separates between the results of the nurse students and the novices. It can be seen that device-training improves the performance of effective CPR significantly of app. 20pp or even more (with an advantage when administered after the teaching lesson). A teaching lesson, on the other hand, can only influence the performance positively when it comes first. When teaching comes after the device-training, it has little to

no impact. A glance at the performance at the end of the day though, shows that a teaching lesson that provides all relevant information, boosts the effect of the following training (total improvement of teaching + training is 44.5pp!), while after training teaching has no effect (total increase of training + teaching is only 24.4pp). This effect makes sense in the way that both devices cannot explain how to perform CPR correctly (correct posture, where to apply the pressure, etc.) which is done in the teaching session. On the other hand, a teaching lesson after the user has gained some muscle memory in training prompts the trainee to over-think the new information instead of trusting the skills achieved before.

	nurses	novices	total			
<b>TEACHING First</b>						
N	10	15	25			
effect. CPR	avg. %	avg. %	avg. %	p-val.	f-val.	f-crit.
baseline	32.54	19.47	23.14			95%
after teach.	37.94	38.47	37.76			
<b>improv. (pp)</b>	<b>5.40</b>	<b>19.01</b>	<b>14.62</b>	<b>0.07</b>	<b>3.58</b>	4.04
after train.	63.95	68.24	65.21			
<b>improv. (pp)</b>	<b>26.01</b>	<b>29.77</b>	<b>27.45</b>	<b>0.00</b>	<b>10.63</b>	4.04
end of day						
<b>improv. (pp)</b>	<b>37.49</b>	<b>48.69</b>	<b>44.46</b>	<b>0.00</b>	<b>27.67</b>	4.04
<b>TRAINING First</b>						
N	13	12	25			
effect. CPR	avg. %	avg. %	avg. %	p-val.	f-val.	f-crit.
baseline	32.42	14.50	23.82			95%
after train.	51.75	38.11	45.20			
<b>improv. (pp)</b>	<b>19.33</b>	<b>23.61</b>	<b>21.38</b>	<b>0.03</b>	<b>5.14</b>	4.04
after teach.	58.21	37.34	48.19			
<b>improv. (pp)</b>	<b>6.46</b>	<b>-0.77</b>	<b>2.99</b>	<b>0.78</b>	<b>0.08</b>	4.04
end of day						
<b>improv. (pp)</b>	<b>25.79</b>	<b>22.84</b>	<b>24.37</b>	<b>0.01</b>	<b>7.06</b>	4.04

**Table 2. Effects of teaching first (top) vs training first (lower half) on each performance after teaching/training and total improv. at end of the day.**

Figure 3 shows a comparison of how many persons at least improved their skills with teaching vs. device training. Again, this confirms that more persons were able to improve their skills with the help of the device training.



**Figure 3. The effects of training and teaching on the improvement of performing CPR.**

Finally, we evaluated which of the training devices has a better impact on the CPR performance (Table 3). Direct feedback from students during initial earlier tests did not favor one of the devices in particular (a reason why both devices were used in this study). The results of the evaluation also do not clearly favor one of the devices. In total numbers, the group using the Google-Glass slightly performs better after training (app. 2.5pp), nevertheless is less effective in regards of compression

depth. The Watch group shows a higher improvement of depth of 10pp in comparison. Glass again is slightly better concerning speed.

	before	after	impr.	p-val.	f-val.	f-crit
<b>WATCH</b>	N = 24					95%
% effect. CPR	<b>27.14</b>	<b>53.12</b>	<b>25.98</b>	<b>0.01</b>	<b>7.84</b>	4.05
% corr. depth	42.33	70.57	28.24	0.02	6.17	
% corr. speed	40.86	64.32	23.46	0.02	6.30	
<b>GLASS</b>	N = 26					
% effect. CPR	<b>32.53</b>	<b>60.65</b>	<b>28.12</b>	<b>0.00</b>	<b>9.38</b>	4.03
% corr. depth	47.53	65.63	18.10	0.11	2.63	
% corr. speed	58.44	83.44	25.00	0.01	8.57	

**Table 3. Watch vs. Glass.** The comparison of the effect between the Glass and the Watch group shows an advantage of the watch regarding compression depth.

### CONCLUSION AND OUTLOOK

The fact that a short teaching session fails to lead to significant improvement in effective CPR immediately is no surprise. In general, students follow such a teaching lesson with more extensive individual practice and further teaching lessons followed by more practice. The fact that even a short personal training session with real-time wearable feedback though produces significant results is an indication that it is a powerful tool for teaching CPR.

A likely explanation for the discrepancy between the effect of traditional teaching on individual aspects (where it worked) and on the overall effectiveness (where it did not) is the complexity of the motor coordination task. Achieving the right speed OR the proper depth individually is much simpler than achieving both at the same time. Thus getting one of the two right can be accomplished through conscious control based on teacher instructions. Getting both right requires the motion to be done automatically which is more natural with real-time feedback. Nevertheless, the results also show that the training devices work best as an addition to human teaching. Trainees using a device for training after a teaching lesson improved their overall performance by almost 45% in comparison to trainees who trained first and later received teaching (overall enhancement only 24%). This effect makes sense since both devices cannot explain how to perform CPR correctly (posture, where to apply the pressure, etc.) which can be done in a single teaching lesson. Thus this either suggests the usage of both methods in an effective order or calls for a possible feedback system using an augmented reality device that could combine both methods (e.g., a HoloLens Teacher).

In future research, we will focus on long-term effects (how long does the impact of learning last? What are the right number of training sessions to have a long-lasting impact and even more improvement?). We will also look in more detail into improving the feedback delivery (better, individualized representation) and possible adaptations onto HoloLens.

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