Available online at www.sciencedirect.com

Resuscitation

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

ELSEVIER

EUROPEAN RESUSCITATION COUNCIL

Simulation and education

Optimal training frequency for acquisition and retention of high-quality CPR skills: A randomized trial

Robert Anderson[a], Alexandre Sebaldt[b,*], Yiqun Lin[c], Adam Cheng[d]

[a] Northern Ontario School of Medicine, Sudbury Outpatient Centre, 865 Regent Street S, Sudbury, P3E 3Y9, Ontario, Canada
[b] Northern Ontario School of Medicine, Department of Anesthesiology, Health Sciences North, 41 Ramsey Lake Road, Sudbury, P3E 5J1, Ontario, Canada
[c] Department of Community Health Sciences, University of Calgary, 2888 Shaganappi Trail NW, Calgary, T3B 6A8, Alberta, Canada
[d] Departments of Pediatrics and Emergency Medicine, University of Calgary, 2888 Shaganappi Trail NW, Calgary, T3B 6A8, Alberta, Canada

Abstract

Aim: Spaced training programs employ short, frequent CPR training sessions to improve provider skills. The optimum training frequency for CPR skill acquisition and retention has not been determined. We aimed to determine the training interval associated with the highest quality CPR performance at one year.

Methods: Participants were randomized to 1-month, 3-month, 6-month, and 12-month CPR training intervals over the course of a 12-month study period. Practice sessions included repeated two-minute CPR practice sessions with visual feedback and verbal coaching until Excellent CPR was achieved, to a maximum of three attempts. Excellent CPR was defined as a two-minute CPR session with $\geq$90% of compressions with a depth of 50–60 millimeters, a rate of 100–120 per minute, and with complete chest recoil. CPR performance was assessed in all groups at 12 months. The primary outcome was the proportion of participants able to perform Excellent CPR in each group.

Results: A total of 167 participants were included in the analysis. Baseline assessment showed no difference in CPR performance ($p = 0.38$). Participants who were trained monthly had a significantly higher proportion of Excellent CPR performance (58%) than those in all other groups (26% in the 3-month group, $p = 0.008$; 21% in the 6-month group, $p = 0.002$; and 15% in the 12-month group, $p < 0.001$).

Conclusion: Short-duration, distributed CPR training on a manikin with real-time visual feedback is effective in improving CPR performance, with monthly training more effective than training every 3, 6, or 12 months.

Keywords: Basic life support, Cardiopulmonary resuscitation, Chest compressions, Education, Simulation, Retention

Abbreviations: BLS, Basic life support; CPR, Cardiopulmonary resuscitation; HCP, Health care provider; IHCA, In-hospital cardiac arrest; JIT, Just-in-time; RQI, Resuscitation quality improvement.

* Corresponding author.
E-mail addresses: randerson@nosm.ca (R. Anderson), asebaldt@nosm.ca (A. Sebaldt), jeffylin@hotmail.com (Y. Lin), chenger@me.com (A. Cheng).

https://doi.org/10.1016/j.resuscitation.2018.10.033
Received 6 August 2018; Received in revised form 2 October 2018; Accepted 30 October 2018
0300-9572/

Introduction

Cardiac arrest is a tragic event with low survival rates to hospital discharge.[1–3] Health care providers (HCPs) often struggle to provide high-quality cardiopulmonary resuscitation (CPR) that meets American Heart Association (AHA) and European Resuscitation Council (ERC) guidelines[4,5] despite clear evidence that guideline-compliant CPR improves patient survival.[3,6–11] Specifically, providers often fall short of delivering CPR within target ranges for chest compression depth, rate, recoil, and chest compression fraction during both simulated and real cardiac arrest events.[7,12–16] Current training regimens that require annual certification do not adequately support the acquisition or retention of high-quality CPR skills. There is growing evidence that spaced (i.e. frequent, brief, and workplace-based) CPR training may lead to improved skill retention.[16–23] Unfortunately, the optimal training frequency is unknown.

CPR feedback devices provide HCPs with detailed information about their CPR performance, including real-time audiovisual feedback on compression rate, depth and recoil. Training regimens that use these devices dramatically improve CPR quality and guideline compliance immediately after a short just-in-time (JIT) training session.[16–23] However, without repetition, CPR performance degrades over time.[21–27]

The AHA's Resuscitation Quality Improvement (RQI) program provides spaced training[21] in the form of short duration CPR training and skill assessment at least every 3 months.[28] While more frequent practice improves CPR performance, there is little evidence to support the 3-month interval as the optimal frequency of these training sessions. Identifying the ideal training interval that results in optimal acquisition and retention of CPR skills may help to improve CPR performance during cardiac arrest care.

In this study, we compare HCPs' ability to perform guideline-compliant CPR after undergoing short, workplace-based CPR training sessions at different intervals: 1, 3, 6, and 12 months over a one-year period. The primary objective is to determine the training interval associated with the highest quality CPR performance at one year.

Methods

Study participants

We conducted a randomized controlled trial with nurses recruited from the intensive care unit, operating room, emergency room, and medical and surgical wards of Health Sciences North Hospital in Sudbury, Ontario, Canada. Recruitment occurred from April to September 2016, and follow-up sessions ended in September 2017. Nurses were chosen as our population of interest because they are the frontline CPR providers at our hospital. To be included in the study, participants were required to be certified in Basic Life Support (BLS), Advanced Cardiac Life Support (ACLS), and/or Pediatric Advanced Life Support (PALS) at the time of enrollment. Participants were excluded if they were physically unable to perform CPR. Ethics approval was obtained from the Health Sciences North Hospital and Laurentian University research ethics boards and written informed consent was obtained from all participants.

Randomization

We used an online random number generator (https://www.randomizer.org/) to create a list of random numbers from 1 to 4, each representing a study group, prior to beginning enrollment. This list was concealed in the opaque study package envelope. Participants were assigned the next available number in the list by our research assistant after consenting to participate in the study. Groups were characterized by their session frequency that occurred either: 1) monthly, 2) every 3 months, 3) every 6 months, or 4) every 12 months (control group). The study design is shown in Fig. 1. Given the study setup, it was not possible to blind the participants or investigators.

Participants completed a demographics questionnaire after enrolling in the study, including questions about physical characteristics, work experience, CPR training courses taken or taught, and prior CPR performance in clinical or simulated settings.

Intervention – CPR testing and training program

Nurses participated in intermittent, sequential CPR testing and training sessions on a mobile training cart (Online supplemental material, Fig. 1). The cart's height was 82 cm, and a 23 cm stool was used by all participants. The bed height was fixed to allow for standardization and generalizability to the AHA RQI program, which also has a fixed bed height and encourages the use of a stool. CPR was performed on an adult CPR torso manikin (Resusci Anne, Laerdal Medical, Stavanger, Norway), from which performance data was collected. The cart was brought to the participating nurse's ward at a mutually agreed-upon time, where he or she would participate in the CPR session during a break in clinical duties. A research assistant, who is also a qualified CPR instructor, facilitated the test and the training session.

Each session began with an assessment, where two minutes of CPR was performed without real-time feedback from the manikin or research

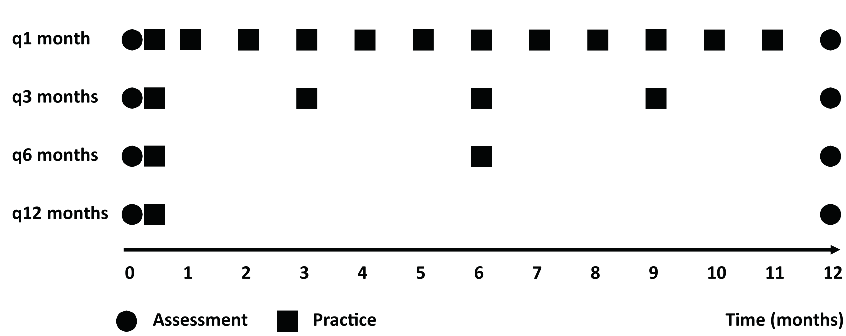

Fig. 1 – Study design.

assistant. This was followed by a training session, unless the participant performed Excellent CPR (see definition below) during the assessment session. The training session included 1) a verbal briefing from the research assistant on the components of high-quality CPR according to the AHA guidelines, and 2) performance of two minutes of CPR with real-time performance feedback both verbally from the research assistant and visually from the computer screen attached to the manikin. Participants were then able to view their overall performance results for these two minutes of CPR. This was followed by a short break, at the participant's discretion, and was repeated until: 1) the participant performed Excellent CPR during the two-minute training session; 2) the participant reached the maximum number of allowed attempts (three); or 3) the participant was too fatigued to continue.

Outcome measures

The primary outcome measure was the proportion of participants in each group that performed Excellent CPR at the 12-month time point. Excellent CPR was defined as a two-minute CPR session where three metrics were achieved: 1) ≥90% of compressions with correct depth (50–60 millimeters), 2) ≥90% of compressions with correct rate (100–120 per minute), and 3) ≥90% of compressions with full chest recoil. This benchmark was chosen to set a rigorous standard for chest compression performance.

Secondary outcomes were the individual CPR performance metrics in each group at 12 months, specifically the percentage of all chest compressions performed with guideline-compliant depth (50–60 millimeters), rate (100–120 per minute), and recoil (full chest recoil) individually.

Sample size

A chi-square test was used to evaluate the difference in rates of Excellent CPR between the four groups. One hundred twenty-two participants were required to detect a moderate effect size (Cohen's $w = 0.3$) with 3 degrees of freedom at an alpha of 0.05 and power of 0.8. Given the high frequency of practice required in some groups, we recruited 244 participants to preserve statistical power for up to a 50% dropout rate.

Statistical analysis

All data analysis was performed with Microsoft Excel (Office 365, Version 1705), R (http://www.r-project.org) and Social Science Statistics (http://www.socscistatistics.com/tests/Default.aspx).

The proportion of participants in each group that achieved Excellent CPR (i.e. 90% compliant for depth, rate, and recoil) was compared using a chi-square test, first in a 4×2 table to compare all groups together, and then in multiple 2×2 tables to compare each group individually. Using a Bonferroni correction to account for these 6 comparisons, a p value of less than 0.008 was considered statistically significant. A sensitivity analysis was conducted by using 80% and 100% as benchmarks of compression metrics for Excellent CPR.

The percentage of guideline-compliant chest compressions in each group for depth, rate, and recoil individually was first compared using a one-way ANOVA. If this test achieved statistical significance at $p < 0.05$, post-hoc pairwise comparisons were conducted with Bonferroni adjustment.

To explore factors associated with performing Excellent CPR at 12 months, we used multiple logistic regression models that adjusted for the intervention received by participants. The factors included were gender, height, age, previous experience performing CPR on patients with real-time feedback, AHA instructor status, and ability to climb two flights of stairs without dyspnea. Adjusted odds ratios (AOR) and their 95% confidence intervals (CI) were calculated. To avoid collinearity, factors of gender and height were put in separate models.

Results

Study population

Two hundred forty-four participants were enrolled in the study. There were no significant differences in participant demographics across groups (Table 1). A total of 68% of all participants (167/244) completed all planned sessions and were included in the analysis (Fig. 2). The monthly training group had the lowest completion rate, with 46% (26/56) of participants completing all training sessions. Significantly higher completion rates occurred in the 3-month (46/67, 69%), 6-month (47/60, 78%), and 12-month groups (48/61, 79%). Data was analyzed from 167 participants from the four study arms. Participants who completed the study were not systematically different from those who did not with respect to initial performance, demographics, and prior training (Online supplemental material, Table 1).

Effect of training frequency on ability to perform Excellent CPR

At the baseline assessment, 5% of participants (9/167) performed Excellent CPR. There was no difference in performance between groups at baseline ($p = 0.38$). After 12 months, 26% of all participants (44/167) performed Excellent CPR. Participants who trained monthly had a significantly higher rate of Excellent CPR performance (15/26, 58%) than those in all other groups (12/46, 26% in the 3-month group, $p = 0.008$; 10/47, 21% in the 6-month group, $p = 0.002$; and 7/48, 15% in the 12-month group, $p < 0.001$) (Fig. 3). There were no significant differences in proportions of Excellent CPR performance between the 3-month, 6-month, and 12-month groups (3 months vs. 6 months, $p = 0.59$; 3 months vs. 12 months, $p = 0.17$; 6 months vs. 12 months, $p = 0.39$). Sensitivity analyses demonstrated that when using an 80% or 100% benchmark for Excellent CPR, the conclusion remained the same. (Online supplemental material, Table 2).

Effect of training frequency on chest compression depth, rate, and recoil

Performance results for each individual CPR metric, measured as percentage of compressions with guideline-compliant depth, rate, and recoil, are shown in Fig. 4 a, b, and c. At baseline, there were no differences between groups in compression depth ($p = 0.52$), rate ($p = 0.43$), or recoil ($p = 0.82$).

Table 1 – Demographic characteristics of participants randomized to each training frequency group.

Demographic characteristics	q1 month	q3 months	q6 months	q12 months
Number (n, % of total)	56 (23%)	67 (27%)	60 (25%)	61 (25%)
Women (n, % of group)	49 (88%)	59 (88%)	52 (87%)	55 (90%)
Age (mean, SD)	41.2 (18.7)	40.0 (10.0)	39.3 (11.3)	35.9 (7.9)
Height in cm (mean, SD)	164.2 (20.1)	165.7 (9.3)	166.0 (7.5)	167.0 (8.5)
Weight in kg (mean, SD)	75.7 (17.1)	71.3 (16.8)	74.3 (14.9)	74.7 (19.9)
Ability to climb 2 flights of stairs without dyspnea (n, % of group)	12 (21%)	9 (13%)	12 (20%)	8 (13%)
Location of work (n, % of group)				
Emergency room	17 (30%)	14 (21%)	7 (12%)	9 (15%)
Intensive care	12 (21%)	11 (16%)	20 (33%)	19 (31%)
Perioperative area	11 (20%)	21 (31%)	12 (20%)	11 (18%)
Medical ward or clinic	14 (25%)	14 (21%)	20 (33%)	19 (31%)
Surgical ward	2 (4%)	7 (10%)	1 (2%)	3 (5%)
Years working as a nurse (mean, SD)	13.0 (8.7)	15.0 (10.9)	14.9 (11.4)	10.9 (7.3)
Last BLS course in months (n, % of group)				
<1	4 (7%)	11 (16%)	7 (12%)	7 (11%)
1 to 6	17 (30%)	14 (21%)	14 (23%)	19 (31%)
7 to 12	9 (16%)	12 (18%)	11 (18%)	13 (21%)
>12	26 (46%)	30 (45%)	28 (47%)	22 (36%)
Last ACLS course in months (n, % of group)				
<1	4 (7%)	3 (4%)	2 (3%)	6 (10%)
1 to 6	9 (16%)	15 (22%)	9 (15%)	7 (11%)
7 to 12	3 (5%)	3 (4%)	8 (13%)	9 (15%)
>12	18 (32%)	22 (33%)	21 (35%)	15 (25%)
Never taken	22 (39%)	24 (36%)	20 (33%)	24 (39%)
Last PALS course in months (n, % of group)				
<1	1 (2%)	0 (0%)	0 (0%)	1 (2%)
1 to 6	2 (4%)	3 (4%)	0 (0%)	0 (0%)
7 to 12	2 (4%)	2 (3%)	3 (5%)	1 (2%)
>12	14 (25%)	11 (16%)	7 (12%)	9 (15%)
Never taken	37 (66%)	51 (76%)	50 (83%)	50 (82%)
Course instructor (n, % of group)	2 (4%)	3 (4%)	0 (0%)	2 (3%)
Times performed CPR on a real patient in the past 2 years (n, % of group)				
Never	20 (36%)	24 (36%)	28 (47%)	25 (41%)
1 to 5	24 (43%)	35 (52%)	24 (40%)	24 (39%)
>5	12 (21%)	8 (12%)	8 (13%)	12 (20%)
Times performed CPR on a simulated patient in the past 2 years (n, % of group)				
Never	18 (32%)	20 (30%)	11 (18%)	12 (20%)
1 to 5	34 (61%)	41 (61%)	46 (77%)	45 (74%)
>5	4 (7%)	6 (9%)	3 (5%)	4 (7%)
Previous use of a CPR feedback device on a real patient (n, % of group)	7 (13%)	10 (15%)	15 (25%)	5 (8%)
Previous use of a CPR feedback device on a simulated patient (n, % of group)	22 (39%)	34 (51%)	35 (58%)	29 (48%)

Standard deviation (SD), basic life support (BLS), advanced cardiac life support (ACLS), pediatric advanced life support (PALS), cardiopulmonary resuscitation (CPR).

Chest compression depth

At 12 months, 78% of all chest compressions performed by participants in the monthly group, 63% in the 3-month group, 57% in the 6-month group, and 62% in the 12-month group were between 50 and 60 mm in depth. There was no significant difference among training frequency groups ($p = 0.17$).

Chest compression rate

At 12 months, 90% of all chest compressions performed by participants in the monthly group, 81% in the 3-month group, 83% in the 6-month group, and 77% in the 12-month group were at a rate of 100–120 compressions per minute. There was no significant difference among training frequency groups ($p = 0.28$).

Chest compression recoil

At 12 months, 95% of all chest compressions performed by participants in the monthly group, 96% in the 3-month group, 99% in the 6-month group, and 88% in the 12-month group had full chest recoil. There was a significant difference among training frequency groups ($p = 0.01$), but individual comparisons between groups only revealed a significant difference between the 6-month and 12-month groups ($p = 0.006$). All other individual comparisons revealed no significant differences between groups (1 month vs. 3 months, $p = 0.83$; 1 month vs. 6 months, $p = 0.17$; 1 month vs. 12 months, $p = 0.20$; 3 months vs. 6 months, $p = 0.06$; 3 months vs. 12 months, $p = 0.06$).

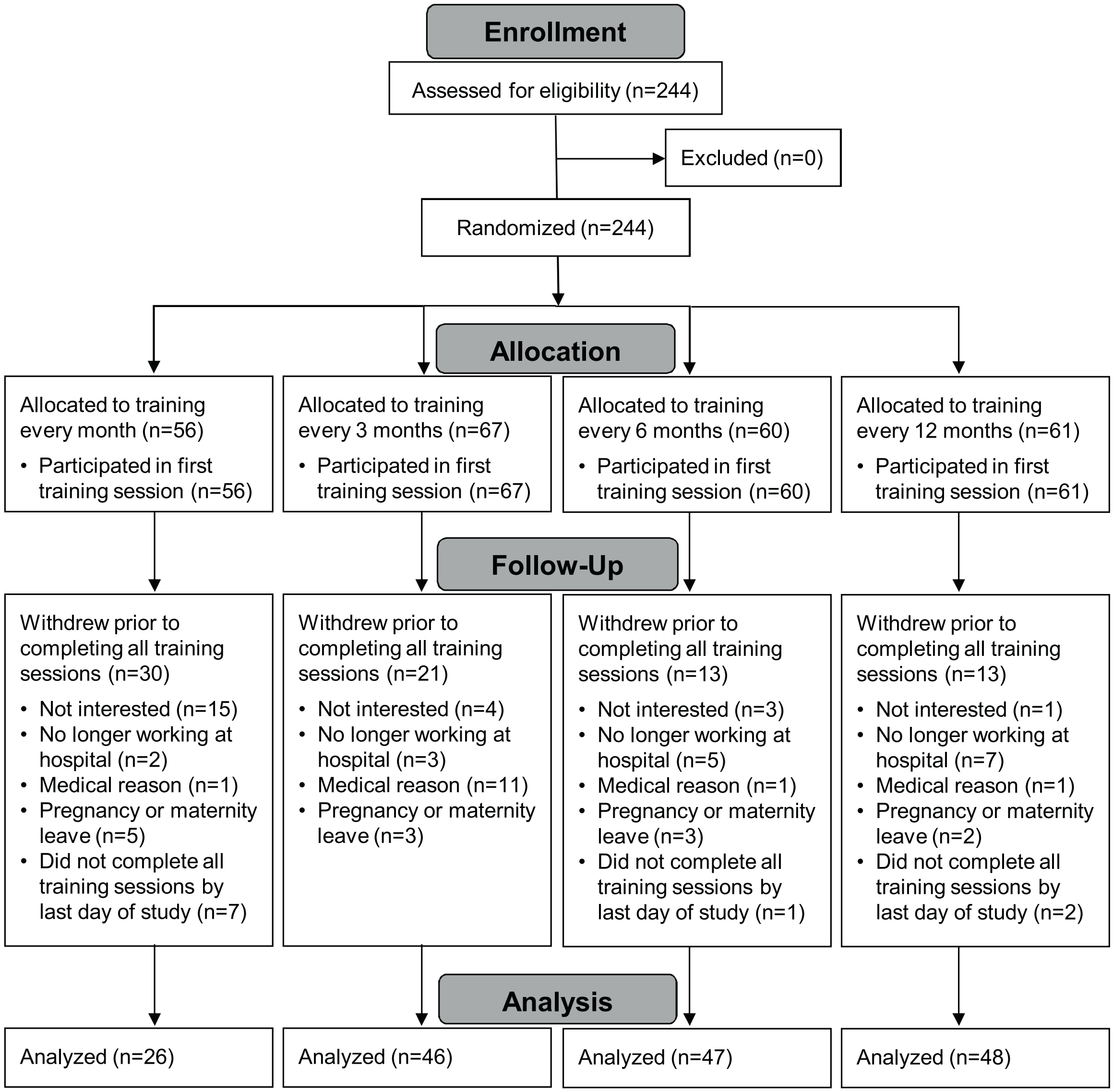

Fig. 2 – Participant flow chart.

Predictors of ability to perform Excellent CPR

In the multiple logistic regression models that adjusted for intervention, independent factors associated with performing Excellent CPR at 12 months included male gender (AOR 4.95, 95%CI 1.69–14.79), height (AOR 1.07, 95%CI 1.02–1.12 for each 1 cm increase in height), and age (AOR 1.05, 95%CI 1.01–1.10 for each 1 year younger). Other factors such as previous experience performing CPR on patients with real-time feedback, being an AHA course instructor, and the ability to climb two flights of stairs without dyspnea were not found to be significantly associated with performing Excellent CPR (Table 2).

Discussion

Even though our participants were all certified in BLS, with more than half having completed the course in the past 12 months, only 5% were able to perform Excellent CPR at their first test session. This aligns with previous findings on CPR quality in both simulated and clinical environments[12–16] and in studies of providers participating in BLS training courses.[29–33] A significant performance gap in CPR skills exists despite mandatory recertification courses and awareness campaigns that highlight the importance of high-quality CPR. To address this issue, the AHA RQI program utilizes a spaced training design, where CPR skills are practiced at least every 3 months. Our results suggest that monthly training is superior to quarterly training, with double the amount of CPR providers able to perform Excellent CPR after 12 months. In our study, quarterly training did not achieve statistical improvement over biannual or even annual training after a 12-month training period.

Several prior studies have described benefits of spaced CPR training,[16–23] but none have conducted a head-to-head comparison of different training frequencies. Oermann et al. demonstrated the benefit of short, monthly CPR training over 12 months. Their study had

Table 2 – Factors associated with performing excellent CPR at 12 months.

	Model 1 AOR (95%CI)	Model 2 AOR (95%CI)
Intervention		
q12 months	1 [reference]	1 [reference]
q6 months	1.99 (0.64, 6.49)	2.19 (0.71, 7.12)
q3 months	2.52 (0.86, 7.93)	3.00 (1.00, 9.52)
q1 month	11.90 (3.67, 43.49)	12.71 (3.89, 46.93)
Gender		
Female	1 [reference]	Not included*
Male	4.95 (1.69, 14.79)	
Age		
Per 1 year younger	1.05 (1.01, 1.10)	1.05 (1.01, 1.10)
Height		
Per 1 cm taller	Not included*	1.07 (1.02, 1.12)
Previous experience with real-time feedback device on patient		
No	1 [reference]	1 [reference]
Yes	0.32 (0.07, 1.09)	0.41 (0.09, 1.37)
AHA course instructor		
No	1 [reference]	1 [reference]
Yes	3.95 (0.42, 31.02)	3.83 (0.38, 31.55)
Ability to climb 2 flights of stairs without dyspnea		
No	1 [reference]	1 [reference]
Yes	1.46 (0.46, 4.33)	1.39 (0.45, 3.99)

Adjusted odds ratio (AOR), confidence interval (CI).

Model 1: Includes intervention, gender, age, previous experience with real-time feedback on patient, AHA course instructor, and ability to climb 2 flights of stairs without dyspnea. Excludes height.

Model 2: Includes intervention, height, age, previous experience with real-time feedback on patient, AHA course instructor, and ability to climb 2 flights of stairs without dyspnea. Excludes gender.

* Since gender and height are highly correlated, these two factors are not put in the same model to avoid collinearity.

a control group that received no training, and they did not report a composite CPR score.[22] Sutton et al. demonstrated the benefit of short, just-in-time CPR training at 1, 3, and 6 months over a six-month period. The primary outcome was a composite Excellent CPR score based on previous AHA guidelines.[20] Lin et al. recently published a study demonstrating improved retention of CPR skills at one year in a group of nurses randomized to monthly just-in-time CPR training with real-time feedback compared with those receiving annual recertification.[23] Integrating this data with our study's results supports that short duration just-in-time CPR training is more effective when performed monthly than quarterly in the general nursing population.

Examining the individual metrics of success revealed that the largest magnitude of performance improvement was found with chest compression rate. This was consistent across training groups, including the control group that had only one training session. This may be explained by increased awareness of CPR metrics, influenced by the implementation of this study at our institution. It may also be that training rate compliance is easier than for other metrics.

Depth compliance improvement was seen in the monthly, 3-month, and 12-month groups. Compliance with recommended guidelines for depth has significant clinical impact and is associated with improved survival outcomes from cardiac arrest.[3,6–11] Sustained improvements in depth compliance seem harder to achieve and may require more frequent training.[13–16] Comparatively, recoil was fairly well done in the initial test, and although the magnitude of change over the 12-month period was not large, there was improvement in all groups.

As expected, there was a high rate of participants who did not complete the entire study. This was significantly higher in the monthly training group. Reasons for dropping out included loss of interest or time, no longer working at the hospital, developing an injury unrelated to the study after enrollment, and going on

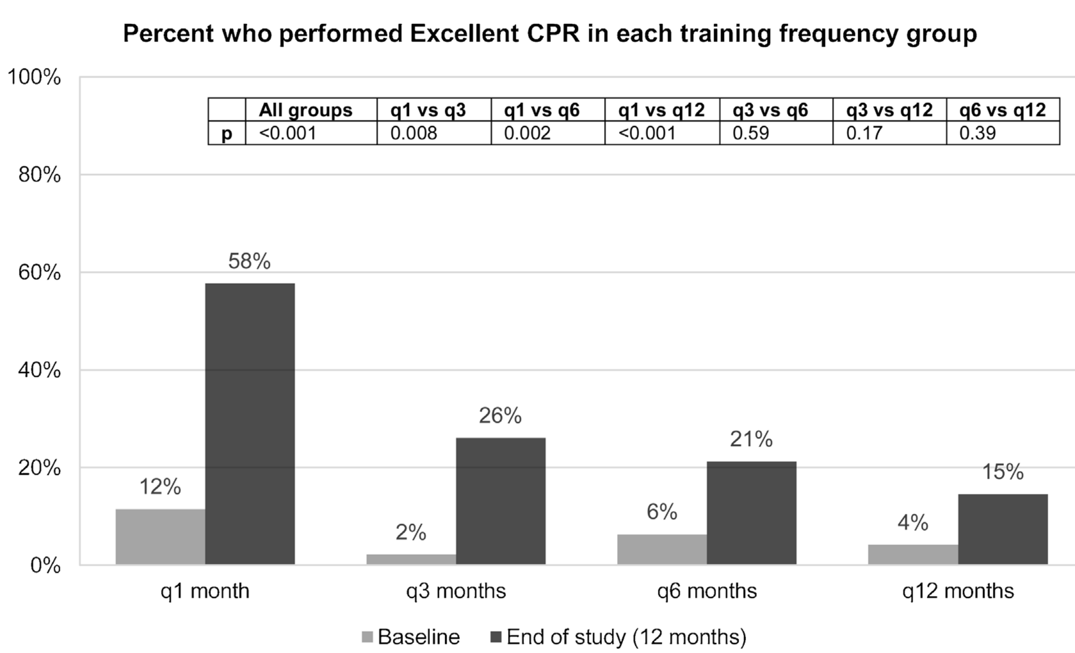

Fig. 3 – Percentage of participants who performed Excellent CPR in each training frequency group at baseline and at 12 months. Note that the statistically significant p value here is 0.008 (0.05 divided by 6) to adjust for the six comparisons performed in each analysis.

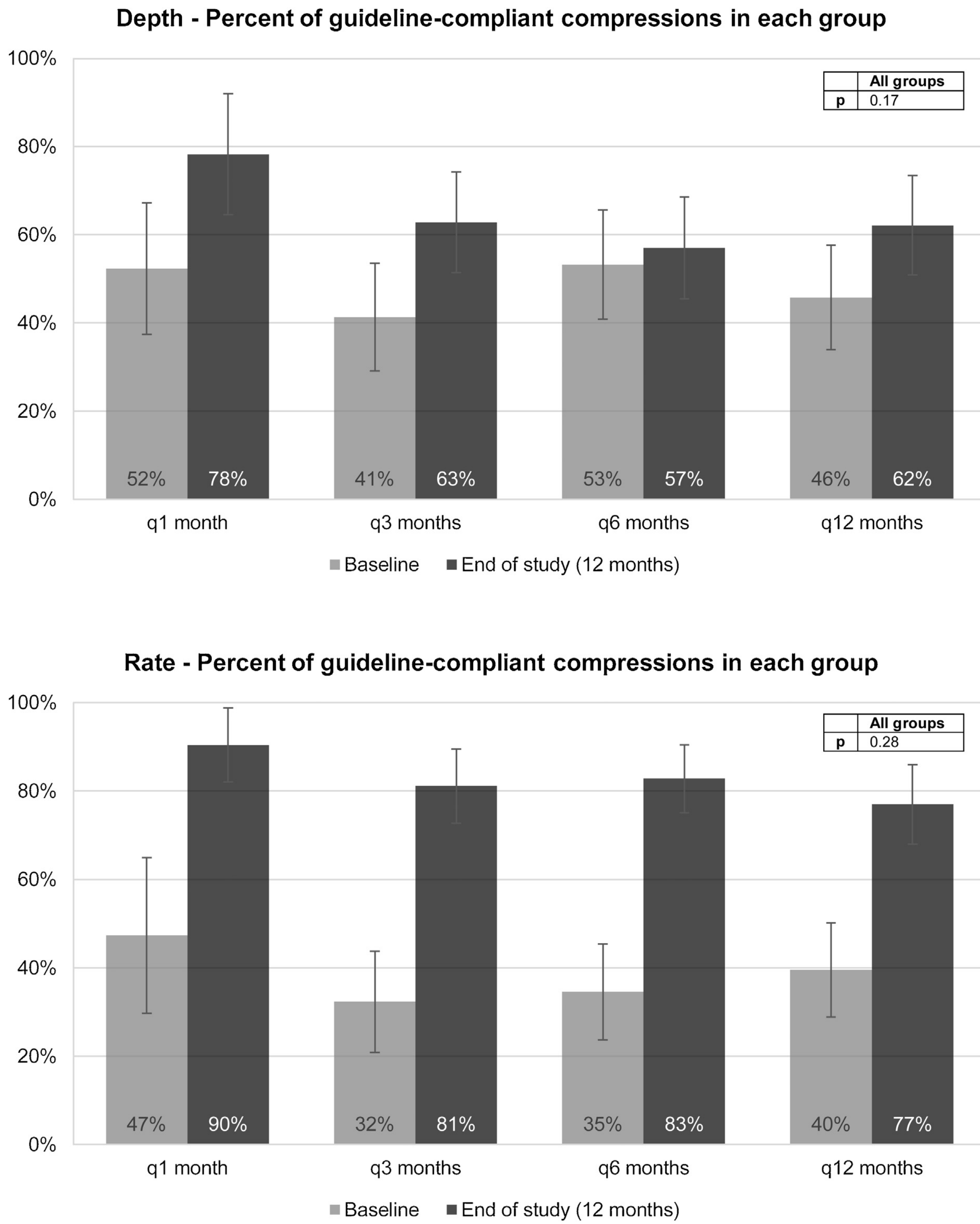

Fig. 4 – a, b, c. Percentage of chest compressions performed that were compliant with the American Heart Association guidelines for depth, rate, and recoil individually in each training frequency group at baseline and at 12 months. Error bars represent 95% confidence intervals.

pregnancy or maternity leave. While monthly, brief, workplace-based training is superior to less frequent regimens, increased logistical barriers may hinder successful implementation. This should be carefully considered by educators and administrators when implementing a spaced CPR training program. In this study, logistical barriers included the need for a study team member to be present at the time when the participant was available and equipment transport throughout the hospital to each study participant's ward. There are many strategies to decrease these implementation barriers including institute-mandated training, standalone trainers available around the clock, and the use of self-learning modules with feedback.[34]

CPR is a highly physical task and there is evidence that some personal characteristics may predict individuals who cannot achieve Excellent CPR despite optimal training.[35–38] In the subgroup analysis, younger, taller and/or male participants were more likely to be able to perform Excellent CPR. Despite this, height and gender could not definitively be used to predict success over the year. Given these findings and the potential implication on human resources in clinical environments, we do not recommend using these characteristics to guide CPR provider selection.

Limitations

In an effort to standardize the testing environment, the physical environment was fixed. The height of the bed and use of a stool were the same for all participants. This may not translate exactly to the clinical environment where providers may choose to alter the height to get an ergonomic advantage. Furthermore, the testing environment was an individual skills station and not a team-based resuscitation environment. As such, we cannot determine if these CPR skills would translate to similar performance in a real cardiac arrest situation. Our study recruited a group of nurses from a single institution, so there may be challenges with the generalizability of our results. Nevertheless, our results are comparable to those from a different cohort of participants who received monthly training in a recently published study.[23] This suggests that despite being from a single-center study, our results may in fact be generalizable to other institutions.

We had a large dropout rate in the monthly training group. Despite this, participants who did not complete the entire study were not systematically different from those who did with respect to demographics or initial CPR performance. Also, we did not capture the number of times participants were involved in the management of a cardiac arrest patient over the course of the study. While this may serve as a potential confounder, we believe the effect is minimal given that participant demographics were similar across both groups, meaning those participants with the greatest likelihood of being exposed to cardiac arrests were evenly distributed across arms. Additionally, our institution does not have real-time CPR feedback devices, CPR coaches, or a structured clinical debriefing program,[38,39] making it unlikely that participants were able to accurately identify and correct CPR performance deficits after these events.[40]

Although monthly training achieved the best results in our study, increased training frequency could result in increased costs from equipment depreciation, time spent to train staff members, and loss of clinical hours by health care providers. We did not examine the costs of each training group in the study. The cost-effectiveness of spaced training at various time intervals should be the subject of a future study using a strictly-designed economic evaluation.

Conclusion

Health care providers struggle to perform guideline-compliant CPR. Short-duration, spaced CPR training on a manikin with real-time visual feedback is effective in improving CPR performance. Training every month is more effective than training every 3, 6, and 12 months. Spaced training may confer important logistical barriers that must be considered during implementation.

Funding sources

This study was funded by research grants from the Northern Ontario Academic Medicine Association (NOAMA) Clinical Innovation Opportunities Fund Award, the Department of Anesthesia Research Enhancement Fund at Health Sciences North, and the Health Sciences North Innovation Fund. Funds from these grants were used for the design and conduct of the study, the purchase of the CPR cart and Resusci Anne manikin, as well as the collection, management, analysis, and interpretation of data.

Contributors' statements

Robert Anderson: Dr. Robert Anderson conceptualized and designed the study, drafted and revised the manuscript critically for intellectual content, and approved the final manuscript as submitted.

Alexandre Sebaldt: Dr. Alexandre Sebaldt conceptualized and designed the study, participated in data collection, conducted the statistical analysis and interpretation of data, drafted the initial manuscript, and approved the final manuscript as submitted.

Yiqun Lin: Dr. Yiqun Lin conducted the statistical analysis and interpretation of data, revised the manuscript critically for intellectual content, and approved the final manuscript as submitted.

Adam Cheng: Dr. Adam Cheng conceptualized and designed the study, revised the manuscript critically for intellectual content, and approved the final manuscript as submitted.

Acknowledgements

The authors would like to thank and acknowledge the contributions of the following individuals: Alex Wood, RN, and Sarah Isaac, RRT, who performed the data collection; Quoc Hao Mach who helped with statistical analysis; Suzanne Lortie-Carlyle who provided administrative assistance.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2018.10.033.

REFERENCES

1. Merchant RM, Yang L, Becker LB, et al. American Heart Association get with the guidelines-resuscitation investigators. Incidence of treated cardiac arrest in hospitalized patients in the United States. Crit Care Med 2011;39:2401–6.
2. Mozaffarian D, Benjamin EJ, Go AS, et al. Heart disease and stroke statistics–2015 update: a report from the American Heart Association. Circulation 2014;131:e29–e322.

3. Meaney PA, Bobrow BJ, Mancini ME, et al. Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American heart association. Circulation 2013;128:417–35.
4. Perkins GD, Olasveengen TM, Maconochie I, et al. European resuscitation council guidelines for resuscitation: 2017 update. Resuscitation 2017;(123):43–50.
5. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: adult basic life support and cardiopulmonary resuscitation quality. 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2015;(132):S414–35.
6. Abella BS, Sandbo N, Vassilatos P, et al. Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. Circulation 2005;111:428–34.
7. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137–45.
8. Edelson DP, Litzinger B, Arora V, et al. Improving in-hospital cardiac arrest process and outcomes with performance debriefing. Arch Intern Med 2008;168:1063–9.
9. Idris AH, Guffey D, Aufderheide TP, et al. Resuscitation Outcomes Consortium (ROC) Investigators. Relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004–12.
10. Wolfe H, Zebuhr C, Topjian AA, et al. Interdisciplinary ICU cardiac arrest debriefing improves survival outcomes. Crit Care Med 2014;42:1688–95.
11. Vadeboncoeur T, Stolz U, Panchal A, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. Resuscitation 2014;85:182–8.
12. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 2005;293:305–10.
13. Sutton RM, Niles D, Nysaether J, et al. Quantitative analysis of CPR quality during in-hospital resuscitation of older children and adolescents. Pediatrics 2009;124:494–9.
14. Sutton RM, Maltese MR, Niles D, et al. Quantitative analysis of chest compression interruptions during in-hospital resuscitation of older children and adolescents. Resuscitation 2009;80:1259–63.
15. Sutton RM, Wolfe H, Nishisaki A, et al. Pushing harder, pushing faster, minimizing interruptions . . . but falling short of 2010 cardiopulmonary resuscitation targets during in-hospital pediatric and adolescent resuscitation. Resuscitation 2013;84:1680–4.
16. Cheng A, Brown L, Duff J, et al. Improving CardioPulmonary resuscitation with a CPR feedback device and refresher simulations (CPRCARES study): a multicenter, randomized trial. JAMA Pediatr 2015;169:137–44.
17. Bhanji F, Donoghue AJ, Wolff MS, et al. Part 14: education. 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2015;132:S561–73.
18. Sutton RM, Niles D, Meaney PM, et al. "Booster" training; evaluation of instructor-led bedside cardiopulmonary resuscitation skill training and automated corrective feedback to improve cardiopulmonary resuscitation compliance of pediatric basic life support providers during simulated cardiac arrest. Pediatr Crit Care Med 2011;12:e116–21.
19. Niles D, Sutton RM, Donoghue A, et al. "Rolling refreshers": a novel approach to maintain CPR psychomotor skill competence. Resuscitation 2009;80:909–12.
20. Sutton RM, Niles D, Meaney PA, et al. Low-dose, high-frequency CPR training improves skill retention of in-hospital pediatric providers. Pediatrics 2011;128:e145–51.
21. Cheng A, Nadkarni V, Mancini ME, et al. For the american heart association education and implementation investigators. Resuscitation education science: improving cardiac resuscitation outcomes with enhanced instructional design and implementation. Circulation 2018, doi:http://dx.doi.org/10.1161/CIR.0000000000000583 Published online June 21.
22. Oermann MH, Kardong-Edgren SE, Odom-Maryon T. Effects of monthly practice on nursing students' CPR psychomotor skill performance. Resuscitation 2011;82:447–53.
23. Lin Y, Cheng A, Grant VJ, Currie GR, Hecker KG. Improving CPR quality with distributed practice and real-time feedback in pediatric healthcare providers – a randomized controlled trial. Resuscitation 2018;130:6–12.
24. Soar J, Monsieurs KG, Ballance JH, et al. European Resuscitation Council Guidelines for resuscitation 2010 section 9. Principles of education in resuscitation. Resuscitation 2010;81:1434–44.
25. Mpotos N, De Wever B, Cleymans N, et al. Efficiency of short individualized CPR self-learning sessions with automated assessment and feedback. Resuscitation 2013;84:1267–73.
26. Mpotos N, De Wever B, Cleymans N, et al. Repetitive sessions of formative self-testing to refresh CPR skills: a randomised non-inferiority trial. Resuscitation 2014;85:1282–6.
27. Mpotos N, Decaluwe K, Van Belleghem V, et al. Automated testing combined with automated retraining to improve CPR skill level in emergency nurses. Nurse Educ Pract 2015;15:212–7.
28. American Heart Association. Resuscitation quality improvement program frequently asked questions. (Accessed 22 July 2018, at. . http://cpr.heart.org/idc/groups/heart-public/@wcm/@ecc/documents/downloadable/ucm_459992.pdf).
29. Smith K, Gilcreast D, Pierce K. Evaluation of staff's retention of ACLS and BLS skills. Resuscitation 2008;78:59–65.
30. De Regge M, Calle PA, De Paepe P, Monsieurs KG. Basic life support refresher training of nurses: individual training and group training are equally effective. Resuscitation 2008;79:283–7.
31. Einspruch EL, Lynch B, Aufderheide TP, Nichol G, Becker L. Retention of CPR skills learned in a traditional AHA Heartsaver course versus 30-min video self-training: a controlled randomized study. Resuscitation 2007;74:476–86.
32. Madden C. Undergraduate nursing students' acquisition and retention of CPR knowledge and skills. Nurs Educ Today 2006;26:218–27.
33. Hamilton R. Nurses' knowledge and skill retention following cardiopulmonary resuscitation training: a review of the literature. J Adv Nurs 2005;51:288–97.
34. Panchal AR, Norton G, Gibbons E, et al. In-hospital evaluation of low dose-high frequency, case based psychomotor CPR training demonstrates high levels of program compliance with good CPR quality metrics. Circulation 2015;132:A18403.
35. Cheng A, Lin Y, Nadkarni V, et al. For the INSPIRE CPR Investigators. The effect of step stool use and provider height on quality of chest compressions during pediatric cardiac arrest: a simulation-based multicentre study. CJEM 2018;20:80–8.
36. Roh YS, Lim EJ. Factors influencing quality of chest compression depth in nursing students. Int J Nurs Pract 2013;19:591–5.
37. Hasegawa T, Daikoku R, Saito S, Saito Y. Relationship between weight of rescuer and quality of chest compression during cardiopulmonary resuscitation. J Physiol Anthropol 2014;33:16.
38. Cheng A, Duff JP, Kessler D, et al. Optimizing CPR performance with CPR coaching for pediatric cardiac arrest: a randomized simulation-based clinical trial. Resuscitation 2018;132:33–40.
39. Kessler D, Cheng A, Mullan P. Debriefing in the emergency department after clinical events: a practical guide. Ann Emerg Med 2015;65:690–8.
40. Jones A, Lin Y, Nettel-Aguirre A, Gilfoyle E, Cheng A. Visual assessment of CPR quality during pediatric cardiac arrest: Does point of view matter? Resuscitation 2015;90:50–5.