Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Simulation and education

Using a smartphone application (PocketCPR) to determine CPR quality in a bystander CPR scenario — A manikin trial

Christopher Plata[a,*], *Miriam Stolz*[a], *Tobias Warnecke*[b], *Susanne Steinhauser*[c], *Jochen Hinkelbein*[a], *Wolfgang A. Wetsch*[a], *Bernd W Böttiger*[a], *Oliver Spelten*[d]

[a] *University of Cologne, Faculty of Medicine and University Hospital Cologne, Department of Anaesthesiology and Intensive Care Medicine, Kerpener Strasse 62, 50937 Cologne, Germany*

[b] *Department of Anaesthesiology, Intensive Care and Emergency Medicine, Evangelisches Klinikum Niederrhein, Fahrner Strasse 133, 47169 Duisburg, Germany*

[c] *University of Cologne, Faculty of Medicine, Institute of Medical Statistics and Computational Biology, Kerpener Strasse 62, 50937 Cologne, Germany*

[d] *Department of Anaesthesiology and Intensive Care Medicine, Schön Klinik Düsseldorf, Am Heerdter Krankenhaus 2, 40549 Düsseldorf, Germany*

Abstract

Purpose of the study: Feedback devices and dispatcher assistance increase CPR quality in bystander resuscitation. Yet, there is no data comparing both approaches with uninstructed CPR. The present prospective, randomized, controlled, manikin trial aims to determine the effects of the use of a smartphone application (PocketCPR) on CPR quality in a bystander CPR scenario compared to dispatcher-assisted telephone CPR and uninstructed CPR.

Methods: 100 laypersons were included to perform 8-min CPR on a manikin. Volunteers were randomly assigned to one of four groups: (1) uninstructed CPR (uninstructed group), (2) dispatcher-assisted telephone CPR (telephone-group), (3) guidance and feedback through a smartphone application (app-group) and (4) dispatcher-assisted telephone CPR combined with the smartphone-app (telephone + app-group).

Results and discussion: There was no significant difference in the time to first compression between the uninstructed and the app-group ($p = 0.052$), likewise between the telephone- and the telephone + app-group ($p = 0.193$). The no-flow-time of the uninstructed group was significantly longer compared to all other groups ($p < 0.001$). Median compression rate was significantly higher and within the recommended range in the app- and the telephone + app-group. There was no significant difference regarding correct compression depth between the four groups. Correct hand position and complete thorax release was found significantly more frequently in groups with smartphone-app support.

Conclusions: Feedback by a smartphone application can improve bystander CPR quality in terms of no-flow-time, compression rate, correct hand position, thorax release and does not delay CPR onset. However, the use of a smartphone application does not improve compression depth significantly.

Keywords: CPR, PocketCPR, Resuscitation, Simulator, Simulation, Feedback, Feedback device

* Corresponding author.
E-mail address: christopher.plata@uk-koeln.de (C. Plata).

https://doi.org/10.1016/j.resuscitation.2019.01.039
Received 13 November 2018; Received in revised form 23 January 2019; Accepted 30 January 2019
0300-9572/© 2019 Elsevier B.V. All rights reserved.

Introduction

Despite declining mortality rates of cardiovascular diseases in Western Europe, sudden cardiac death remains the leading cause of cardiovascular related death in Europe with an incidence of approximately 1/1000 per year.[1–3] Further, only 10% of patients experiencing an out-of-hospital cardiac arrest (OHCA) can be discharged from the hospital in a good neurological status.[4–6] Thereby, early initiation of bystander cardiopulmonary resuscitation (CPR) in addition with high quality chest compressions are crucial factors for surviving OHCA.[7,8]

Over the last few years real-time feedback devices have been introduced and their use has been recommended by the 2015 European Resuscitation Council guidelines.[8] They have been shown to increase the level of confidence and quality during CPR.[9] Especially smartphone applications for real-time feedback are an interesting and innovative tool in layperson CPR[10] since smartphones are widely spread. The use of feedback devices has been shown to increase CPR quality.[11–14] Dispatcher-assisted telephone CPR has been established in many dispatcher centres in Europe and the USA[15] due to its beneficial effects on CPR quality.[4,16–18] However, dispatcher explanations and instructions can delay the onset of chest compressions significantly and, therefore, worsen overall CPR quality.[19–24] Furthermore, dispatchers cannot evaluate the CPR quality provided by bystanders.

The aim of the present study was to evaluate the effects of telephone CPR, a smartphone feedback application and their combination on bystander CPR quality. We hypothesized that the use of the smartphone application leads to higher CPR quality compared to telephone CPR or uninstructed standard CPR.

Materials and methods

Study design

This prospective, randomized, controlled parallel group and single-blind manikin trial was performed in a tertiary university hospital in Germany. The study was approved by the local Ethics Committee of the University Hospital Cologne (no. 16-379, 12th of January 2017) and registered at the German Clinical Trial Register (DRKS00011605). Data were collected from February 2017 to March 2017. Written informed consent was obtained from each participant prior to inclusion.

Study protocol

100 laypersons between 18 and 65 years performed eight minute CPR on a manikin in a randomized order. Medically educated individuals, medical professionals, medical students and pregnant women were excluded. Data on sex, age, experience with real patient resuscitation and training in Basic Life Support training (BLS) were recorded. Volunteers were randomly assigned by lot to one of four groups: (1) uninstructed CPR (uninstructed group), (2) dispatcher-assisted telephone CPR (telephone-group), (3) guidance and feedback through a smartphone application (app-group) and (4) dispatcher-assisted telephone CPR combined with the smartphone-application (telephone + app-group).

After a standardized introduction to the simulation environment and the emergency situation, all volunteers were instructed how to use the cordless telephone in order to call the simulated rescue coordination centre at the beginning of the scenario. A standardized T-CPR protocol was used for all groups with telephone-support. Members of the app-group and the telephone + app-group additionally received an introduction in the iPhone 4 and how to activate the preinstalled "PocketCPR" application. They did not receive training on the application or how to hold the smartphone during CPR. The smartphone application provides audiovisual real-time feedback in form of a bar indicating actual compression depth. Using the internal accelerometer of the smartphone to analyse compression depth and rate has been described and validated previously.[25,26] Verbal feedback prompts by "push harder", "push faster", "push slower", "good depth" and by a permanent metronome with 100 min^{-1}. There are no commands on ventilations since the application is designed for the compression-only-approach according to the European Resuscitation Council (ERC) Guidelines 2015.[8] Members of the telephone-group and the telephone + app-group were given dispatcher-assisted guidance according to a standardized protocol. Members of the U-group did not receive any support. Test period started by dispatching the emergency medical services (EMS) during the simulated emergency call. The experiment was stopped after eight minutes, based on the mean period of time for an EMS-crew to arrive.[8]

Materials used

Volunteers of the app- and telephone + app-group used the "PocketCPR" smartphone application (Zoll, Massachusetts, USA) on a smartphone (iPhone 4, Apple, California, USA). Ambu Man W (Ambu GmbH, Bad Nauheim, Germany) was used as a manikin and data recorder. To make an emergency call, a cordless telephone connection using a Gigaset AL 275 Duo (Siemens AG, Munich, Germany) was established. Data on CPR quality were collected via Ambu CPR Software Version 3.1.1 (Ambu GmbH, Bad Nauheim, Germany) and were processed with MS Excel (Version 14.0; Microsoft Corp., Redmond, USA) and SPSS 23.

Measurements and outcomes

Our primary outcome parameters were total number of chest compressions (defined as >2 cm of compression depth), number of correct chest compressions (defined as 50–60 mm of depth), compression rate (defined as any compression of the thorax), correct compression rate (defined as 100–120 compressions min^{-1}). Additionally, secondary outcome parameters were: time to first chest compression (defined as the time interval from dispatching the EMS during the simulated emergency call until onset of chest compressions), no-flow-time (defined as the time without effective compression after the onset of chest compressions or interruption of more than 2 s), compression depth and compression rate over time in intervals of one minute, correct hand positioning and correct thorax release after compression.

Statistical analysis

Following a previous study[24] and a power analysis, a study group size of 25 ([alpha] = 5%, [beta] = 80%) was chosen. Normally distributed data are presented as mean + standard deviation and were compared between the four groups using Kruskal–Wallis-test. Quantitative data not following normal distribution are presented as median and interquartile range (IQR). To compare the four different groups, the

Kruskal–Wallis-test was used. For the post hoc analysis, Mann–Whitney U tests with unadjusted p values were used. Dichotomous data are presented as numbers and percentages and were compared between the four groups using a χ^2-test. A p-value less than 0.05 was considered statistically significant.

Results

100 volunteers were recruited, randomized and included in our trial according to the inclusion criteria (Fig. 1). Two participants did not finish the experiment due to early cessation of CPR because of physical overstrain (one of uninstructed group, one of app-group). Further, two volunteers did not dial the emergency number (one of the telephone-group, one of the app-group). One member of the app-group and another member of the telephone + app-group did not use the smartphone application. Following the intention to treat principle (ITT), we did not exclude these volunteers. Demographic characteristics of the volunteers and the four study groups are shown in Table 1. There were no significant differences amongst the members of the four groups regarding sex, age, real patient resuscitation or basic resuscitation training.

Time to first chest compression

Median time to first chest compression was shortest in uninstructed group (76 s [61 s–86 s]), followed by the app-group (87 s [74 s–105 s]), the telephone + app-group (114 s [106 s–132 s]) and the telephone-group (124 s [111 s–139 s]). As a consequence, the performed Kruskal–Wallis test showed significant differences (Table 2) between the four groups. In the post hoc analysis, time to first compression in the app-group was significantly lower than in the telephone-group ($p < 0.001$) and in the telephone + app-group ($p = 0.001$). Additionally, time to first compression was significantly higher in the telephone-group ($p < 0.001$) and the telephone + app-group ($p < 0.001$) compared to the uninstructed group. However, there was no significant difference between the uninstructed group and the app-group ($p = 0.052$), likewise between the telephone-group and the telephone + app-group ($p = 0.193$).

No-flow-time

The no-flow-time of the uninstructed group (139 s [50–162 s]) was significantly longer compared to all other groups ($p < 0.001$). There was no significant difference between the app-, telephone- and telephone + app-group (Table 2).

Compression parameters

The total number of chest compressions as well as the compression rate differed significantly between the four groups (Table 2). In the post hoc analysis the total number of chest compressions in the app-group (751 [543–866]) was significantly higher compared to the uninstructed group (427 [322–523]) and the telephone-group (539 [343–679]), but showed no significant difference compared to the telephone + app-group (696 [628–786]) (Table2). The median compression rate in the app-group (107 min^{-1} [95–117 min^{-1}]) and the telephone + app-group (106 min^{-1} [101–119 min^{-1}]) were within the recommended range of 100–120 min^{-1}. Their median compressions rates were significantly higher compared to the uninstructed group (62 min^{-1} [51–77 min^{-1}]) and the telephone-group (82 min^{-1} [58–105 min^{-1}]), whereas results of the telephone-group showed no significant difference compared to those of the uninstructed group. Regarding compression depth, there was no significant difference in the median number of chest compressions with correct depth between the four groups ($p = 0.629$).

Time-related compression parameters

In contrast to the previous analysis and due to the limited number of volunteers performing CPR for more than 6 min, the minute-wise analysis of compression depth and compression rate included only minute one to six of actually performed CPR. After six minutes, 89% of the volunteers had been performing CPR and thus were included in

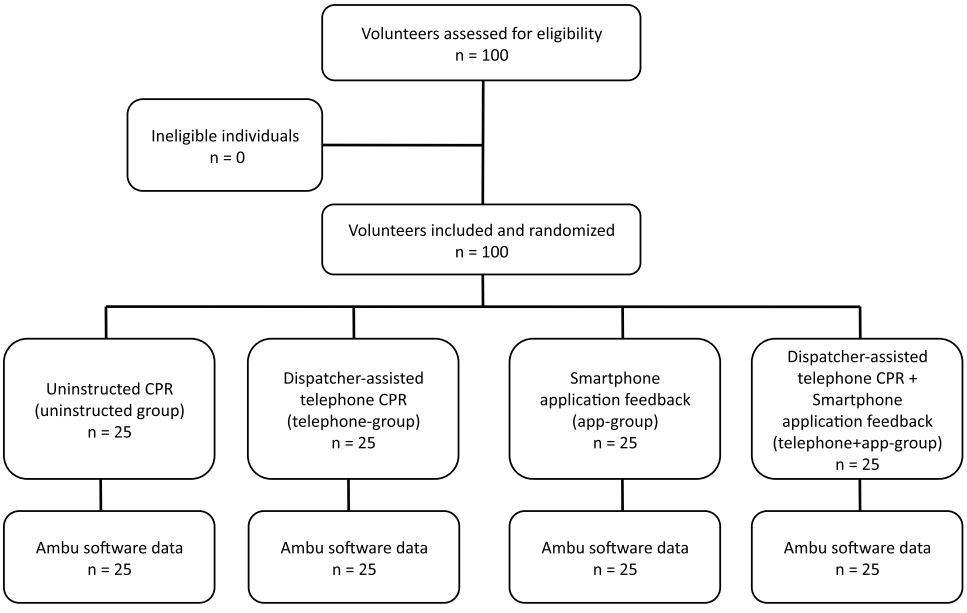

Fig. 1 – Study flow chart.

Table 1 – Baseline characteristics.

	U-group n = 25	T-group n = 25	A-group n = 25	TA-group n = 25	*p*-Value
Sex (female), *n*/%	15/60	11/44	13/52	10/40	0.501
Age [years]	31.2 + 13.5	32.2 + 11.8	35.5 + 14	31.4 + 11.7	0.551
Real patient resuscitation performed, *n*/%	2/8	0	0	2/8	0.244
Last BLS training within *n*/%					
<1 year ago	4/16	8/32	1/4	3/12	0.061
1–5 years ago	9/36	8/32	8/32	6/24	
5–10 years ago	8/32	2/8	5/20	6/24	
>10 years ago	4/16	7/28	11/44	10/40	

Table 2 – CPR and time related parameters.

	U-group n = 25	T-group n = 25	A-group n = 25	TA-group n = 25	*p*-value
Time to first chest compression (TTFC)[a] [s]	76 (61–86)	124 (111–139)	87 (74–105)	114 (106–132)	Kruskall–Wallis-test[b] < 0.001 U-group vs. T-group < 0.001 U-group vs. TA-group < 0.001 T-group vs. A-group < 0.001 A-group vs. TA-group = 0.001 Others: n.s.
No-flow-time (NFT)[c] [s]	139 (50–162)	6 (0–51)	8 (1–28)	8 (0–27)	Kruskall–Wallis-test < 0.001 U-group vs. T-group = 0.001 U-group vs. A-group < 0.001 U-group vs. TA-group < 0.001 Others: n.s.
Total number of chest compressions [n]	427 (322-523)	539 (343-679)	751 (543-866)	696 (628-786)	Kruskall–Wallis-test < 0.001 U-group vs. A-group = 0.001 U-group vs. TA-group < 0.001 T-group vs. TA-group = 0.003 T-group vs. A-group = 0.015 Others: n.s.
Chest compressions with correct depth[d] [n]	97 (7–198)	77 (12–236)	89 (4–283)	192 (16–300)	Kruskall–Wallis- test = 0.629 All n.s.
Compression rate [min^{-1}]	62 (51–77)	82 (58–105)	107 (95–117)	106 (101–119)	Kruskall–Wallis-test < 0.001 U-group vs. A-group < 0.001 U-group vs. TA-group < 0.001 T-group vs. TA-group = 0.002 T-group vs. A-group = 0.024 Others: n.s.
Correct hand position (CHP) [n]	453 (326-568)	527 (309-707)	700 (587-836)	694 (563-749)	Kruskall–Wallis-test = 0.012 U-group vs. A-group = 0.009 U-group vs. TA-group = 0.008 T-group vs. A-group = 0.041 Others: n.s.
Correct thorax release after compression (cTRAC) [n]	372 (256-503)	348 (286-523)	715 (366-826)	652 (475-762)	Kruskall–Wallis-test < 0.001 U-group vs. A-group = 0.003 U-group vs. TA-group < 0.001 T-group vs. A- group = 0.007 T- group vs. TA-group < 0.001 Others: n.s.

Quantitative data presented as median (IQR), qualitative data as n/%. n.s., not significant.
[a] Defined as the time interval from dispatching the EMS during the simulated emergency call until onset of first chest compression.
[b] Unadjusted.
[c] Defined as the time without chest compressions of more than 2 s after onset of CPR or depth of compression <2 cm.
[d] Defined as 50–60 mm.

the minute-wise analysis. Regarding median compression rate, a significant difference was found in every minute between the four groups ($p < 0.001$ for every minute). Further, the median compression rate of the app- and the telephone + app-group was within the recommended range of 100–120 per minute from minute one to six (Fig. 2A). Results of the uninstructed and the telephone-group were below 100 min^{-1} in this time span. Regarding correct compression depth, the minute-wise analysis showed no significant difference between the four groups in any minute (Fig. 2B). With the exception of the telephone + app-group, all groups showed lower levels of chest compressions with correct depth after six minutes compared to minute one. Study groups with smartphone application support showed a continuously increase until a maximum of 33% (app-group) and 30% (telephone + app-group) in minute three followed by a subsequently decline till minute 6 (app-group) respectively minute 5 (telephone + app-group). In contrast to that maximum in minute three, chest compressions with correct depth of the uninstructed group showed a minimum of 20% at that time. Furthermore, there was no significant

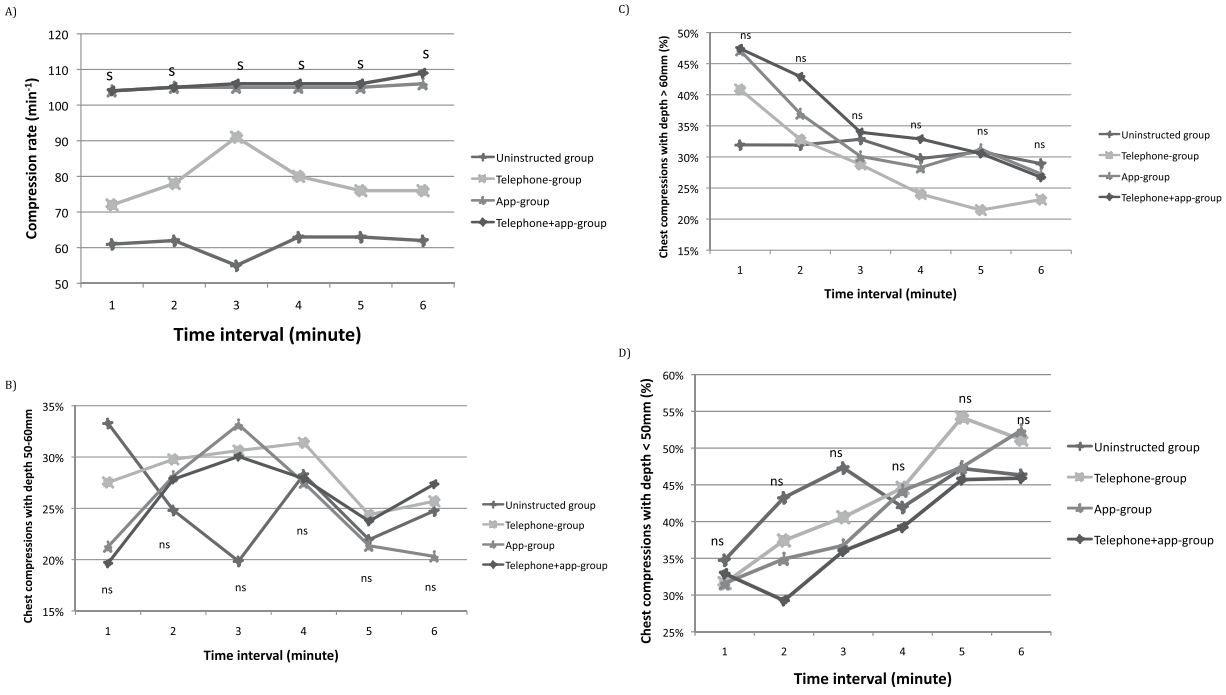

Fig. 2 – Compression rate over time (A), chest compressions with correct depth overtime (B). Chest compressions >60 mm of depth over tiime(C), chest compressions <50 mm of depth overtime (D). s, Significant; ns, not significant.

difference in levels of chest compression with more than 60 mm of depth over time between the four study groups (Fig. 2C). Results of the app- and the telephone + app-group showed the highest percentage of chest compressions deeper than 60 mm in minute one (app-group 47%; telephone + app-group 47%). Further, these groups show the biggest decline over time of all study groups ending at 27% in minute six. Results of the telephone-group show similar results while results of the uninstructed group show an almost horizontal development. Regarding chest compressions of depth less than 50 mm there is no significant difference between the study groups with an increase over time (Fig. 2D).

Correct hand position

There was a significant difference regarding compressions performed with correct hand positioning in groups with smartphone-app support compared to the uninstructed group. Respectively, results did not differ significantly between the app-group and the telephone + app-group. Additionally, there was no significant difference between the telephone-group compared to the telephone + app-group and the uninstructed group compared to the telephone-group.

Correct thorax release after compression

The number of thorax compressions followed by complete thorax release was highest in the telephone + app-group showing a significant difference compared to the telephone-group and the uninstructed group. Further, correct thorax release in the app-group was significantly higher compared to the uninstructed group and the telephone-group. No significant difference was found between the uninstructed group and the telephone-group, as well as between the app-group and the telephone + app-group.

Discussion

The results of the present study confirm the positive impact of feedback devices on CPR quality. Several studies investigated the field of real-time feedback. However, most were simulation studies whose results have yet to be proven in reality. A real-life study of Abella et al.[27] demonstrated, like many simulation studies,[11,13,28–32] global positive effects on CPR quality parameters. However, Zapletal et al. found no significant difference in CPR quality comparing support via smartphone application and standard BLS.[33] On the contrary, Zapletal et al. showed a substantial delay in starting CPR caused by feedback devices compared to standard BLS,[33] which cannot be confirmed by our results. Buléon et al. found significant differences in compression depth and thorax release but not in compression rate in the feedback group compared to the control group.[12] Results of another study by Buléon et al. revealed significantly lower rescuer's fatigue in the feedback group compared to standard CPR without feedback.[13] Our results confirm these findings for the compression rate. In contrast to the groups without feedback, the feedback groups achieved a constantly high compression rate within the recommended range from minute one to six. Our results show no positive impact of the smartphone application on rescuer's fatigue as results of the compressions with correct compression depth do not differ significantly over time between the study groups. On the other hand, the use of a smartphone application does not lead to a significant boost in chest compression depth over time either.

In a recent study by Eaton et al. the authors compared CPR quality parameters of laypersons with and without "PocketCPR" support.[34] Interestingly, compression depth increased significantly in the smartphone group and the compression rate showed no significant difference compared to the control group. These results stand in

contrast to the findings of this study where compression rate in study groups with smartphone application support (app- and telephone + app-group) was significantly higher compared to the uninstructed and the telephone-group.

In general, one reason for the divergent findings in different studies might be caused by the different study designs. Some authors included medical experts while others included laypersons. In some studies a previous BLS training was performed while in other studies "BLS-naive" volunteers performed CPR. Our study followed a realistic approach simulating layperson resuscitation in a cardiac arrest situation. Volunteers neither received a prior BLS training nor an introduction in the smartphone application.

However, introducing probands to the simulation environment represents an indirect education on how to react in a medical emergency situation, which does not take place in reality. Minor problems can delay or actually inhibit the onset of chest compressions. Even if there was such an application on a layperson's smartphone, it can probably be questioned if it was used in a real out-of-hospital cardiac arrest situation. Overall, feedback devices are useful tools to get CPR quality closer to the recommended levels. Consistently, the use of feedback devices has been recommended by the 2015 European Resuscitation Council guidelines including smartwatches, compressiometers or smartphones.[8] Previous studies have shown the feasibility of these tools.[14,25,35–38] Yet, there is no evidence that the use of feedback devices increases the rate of survival in out-of-hospital cardiac arrest or improves patients outcome.[11,27,39] Although BLS training for general public remains essential, smartphones play an important and increasing role in medical emergency situations due to their high prevalence. Kovic and Lulic present a modified "mobile chain of survival" to emphasize the importance of smartphones in medical emergency situations.[40]

Interestingly, the two volunteers who did not finish the eight-minute period were both older than 60 years. Since many bystanders are probably of this age and above it might be of interest if there is a general physical problem in this age group to achieve the CPR quality criteria recommended in the ERC guidelines.

A surprising observation was that the quantity of simultaneously given feedback did not appear to distract the probands' attention from CPR. However, dispatchers' explanations focussed on instructing probands in how to perform high quality CPR (including compression depth and rate), thus extending the time to first chest compression. In contrast, the smartphone application focused on giving audiovisual feedback without giving time-consuming verbal instructions.

Due to the study design and the individual onset of thorax compression, the time interval of CPR performance varies. As a consequence, most of the volunteers performed CPR less than seven minutes. Due to this decline in the number of volunteers performing CPR over time, the minute-wise analysis of compression depth and compression rate was performed from minute one to six. Finally, it should be mentioned that the feedback given by the smartphone application during CPR was contradictory. Though following the recommended compression rate of 100 min^{-1}, the application kept on repeating the command "push faster". This was also found when using other Android-based smartphones and could be caused by not holding the smartphone strictly horizontally. As previously reported by Park,[36] similar difficulties were observed in holding the smartphone stable during CPR. He also reported hand back pain in almost 50% of the users, which is consistent with our experiences.

Limitations and strengths of the study

Several limitations of this study need to be mentioned. Results of simulation studies are inappropriate to draw a conclusion in terms of survival or clinical outcome. Yet, manikin studies are useful to focus on providers and their ability to follow human instructions and feedback devices. Although sufficient for statistical analysis, the number of included volunteers was limited to 100 with a mean age under 35 years. This might not be the representative age for bystanders in real life. Finally, it is not known how many people know that feedback devices exist. Neither, it is not known how often the smartphone application has been downloaded or how often it has been used so far in bystander CPR.

Conclusion

In the present study, the use of a smartphone application singularly or combined with dispatcher assistance has a positive impact on quality of bystander CPR except compression depth. Considering its easy handling and widely availability, it can be considered as a useful CPR tool for laypersons. Further clinical studies need to investigate on the question if findings from this manikin study are consistent with findings in real life CPR.

The smartphone application is no longer available via free download for Android or iOS. There was no influence by the manufacturer (Zoll Medical, Massachusetts, USA) on data or on the manuscript at any stage. Bernd W. Böttiger is European Resuscitation Council (ERC) Board Director Science and Research; Chairman of the German Resuscitation Council (GRC); Member of the, Advanced Life Support (ALS) Task Force of the International Liaison Committee on Resuscitation (ILCOR); Member of the executive committee of the German Interdisciplinary Association for Intensive and Emergency Medicine (DIVI); Associated Editor of the European Journal of Anaesthesiology (EJA), Co-Editor of "Resuscitation"; Editor of the Journal "Notfall + Rettungsmedizin". He received professional fees for lectures from the following companies: Medupdate GmbH, "Forum für medizinische Fortbildung (FomF)", Baxalta Deutschland GmbH, Bayer Vital GmbH, ZOLL Medical Deutschland GmbH, C. R. Bard GmbH, GS Elektromedizinische Geräte G. Stemple GmbH. The other authors do not have a conflict of interest.

Acknowledgments

We would like to thank all volunteers for participating in our study. The study was supported in part by the ERC Research NET.

REFERENCES

1. Sans S, Kesteloot H, Kromhout D. The burden of cardiovascular diseases mortality in Europe. Task Force of the European Society of Cardiology on cardiovascular mortality and morbidity statistics in Europe. Eur Heart J 1997;18:1231–48.
2. Kesteloot H, Sans S, Kromhout D. Dynamics of cardiovascular and all-cause mortality in Western and Eastern Europe between 1970 and 2000. Eur Heart J 2006;27:107–13.
3. Andresen D. Epidemiologie des plötzlichen Herztodes. Intensivmed Notfallmed 2001;44:188–93.
4. Rea TD, Mickey S, Eisenberg M, Becker C. Dispatcher-assisted cardiopulmonary resuscitation and survival in cardiac arrest. Circulation 2001;104:2513–6.

5. Pircher IR, Stadlbauer KH, Severing AC, et al. A prediction model for out-of-hospital cardiopulmonary resuscitation. Anesth Analg 2009;109:1196–201.
6. Herlitz J, Ekstrom L, Wennerblom B, Axelsson A, Bang A, Holmberg S. Effect of bystander initiated cardiopulmonary-resuscitation on ventricular-fibrillation and survival after witnessed cardiac-arrest outside hospital. Br Heart J 1994;72:408–12.
7. Kragholm K, Wissenberg M, Mortensen RN, et al. Bystander efforts and 1-year outcomes in out-of-hospital cardiac arrest. N Engl J Med 2017;376:1737–47.
8. Perkins GD, Handley AJ, Koster RW, et al. European Resuscitation Council Guidelines for Resuscitation 2015: section 2. Adult basic life support and automated external defibrillation. Resuscitation 2015;95:81–99.
9. Renshaw J, Eaton G, Gregory P, Kilner T. The BHF PocketCPR smartphone application: 'staying alive' with bystander CPR. Resuscitation 2017;118:e3–4.
10. Hase M. Quality of bystander cardiopulmonary resuscitation — can a smartphone bring about a revolution? Circ J 2015;79:964–5.
11. Kirkbright S, Finn J, Tohira H, Bremner A, Jacobs I, Celenza A. Audiovisual feedback device use by health care professionals during CPR: a systematic review and meta-analysis of randomised and non-randomised trials. Resuscitation 2014;85:460–71.
12. Buléon C, Parienti JJ, Halbout L, et al. Improvement in chest compression quality using a feedback device (CPRmeter): a simulation randomized crossover study. Am J Emerg Med 2013;31:1457–616.
13. Buléon C, Delaunay J, Parienti JJ, et al. Impact of a feedback device on chest compression quality during extended manikin cardiopulmonary resuscitation: a randomized crossover study. Am J Emerg Med 2016;34:1754–60.
14. Kurowski A, Szarpak Ł, Bogdański Ł, Zaśko P, Czyżewski Ł. Comparison of the effectiveness of cardiopulmonary resuscitation with standard manual chest compressions and the use of TrueCPR and PocketCPR feedback devices. Kardiol Pol 2015;73:924–30.
15. Maier M, Luger M, Baubin M. Telephone-assisted CPR — a literature review. Notfall Rettungsmed 2016;19:468–72.
16. Hallstrom AP, Cobb LA, Johnson E, Copass MK. Dispatcher assisted CPR: implementation and potential benefit. A 12-year study. Resuscitation 2003;57:123–9.
17. Eisenberg MS, Hallstrom AP, Carter WB, Cummins RO, Bergner L, Pierce J. Emergency CPR instruction via telephone. Am J Public Health 1985;75:47–50.
18. Kuisma M, Boyd J, Väyrynen T, Repo J, Nousila-Wiik M, Holmström P. Emergency call processing and survival from out-of-hospital ventricular fibrillation. Resuscitation 2005;67:89–934.
19. Berdowski J, Beekhuis F, Zwinderman AH, Tijssen JG, Koster RW. Importance of the first link: description and recognition of an out-of-hospital cardiac arrest in an emergency call. Circulation 2009;119:2096–102.
20. Culley LL, Clark JJ, Eisenberg MS, Larsen MP. Dispatcher-assisted telephone CPR: common delays and time standards for delivery. Ann Emerg Med 1991;20:362–6.
21. Heward A, Donohoe RT, Whitbread M. Retrospective study into the delivery of telephone cardiopulmonary resuscitation to "999" callers. Emerg Med J 2004;21:233–4.
22. Vaillancourt C, Verma A, Trickett J, et al. Evaluating the effectiveness of dispatch-assisted cardiopulmonary resuscitation instructions. Acad Emerg Med 2007;14:877–83.
23. Dami F, Heymann E, Pasquier M, Fuchs V, Carron PN, Hugli O. Time to identify cardiac arrest and provide dispatch-assisted cardio-pulmonary resuscitation in a criteria-based dispatch system. Resuscitation 2015;97:27–33.
24. Spelten O, Warnecke T, Wetsch WA, Schier R, Böttiger BW, Hinkelbein J. Dispatcher-assisted compression-only cardiopulmonary resuscitation provides best quality cardiopulmonary resuscitation by laypersons: a randomised controlled single-blinded manikin trial. Eur J Anaesthesiol 2016;33:575–80.
25. Gruber J, Strumpf D, Zapletal B, Neuhold S, Fischer H. Real-time feedback systems in CPR. Curr Anaesth Crit Care 2012;2:287–94.
26. Song Y, Oh J, Chee Y. A new chest compression depth feedback algorithm for high quality CPR based on smartphone. Telemed E Health 2015;21:36–41.
27. Abella BS, Edelson DP, Kim S, et al. CPR quality improvement during in-hospital cardiac arrest using a real-time audiovisual feedback system. Resuscitation 2007;73:54–61.
28. Skorning M, Beckers SK, JCh Brokmann, et al. New visual feedback device improves performance of chest compressions by professionals in simulated cardiac arrest. Resuscitation 2009;81:53–8.
29. Pozner CN, Almozlino A, Elmer J, Poole S, McNamara D, Barash D. Cardiopulmonary resuscitation feedback improves the quality of chest compression provided by hospital health care professionals. Am J Emerg Med 2010;29:618–25.
30. Sakai T, Kitamura T, Nishiyama C, et al. Cardiopulmonary resuscitation support application on a smartphone — randomized controlled trial. Circ J. 2015;79:1052–7.
31. Iskrzycki L, Smereka J, Rodriguez-Nunez A, et al. The impact of the use of a CPRMeter monitor on quality of chest compressions: a prospective randomised trial, cross-simulation. Kardiol Pol 2018;76:574–9.
32. Yeung J, Meeks R, Edelson D, Gao F, Soar J, Perkins GD. The use of CPR feedback/prompt devices during training and CPR performance: a systematic review. Resuscitation 2009;80:743–51.
33. Zapletal B, Greif R, Stumpf D, et al. Comparing three CPR feedback devices and standard BLS in a single rescuer scenario: a randomised simulation study. Resuscitation 2014;85:560–6.
34. Eaton G, Renshaw J, Gregory P, Kilner T. Can the British Heart Foundation PocketCPR application improve the performance of chest compressions during bystander resuscitation: a randomised crossover manikin study. Health Inform J 2018;24:14–23.
35. Song Y, Chee Y, Oh J, Ahn C, Lim TH. Smartwatches as chest compression feedback devices: a feasibility study. Resuscitation 2016;103:20–3.
36. Park SS. Comparison of chest compression quality between the modified chest compresion method with the use of smartphone application and the standardized traditional chest compresion method during CPR. Technol Health Care 2014;22:351–8.
37. Ahn C, Lee J, Oh J, et al. Effectiveness of feedback with a smartwatch for high-quality chest compressions during adult cardiac arrest: a randomized controlled simulation study. PLoS One 2017;12.
38. Mamoru H. Quality of bystander cardiopulmonary resuscitation. Circ J 2015;79:964–5.
39. Canadian Agency for Drugs and Technologies in Health. Cardiopulmonary resuscitation feedback devices for adult patients in cardiac arrest: a review of clinical effectiveness and guidelines. 2015.
40. Kovic I, Lulic I. Mobile phone in the chain of survival. Resuscitation 2011;82:776–9.