RESUSCITATION 138 (2019) 284–296

Available online at www.sciencedirect.com

Resuscitation

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

Review

# Improving skills retention after advanced structured resuscitation training: A systematic review of randomized controlled trials

Kelly Au[a,*], Darren Lam[b], Nitan Garg[c], Anthony Chau[a,b], Agata Dzwonek[d], Benjamin Walker[e], Luc Tremblay[f], Sylvain Boet[d], M. Dylan Bould[c,g]

[a] Department of Anesthesiology, BC Women's Hospital, Vancouver, BC, Canada
[b] Department of Anesthesiology Pharmacology and Therapeutics, University of British Columbia, Vancouver, BC, Canada
[c] Department of Anesthesia, University of Toronto, Toronto, ON, Canada
[d] Department of Anesthesiology and Pain Medicine, The Ottawa Hospital, Ottawa, ON, Canada
[e] Department of Anesthesiology and Pain Medicine, The Ottawa Hospital, Ottawa Hospital Research Institute, Ottawa, ON, Canada
[f] Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, ON, Canada
[g] Department of Anesthesiology, Children's Hospital of Eastern Ontario, Ottawa, ON, Canada

## Abstract

**Aims:** To systematically evaluate the literature on interventions that improve skills retention following advanced structured resuscitation training programs designed for healthcare professionals.

**Methods:** A systematic review of MEDLINE, EMBASE, CENTRAL, CINAHL, PsycINFO, ERIC, and Scopus was performed. Only randomized controlled trials investigating skills retention following advanced structured resuscitation training programs for healthcare professionals between inception to November 21, 2018 were included. Publications that assessed only knowledge acquisition were excluded. Relevant data from included studies were extracted and study quality was critically appraised, both independently and in duplicate by multiple reviewers. The risk of bias was assessed with the Cochrane Risk of Bias tool and the Medical Education Research Study Quality Instrument (MERSQI). Due to significant clinical heterogeneity in SRT training, study designs and interventions, a qualitative synthesis was used to summarize findings.

**Main results:** Sixteen studies, with a combined total of 1192 participants, were included in the final analysis. The majority of studies were conducted in North America and involved trainees or novice learners. ACLS was the most extensively studied, followed by NRP, ALS, and ATLS. Skills retention at 6 months was the most commonly used primary endpoint assessed using a simulated resuscitation checklist with either an adopted or created assessment tool. Most studies demonstrated a positive impact on skills retention when an interactive intervention or simulation was used. However, merely having a high-fidelity mannequin alone for simulation was found to have minimal effect on skills retention in the absence of other changes in content delivery. Booster sessions were found to be minimally effective in reinforcing long-term skills retention; however, most studies examining this intervention had small sample sizes and were underpowered.

**Conclusions:** Simulation-based interventions, refresher courses and adjustments to the content delivery of advanced structured resuscitation training courses were found to have the greatest impact on skills retention. However, due to significant heterogeneity and methodological flaws in the available

* Corresponding author.
E-mail address: kellylynnau@gmail.com (K. Au).

https://doi.org/10.1016/j.resuscitation.2019.03.031
Received 31 August 2018; Received in revised form 10 March 2019; Accepted 15 March 2019

studies, no definitive conclusions can be made regarding other interventions. Overall, there is a paucity of skills retention research and further high-quality randomized controlled trials are needed to determine the optimal intervention and design for resuscitation training that would maximize skills retention.

## Introduction

Every year, millions of patients worldwide require resuscitation for acute life-threatening emergencies, with over 500,000 cases per year in the United States considering just cardiac arrests alone.[1] Over the past decades, there has been an increasing emphasis on optimizing and improving resuscitation training for healthcare providers based on the recognition that high-quality resuscitation could directly impact patient outcomes and survival rates.[2] As such, international organizations have established advanced life support guidelines and developed structured resuscitation training (SRT) programs[3–6] for healthcare professionals in an effort to reduce the mortality, disability and costs that are associated with adverse patient outcomes.[7–18] Many of these SRT programs, such as the Advanced Cardiac Life Support (ACLS),[19] the Advanced Trauma Life Support (ATLS),[20] and the Neonatal Resuscitation Program (NRP)[21] are globally accepted as "gold standard" SRT programs that are advocated or mandated for healthcare providers participating in acute or high-risk patient care.[13–15,22]

Despite rigorous standardized skills training and an initial satisfactory demonstration of competence, suboptimal resuscitation is still frequently observed in practice and cited as a preventable harm.[22–28] Consequently, intense research efforts have been dedicated to improving resuscitation education and maintenance of skills following SRT.[29] In 2010, The International Liaison Committee on Resuscitation (ILCOR) proposed a need for a rigorous assessment of the literature investigating the retention of advanced resuscitation skills after SRT for healthcare professionals.[30]

Previous systematic reviews on resuscitation education provided useful but limited information on methods that improve skills retention. A 2012 systematic review focussed on the impact of SRT on both retention of resuscitation knowledge and skills after initial acquisition, but did not specifically employ skills retention or related terms in the search strategy. Yang et al.[31] systematically reviewed studies on retention of adult advanced life support knowledge and skills in healthcare providers, yet examined only ALS and excluded articles on other SRT (e.g. ATLS, or NRP) programs. Moreover, a 2013 systematic review and meta-analysis by Mundell et al. examined the effectiveness of technology-enhanced simulation for resuscitation training but did not specifically discern knowledge from skill outcomes in the analysis.[26] Since actual resuscitation may occur at any time intervals after SRT, skills retention may be a better predictor of quality of resuscitation at the time of patient care. This systematic review aims to directly fill the knowledge gap proposed by ILCOR, overcome limitations in prior reviews and provide an updated review of the existing literature. Our primary objective was to define the current state of knowledge on methods that improve resuscitation skills retention following advanced accredited SRT programs designed for healthcare professionals. Specifically, we wished to determine the amount of literature available on this topic and assess the interventions employed in skills retention studies including outcomes that have been used in hopes of providing new information that would help guide future resuscitation education research.

## Methods

### Protocol and registration

The review protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42014013851). The present review was conducted and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Supplementary Appendix 1)[32] and the Cochrane Collaboration guidelines.

### Search strategy

A systematic literature search was conducted for all articles published up until November 21, 2018. An information specialist (LU) designed the search strategy in consultation with the review authors to search the following databases: MEDLINE, EMBASE, CENTRAL, CINAHL, PsycINFO, ERIC, Scopus, and Northern Light. The electronic database search strategy was independently peer-reviewed by another librarian using the PRESS peer-review system and comprised of the following search terms (combination of subject headings and keywords): "resuscitation," "cardiopulmonary resuscitation," "advanced cardiac life support," "basic life support," "immediate life support," "advanced trauma life support," "neonatal resuscitation program," "paediatric advanced life support," "learning," "education," "retention," "memory," "skill retention," and "task performance" (Supplementary Appendix 2). We restricted the search to all publications written or translated in English. To identify new and ongoing trials, we searched ClinicalTrials.gov and the WHO International Clinical Trials Registry Platform and performed additional searches of the table of contents for the journals *Circulation* and *Resuscitation*. Furthermore, we hand-searched reference lists of relevant systematic reviews.[30,31,33–45]

### Eligibility criteria

Studies were included if they met the following criteria: (1) involved a randomized controlled design; (2) investigated skills retention in healthcare professionals following an accredited advanced SRT; (3) assessed retention or learning after initial training; and (4) specifically reported skills outcome. We excluded studies that used composite outcome measures that did not discern knowledge from skills, or self-assessed skill retention outcomes.

We defined SRT programs as a resuscitation training curriculum (initial or recertification courses) delivered to a group of learners over any reported finite period in a predefined and structured manner.[22] Examples of advanced SRT programs include: ACLS, ALS, ATLS, NRP and Paediatric Advanced Life Support (PALS). We excluded Basic Life Support (BLS) because the skill set required for BLS is much less elaborate than the skill set required for advanced SRT courses. We defined learning as consistent, stable, persistent, and adaptable improvements in performance.[46] The minimally valid proxy for learning was a retention test delivered at least one day following the completion of the resuscitation training course (as opposed to a post-test performed immediately at the end of the SRT program).

### Study selection

Two reviewers (KA, NG or DL) independently screened all titles and abstracts for potentially relevant articles. Only one reviewer was required to include the citation to full-text screening for further consideration, two reviewers were required to exclude a citation. At full-text screening, reviewers independently screened full-text articles in duplicate. Any disagreements were resolved by discussion.

### Data extraction

We prepared a data extraction form a priori that was piloted and refined iteratively. Data collection was performed using an Excel spreadsheet (Microsoft Corporation, Redmond, WA).

Extracted parameters included study design, study setting, participant demographics, content domain (i.e. type of resuscitation such as trauma, neonatal), characteristic of the intervention (e.g. assessment tool, retention interval) and instructional design features (e.g., instructor ratio, delivery of course, audible feedback, booster sessions).

We extracted outcome data separately for skills, behaviours with patients, and patient effects, if applicable. Skills were defined as outcomes from simulated settings. Behaviours and patient effects were defined as outcomes in real clinical settings. Skills were addressed as a measure of time (e.g., time to complete tasks), process (e.g., quality of chest compressions), and product (e.g., successful completion of tasks). Behaviours with patients were distinguished as a measure of time and process (e.g., quality of chest compressions), and patient effects (e.g., return of spontaneous circulation).[26,47]

### Risk of bias assessment

All full-text articles were critically appraised independently and in duplicate among three reviewers (KA, DL, AC). Any disagreements were resolved by discussion. We assessed the risk of bias and study quality using the Cochrane Collaboration's Risk of Bias tool[48] and the Medical Education Research Study Quality Instrument (MERSQI),[49] respectively. Three reviewers (KA, DL, AC) assessed bias for each study using the following seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other sources of bias. Each item was graded as low, high, or unclear. Six study characteristics were assessed for study quality: study design, sampling, type of data, validity of evaluation instrument, data analysis, and outcomes. Reviewers resolved disagreements through discussion.

### Data synthesis and analyses

The literature search and selection of eligible papers are reported on a PRIMSA flow chart (Fig. 1). It was anticipated that significant clinical heterogeneity would exist with respect to SRT training, study designs and interventions. Therefore, only a qualitative synthesis was used to summarize the evidence.

## Results

Database searching yielded a total of 5341 articles. Following the removal of 2009 duplicates, a total of 3332 articles remained. Of these, 2183 articles were excluded during initial screening and 1133 articles were excluded after full-text review. Sixteen studies, with a combined total of 1192 participants, met our eligibility criteria and were included in our final analysis (Fig. 1).

### Study design and population

Study and population characteristics are summarized in Table 1. All 16 studies were single-centre RCTs, a majority of which were conducted in North American countries (eight conducted in the United States,[50–57] and three in Canada.[58–60]) The median number of participants was 75 (range: 25–154). A majority of studies (12 studies, 835 participants) exclusively involved trainee providers (i.e. residents or students), two studies,[54,55] involved a mixed of staff and trainee providers and two studies[56,61] involved solely staff providers.

ACLS was the SRT program tested in eight studies,[51,52,54–58,62] NRP in four studies,[50,53,60,63] ATLS in two studies,[59,61] and ALS in two studies.[64,65] Skills retention test intervals varied widely from two weeks following training[59] to 15 months,[50] but the most common interval was six months,[51,55,57,60,64] followed by three months[55,57,63,65] and one year.[52,53,56,64] Retention tests were administered twice in four studies,[55,57,64,65] while the remaining twelve studies assessed skill retention only once.[50–54,56,58–63]

### Interventions and comparison interventions

There was a wide variability in the types of interventions and comparison interventions examined and their relationship to skills retention (Table 1). Three studies[52,55,63] compared the use of high- vs. low-fidelity mannequin for simulation training. Two studies[59,61] compared participants who completed an ATLS course vs. those who did not. Two studies[50,54] compared the use of simulation booster vs. no booster following initial SRT. Five studies[53,56,57,62,65] examined the effect of a scheduled educational intervention (e.g. refresher course,[62] deliberate simulation-based practice,[53,57] reading,[56] and real-time training).[65] The remaining four studies explored other types of intervention including the use of video vs. hands-on booster course[60]; having prior clinical experience vs. no prior clinical experience[64]; simulation with and without integration of emotional content[51]; and the use of self-regulated vs. instructor-regulated learning.[58]

Analysis of these studies revealed that non-traditional and interactive forms of intervention were frequently selected as interventions. Importantly, ten (62.5%) of the studies incorporated simulation as part of the intervention.

### Outcomes used for skill retention

Simulation was used to assess skill retention in all 16 studies. All 16 studies used a standardized checklist, while four studies used both a standardized checklist and a global rating scale.[50,53,59,61] The construct assessed was "Resuscitation" in all 16 studies, while three studies assessed both "Resuscitation" and "Teamwork."[53,64,65] Half of the studies[50,52,53,55,58,63–65] adopted a published, validated assessment tool, while the other eight studies[51,54,56,57,59–62] used an original assessment tool that was created by the authors and/or evaluators of the study. Studies that adopted an existing validated tool have been published more recently than those that did not (Table 2). Among the studies that used an original created assessment tool, five of the eight attempted to internally validate their tool using methods such as inter-rater reliability and association with other validated measures (ex. USMLE scores).[51,57,59,61,62]

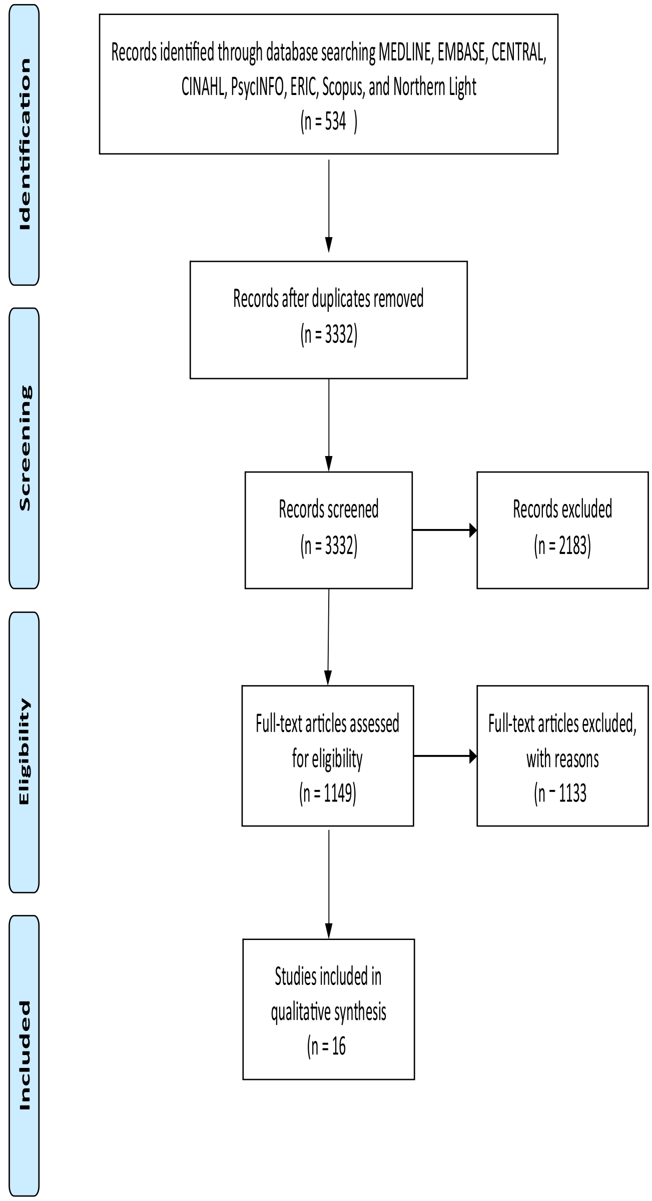


**Fig. 1 – PRIMSA flow diagram of study selection.**

### *ACLS skills retention*

Prior to the use of simulation, Stross et al.[56] found that reinforcement via scheduled reading or problem solving using patient cases can attenuate loss of ACLS knowledge after initial training but motor skills retention is difficult to maintain. With the advent of simulation technology, an important research question was whether simulation could improve ACLS skills retention.

Of the eight RCTs that examined ACLS skills retention, the benefit of simulation was featured in three studies.[54,57,62] Schwid et al.[54] found that reviewing course material using a computerized simulation program significantly improved mean standardized 47-item Mega Code checklist scores compared to using just a textbook at 10–11 months (74.3% vs. 62.1% $p < 0.001$). Similarly, Wayne et al.[57] found the total checklist performance score (out of 300) was significantly higher at 3 months with simulation training versus without (265.6 vs. 192.5, $p < 0.001$). Delasobera et al.[62] randomized 117 paramedic students to either simulation ($n = 39$), multimedia in the form of a video and computer game ($n = 38$), or independent reading ($n = 40$) for their 3-h ACLS refresher course and found that at 3 weeks, the simulation group continued to show the greatest change from baseline (+6% vs. + 1% vs. −1%, respectively).

By contrast, two studies[52,55] found no added benefit when comparing high-fidelity simulation training to the traditional ACLS course. The findings of these studies are difficult to interpret, however, since novice learners with minimal clinical experience were involved and the underlying demographic differences were not assessed or adjusted between groups.

In a mixed population of health care providers, medical students and nursing students, Settles et al.[55] found no significant difference in skills retention between those trained with high-fidelity simulation compared to low-fidelity simulation at three months and six months.

**Table 1 – Study characteristics and outcomes (n = 16; n participants = 1192).**

| Reference | Study design | SRT Course | Population | Sample size (n) | Intervention | Comparator(s) | Retention test interval | Assessment tool | Results | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|
| 62 | R,S | ACLS | T<br>Paramedic students | 125 | Simulation refresher course | Multimedia refresher course OR Individual reading | 3 weeks | C<br>ACLS checklist | Simulation demonstrated better retention of cardiac arrest scenario management than reading ($p < 0.05$). Multimedia or reading did not show a significant difference in skill retention ($p > 0.05$). | Benefit – simulation refresher seems to be an effective method of improving short-term skill retention. |
| 58 | R,S | ACLS | T<br>First-year internal medicine residents | 40 | Simulation based directed self-regulated learning (DSRL) | Instructor-regulated learning (IRL) | 5 months | A<br>ACLS checklist | Post-test scores did not differ significantly between IRL and DSRL ($p = 0.94$). No significant difference in retention between IRL and DSRL at 5 months ($p = 0.25$). | No Difference – DSRL and IRL are equivalent for ACLS skill acquisition and retention. |
| 51 | R,S | ACLS | T<br>First and second-year medical students | 25 | Integration of emotional content into Megacode | Standard simulation without emotional content | 6 months | C<br>Megacode checklist | Emotional content experienced during teaching correlated with significantly higher performance assessment 6 months later ($p = 0.0003$). | Benefit – integration of emotional content seems to improve long-term skill retention. |
| 52 | R,S | ACLS | T<br>Third year medical students | 95 | High-fidelity simulation training with online self-instruction | Traditional 2-day ACLS course | 1 year | A<br>Megacode checklist | At the 1-year follow up the performance of both groups was not statistically significant ($p = 0.84$). | No Difference – there may be no long-term benefits for skill retention when comparing traditional training to high fidelity simulation training. |
| 54 | R,S | ACLS | T and S<br>Anaesthesia staff and residents | 45 | Megacode preparation using a computerized ACLS simulation program | Megacode preparation using self-review of textbooks | 10–11 months | C<br>Megacode checklist | Scores for the simulation group were significantly higher than those of the textbook group ($p = 0.01$). The time spent studying did not vary significantly between the two groups ($p = 0.087$). | Benefit – the intermittent use of an ACLS simulation program as a booster may be an effective option for improving long-term skills retention. |

**Table 1 (continued)**

| Reference | Study design | SRT Course | Population | Sample size (n) | Intervention | Comparator(s) | Retention test interval | Assessment tool | Results | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|
| [55] | R,S | ACLS | T and S<br>Health care providers, medical students and nursing students | 148 | Standard ACLS course with low-fidelity simulation | Standard ACLS course with high-fidelity simulation. | 3 and 6 months | A<br>ACLS checklist | There was no significant difference in ACLS skill competency on Megacodes between the two groups ($p > 0.05$). | No Difference – there may not be additional long-term skills retention benefit from performing ACLS training on a high-fidelity or low-fidelity simulation. |
| [56] | R,S | ACLS | S<br>Physicians: 35% EM, 25% IM 25% GP<br>Remainder: surgery, paediatrics, industrial medicine | 132 | Quarterly reading of ACLS objectives<br>OR<br>Quarterly ACLS clinical cases | Standard ACLS training only | 1 year | C<br>ACLS checklist | There was no statistically significant difference in skills performance between the two intervention groups and the control. However, a multiple-regression analysis suggested that younger age and amount of time spent in ICU were correlated with more successful performance ($p < 0.05$). | No Difference – reading and problem solving can attenuate loss of ACLS knowledge, but does not help with skill retention at one year. |
| [57] | R,S | ACLS | T<br>Second year internal medicine residents | 38 | Four 2-h simulator practice sessions (Group A) | No practice sessions (Group B, wait-list control) | 3 and 6 months | C<br>ACLS checklist | After simulator practice sessions, Group A scored significantly higher during simulated ACLS performance at 3 months compared to the wait-list controls, whom had not yet received practice sessions ($p < 0.0001$). After 6 months, Group A had similar performance scores to Group B, who had received their training 3 months previously. | Benefit – deliberate refresher simulation can result in consistent, sustained improvements in skills, with little decay over time. |
| [64] | R,S | ALS | T | 154 | ALS introduced after participants acquired 6 months of clinical experience | ALS introduced to Participants had no prior clinical experience | 6 months and 1 year | A | The group with prior clinical experience before an ALS course had small but statistically significant higher 6-month | Benefit – placing a resuscitation course after half a year of clinical experience could increases the retention. |

(continued on next page)

**Table 1 (continued)**

| Reference | Study design | SRT Course | Population | Sample size (n) | Intervention | Comparator(s) | Retention test interval | Assessment tool | Results | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | retention compared to the control group ($p = 0.002$). | |
| | | | First-year residents | | | | | CASTest scoring sheet | | |
| [65] | R,S | ALS | T | 73 | Real-time CPR training | Shortened CPR interval training (fake-time CPR) | 1 week and 3 months | A | The intervention group (real-time) showed statistically significant better adherence to the 2-min CPR than the control group (fake-time) ($p < 0.001$). | Benefit – use of real-time simulations may improve quality of training and adherence to time during resuscitation scenarios. |
| | | | Fourth year medical students | | | | | CASTest scoring sheet, adherence to 2-min CPR | | |
| [59] | R,S | ATLS | T | 40 | ATLS course | No ATLS course | 2 weeks | C | The ATLS group performed at a statistically significantly higher level in all of the OSCE stations compared to the non-ATLS group ($p < 0.01$). | Benefit – the ATLS course appears to favour superior skills performance. |
| | | | Fourth-year medical students | | | | | OSCE checklist<br>Priorities adherence score<br>Organized approach score | | |
| [61] | R,S | ATLS | S | 32 | ATLS course | No ATLS course | 5 weeks | C | The ATLS group had a statistically significantly higher score for each of the OSCE stations than the non-ATLS group ($p < 0.05$). | Benefit – the ATLS course appears to favour superior skills performance. |
| | | | Physicians | | | | | OSCE checklist<br>Priorities adherence score<br>Organized approach score | | |
| [50] | R,S | NRP | T | 58 | Simulation booster 7–10 months post NRP training | NRP course without booster | 15-18 months | A | The intervention group that had received a simulation booster demonstrated better procedural skills and teamwork behaviours compared to the control group ($p < 0.05$). | Benefit – simulation booster following NRP training may be beneficial in improving long-term skill retention and teamwork behaviours. |
| | | | Residents from NICU and non-NICU | | | | | NRP Megacode checklist<br>Teamwork behaviour instrument | | |

**Table 1 *(continued)***

| Reference | Study design | SRT Course | Population | Sample size (n) | Intervention | Comparator(s) | Retention test interval | Assessment tool | Results | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|
| [60] | R,S | NRP | T | 59 | Video booster 3-5 months post-training | Standard NRP course only (control) | 6-8 months | C | There were no statistically significant differences in overall performance scores between the three groups ($p = 0.284$). | No difference – the results of this study do not support a recommendation for integrating hands-on or video booster trainings. |
| | | | Family medicine residents | | OR<br>Hands-on booster 3-5 months post-training | | | NRP Megacode checklist | | |
| [53] | R,S | NRP | T | 27 | Simulation-based deliberate practice (SBDP) and mastery learning (ML) booster at 6-9 months (early) or 9-12 months (late) | Baseline | 1 year | A | The booster session significantly increased global rating scores (GRS) in both the early ($p < 0.001$) as well as late groups ($p < 0.001$). Participants in the late group had higher scores at 1 year compared to the early group ($p = 0.046$). Early group participants score significantly lower 4 months after their booster when compared to the late group ($p < 0.001$). | Benefit – a single 30-min simulation-based deliberate practice and mastery learning is effective in boosting paediatric resident neonatal resuscitation skills. This may supplement traditional NRP training for paediatric residents. |
| | | | First to third year paediatric residents | | | | | NRP Megacode checklist | | |
| [63] | R,S | NRP | T | 101 | NRP training over 3 days using a high fidelity simulator (HFS) | NRP training over 3 days using a low fidelity simulator (LFS) | 3 months | A | No significant difference in improvement between groups for the Megacode assessment ($p = 0.92$). Post-test Megacode results at 3 months were similar between groups ($p = 0.41$). | No difference – the degree of improvement in skill acquisition is not significantly different with HFS vs LFS. |
| | | | Final year medical students | | | | | Megacode checklist | | |

Study Design: R = Randomized controlled trial; S = Single centre; SRT Course: SRT = Structured resuscitation training; ALS = Advanced Life Support; ACLS = Advanced cardiovascular life support; ATLS = Advanced trauma life support; NRP = Neonatal resuscitation program; Population: T = trainees (residents or students); S = staff member; EM = Emergency medicine; IM = Internal medicine; GP = General practitioner; ICU = Intensive care unit; NICU = Neonatal intensive care unit; Intervention: CPR = Cardiopulmonary resuscitation; Assessment: A = Adopted; C = Created; CASTest = Cardiac arrest simulation test; OSCE = Objective structured clinical examination.

**Table 2 – Outcome measures.**

| Reference | Outcome measure | Construct assessed | Question type | Simulated vs actual | Adopted vs created | Externally validated | Internally validated |
|---|---|---|---|---|---|---|---|
| 59 | OSCE Exam Checklist<br>Priorities Adherence Score<br>Organized Approach Score | Resuscitation | Checklist and Global Rating Scale | Simulated | Created | N | Y |
| 61 | OSCE Exam Checklist<br>Priorities Adherence Score<br>Organized Approach Score | Resuscitation | Checklist and Global Rating Scale | Simulated | Created | N | N |
| 50 | NRP Megacode Assessment Form<br>Teamwork Behavior Instrument | Resuscitation | Checklist and Global Rating Scale | Simulated | Adopted | Y | Y |
| 62 | ACLS Checklist | Resuscitation | Checklist | Simulated | Created | N | Y |
| 51 | ACLS Megacode Checklist | Resuscitation | Checklist | Simulated | Created | N | Y |
| 52 | ACLS Simulated Checklist | Resuscitation | Checklist | Simulated | Adopted | Y | Y |
| 64 | CASTest Scoring Sheet | Resuscitation and Teamwork | Checklist | Simulated | Adopted | Y | N |
| 60 | NRP Megacode Checklist | Resuscitation | Checklist | Simulated | Created | N | N |
| 65 | CASTest Scoring Sheet | Resuscitation and Teamwork | Checklist | Simulated | Adopted | Y | N |
| 52 | Megacode Checklist | Resuscitation | Checklist | Simulated | Adopted | Y | Y |
| 53 | NRP Checklist | Resuscitation and Teamwork | Checklist and Global Rating Scale | Simulated | Adopted | Y | N |
| 63 | Megacode Assessment | Resuscitation | Checklist | Simulated | Adopted | Y | N |
| 54 | Megacode Checklist | Resuscitation | Checklist | Simulated | Created | N | N |
| 55 | ACLS Skills Competency Checklist | Resuscitation | Checklist | Simulated | Adopted | Y | N |
| 56 | ACLS Checklist | Resuscitation | Checklist | Simulated | Created | N | N |
| 57 | ACLS Checklist | Resuscitation | Checklist | Simulated | Created | N | Y |

Outcome measures: OSCE = Objective structured clinical examination; NRP = Neonatal resuscitation program; ACLS = Advanced cardiovascular life support; CASTest = Cardiac arrest simulation test; Validated: N = No, Y = Yes.

Regardless of group assignment, the investigators found that ACLS skills rapidly decay at 3–6 months after initial testing. However, it was concluded that without changes in other elements of content delivery, just merely employing a high-fidelity mannequin resulted in no significant improvements in retention.

A few studies have examined varying the elements of content delivery to improve skills retention. Demaria et al.[51] found that simulation with added emotional stressors resulted in significantly better performance and skills retention scores at six months. Devine et al.[58] investigated the impact of simulation-based directed self-regulated learning (DSRL) versus simulation-based instructor-regulated learning (IRL) on skills retention test scores at 5 months. Participants in the DSRL had structured debriefing performed by the resident who led the resuscitation in the simulation and those in the IRL had structured debriefing performed by a certified instructor. The authors found no difference between the two groups on the post-test or retention test after controlling for pre-test scores.

### *PALS skills retention*

We found no RCTs on PALS skills retention that met the eligibility criteria.

### *NRP skills retention*

Refresher courses or "booster sessions" are well described in cardiopulmonary resuscitation (CPR) skills retention[66] and two RCTs in this systematic review have explored the use of booster sessions to improve skills retention in NRP.[50,60]

Bender et al.[50] examined whether a single simulation-enhanced booster session administered 7–10 months post-NRP training would result in better procedural skills and teamwork behaviour at 15–18 months post-NRP training. Despite demonstrating improved procedural skills and teamwork in the simulation booster group, this study was high risk for selection bias due to 20% attrition and was underpowered to definitively conclude the impact of booster session on procedural skill or teamwork behaviours.

Kaczorowski et al.[60] investigated the use of booster sessions on skills retention post-NRP training. Compared to no booster session, mean follow-up test scores as judged by NRP performance checklists at 6–8 months were similar but higher in both booster session groups. However, the sample size for this study was small and underpowered to detect any difference smaller than 16% on knowledge and 9% between groups with a high probability for a type II error.

Matterson et al.[53] randomized 27 paediatric residents to receive a video-recorded baseline assessment with a simulation-based booster session administered either early (6–9 months) or late (9–12 months) post-NRP training and assessed short-term skill retention. This was the first study to demonstrate a significant improvement in performance scores by booster sessions at 2 months, but decay within 4 months. Again, the sample size for this study was small, so a larger follow-up study would be required to confirm the results of the findings.

Nimbalkar et al.[63] compared the use of high- vs. low-fidelity mannequins in 101 final year medical students and found that NRP skills can be taught and maintained at three months after initial training effectively by both types of mannequins.

### *Methods to improve skill retention in ATLS*

In 1995 and 1996, Ali et al. examined ATLS skill retention in medical students[59] and physicians.[61] Unfortunately, these studies are small, out-dated and lacked novelty in ATLS delivery, thus limited conclusions could be drawn from these studies.

### *Methods to improve skill retention in ALS*

Clinical experience prior to resuscitation training and improving adherence to core elements of resuscitation such as CPR time have been shown to improve skills retention in ALS.

Jensen et al.[64] randomized first-year residents to ALS course immediately following graduation vs. six months after acquiring some clinical experience and found a significantly higher 6-month mean retention scores in those with prior clinical experience (82% vs. 78%, $p = 0.002$). Krogh et al.[65] examined CPR taught in real-time training cycles (120 s) compared to shortened CPR training cycles (30–45 sec). When CPR training was delivered in real-time, trainees had statistically significant better adherence to 2-min CPR during retention testing delivered twelve weeks later ($p < 0.001$).

### *Risk of bias*

We found many domains for potential biases were deemed unclear, including random sequence generation (selection bias) and blinding of outcome assessment (detection bias). Blinding of participants and personnel (performance bias) had a high risk of bias in most studies. Another potential source of bias was the fact that SRT course instructors were also the assessors,[64] suggesting room for improvement in the way studies are reported in this field (Table 3).

## Discussion

Our systematic review revealed a paucity of high-quality randomized controlled trials examining interventions that improve resuscitation skills retention after SRT programs. Of the 16 eligible studies, a majority involved trainees or novice providers and focussed on improving ACLS retention skills. However, studies that examined non-trainee providers and other SRT programs such as ATLS and NRP were few, underpowered, or out-dated. Most importantly, we found no eligible study on PALS skills retention, uncovering a knowledge gap that should be highlighted in future resuscitation research.

We also found marked heterogeneity across studies. Most of the differences are related to the intervention, outcomes and measurement of skills retention used. Broadly speaking, the interventions used can be categorized into booster training following SRT or altered content delivery of SRT. Among the seven studies[50,53,54,56,57,60,62] that evaluated refresher or booster courses, five[50,53,54,57,62] suggested additional training improved skills retention. The finding that booster sessions improve performance is consistent with cognitive overload and spaced practice research. Repetition after initial learning stimulates retrieval of information from another part of the brain, which augments deeper processing of the information into memory.[67] The optimal time interval between these spaced interventions, however, has yet to be identified.

In the eight studies that evaluated altered content delivery of SRT (e.g. timing, content, or use of simulation),[51,52,54–58,62] several strategies were found to be effective in promoting long-term skill retention. First, in novice providers, initial clinical experience prior to SRT acquisition resulted in slower decay of skills[64]; however, the optimal duration and amount of clinical experience required prior to training is unclear. Additionally, practical skills retention was found to be significantly improved by altering of the training course to integrate learning scenarios with emotional and stressful contents.[51] It is well established that emotions are linked to memory and decision-making,[68,69] and

**Table 3 – Risk of bias.**

| Reference | Random sequence generation | Allocation concealment | Blinding of participants and personnel | Blinding of outcome assessment | Incomplete outcome data | Selective reporting | Other bias |
|---|---|---|---|---|---|---|---|
| 59 | Unclear | Unclear | High risk | Low risk | Low risk | Low risk | Low risk |
| 61 | Unclear | Unclear | High risk | Low risk | Low risk | Low risk | Low risk |
| 50 | Low risk | High risk | High risk | Unclear | Low risk | Low risk | Low risk |
| 62 | High risk | High risk | High risk | Unclear | Low risk | Low risk | Low risk |
| 51 | Unclear | Unclear | High risk | Low risk | High risk | Low risk | Low risk |
| 52 | Low risk | Unclear | High risk | High risk | High risk | Unclear | Low risk |
| 64 | Low risk | Low risk | High risk | Low risk | Low risk | Low risk | High risk |
| 60 | Unclear | Unclear | High risk | Low risk | Low risk | Low risk | Low risk |
| 65 | Low risk | Low risk | Low risk | Low risk | High risk | Low risk | Low risk |
| 52 | Unclear | Unclear | High risk | Low risk | Unclear | Low risk | High risk |
| 53 | Unclear | Unclear | High risk | Low risk | Low risk | Unclear | Low risk |
| 63 | Low risk | Unclear | High risk | High risk | Low risk | Low risk | Low risk |
| 54 | Unclear | Unclear | High risk | Low risk | Low risk | Low risk | Low risk |
| 55 | High risk | High risk | High risk | Unclear | High risk | Low risk | Low risk |
| 56 | Low risk | Unclear | High risk | Unclear | Low risk | Low risk | Low risk |
| 57 | Unclear | Unclear | High risk | Low risk | Low risk | Low risk | Low risk |

learner factors such as the level of anxiety generated from stressful scenarios can help contextualize learning, fostering realism and retention of specific knowledge, skills and behaviours. Further, environmental factors, such as the use of high-fidelity mannequins have been thought to optimize the context of learning[29]; however, several studies in this systematic review found that just simply employing a high-fidelity mannequin in the absence of other content delivery changes resulted in no significant improvement in resuscitation skills retention.[55,63]

We found that the most frequently used outcomes to assess skills retention included standardized checklists and global rating scales. Only 50% of the studies in this review adopted a published tool, despite recent emphasis on the importance of using established outcome measures.[29] Although studies with original, non-validated assessment tools were published in the more distant past, it is fundamental to select high-quality published assessment tools in future studies to validate outcome measures. A sample list of published resuscitation tools can be found in a recent paper by Cheng et al.[29]

Most studies found incorporation of simulation to have a salutary effect on skills retention. The effectiveness of simulation training for promoting skills retention has been validated among multiple other skills training courses.[58] In studies that evaluated ACLS, there were conflicting conclusions regarding the role of simulation in skill retention; a majority suggested that simulation aids in skill retention,[54,57,62] while others did not have a significant effect.[52,55] Varying time intervals used to assess skills retention after initial resuscitation training, which range from three months to one year, may explain these conflicting conclusions. Studies that found no difference were generally small and underpowered.[51,54,57] Future studies should select an appropriate effect size for sample size calculation and consider quantifying the rate of attenuation of ACLS resuscitation skills so that stronger recommendations can be made regarding the optimal time interval before re-certification is required.

Similarly, this systematic review identified studies that suggest booster simulation interventions can aid in NRP skill retention. However, more data is required to determine whether the required re-certification process should be implanted earlier than two years currently recommended by the American Academy of Pediatrics.

### *Limitations and future directions*

Interpretations of the findings in this review are limited by the paucity of large, appropriately powered, well-designed RCT on this topic and the significant heterogeneity in the methodologies of included trials. Additionally, the time interval and metrics used to determine skills retention varied across the four different SRT programs. We could not identify any eligible study examining PALS skill retention and further research is needed in this specific area. Due to the inherent differences between SRT programs in terms of target population, content, curriculum and structure, as well as method of competency assessment, findings from one individual SRT course cannot be easily generalized to other programs. There is also some variability in content within a given SRT program itself, with frequent updates in guidelines potentially changing resuscitation practices. Furthermore, although skill outcomes were objectively measured in these studies, few directly examined acquisition and retention of human factors, which undoubtedly contributes to quality of resuscitation as well.[70] While difficult to evaluate, an area of potential future research is the acquisition and retention of these complex intangible behaviours.

Overall, the studies included in this review were at low or intermediate risk of bias. All but one study[65] included in this review are at high risk of performance bias due to inadequate blinding of personnel and participants. Future studies should focus on better blinding of SRT program instructors, participants and assessors. With 10 out of the 14 studies included in this review reporting positive results, it is possible that the studies included in this review suffer from publication bias. The tendency to favour reporting positive results may have resulted in our body of evidence being an unrepresentative sample of skills retention interventions.

## Conclusions

Our results demonstrated that there are currently insufficient data on resuscitation skills retention and further well-designed, high-quality trials are needed to determine the optimal intervention for resuscitation training that would maximize skills retention. There is encouraging evidence that simulation-based interventions, refresher courses and adjustments to the content of SRT programs can improve skills retention. However, no definitive conclusions can be made regarding other interventions. International organizations such as the American Heart Association (AHA) and the Heart and Stroke Foundation of Canada (HSFC) should consider allocating greater resources to help redesign SRT programs and address some of the research gaps highlighted in this paper.

## Conflicts of interest

None.


## Role of funding source

Not applicable.


## Ethics and patient consent

Not applicable.


## Acknowledgements

We thank Lee-Anne Ufholz, an expert health sciences librarian for her assistance with the literature search; Sepand Alavifard, Julien Blacklock, Olivia Cheng-Boivin, and Dania Koudieh for their assistance with article retrieval; Nicole Etherington for her assistance with the manuscript and Andrew Beck for his guidance on the project and manuscript.


## 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.2019.03.031.

## REFERENCES


1. Meaney PA, Bobrow BJ, Mancini ME, et al. Cardiopulmonary resuscitation quality: [corrected] improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. Circulation 2013;128:417–35.
2. Girotra S, Nallamothu BK, Spertus JA, Li Y, Krumholz HM, Chan PS. Trends in survival after in-hospital cardiac arrest. New Engl J Med 2012;367:1912–20.
3. Bell RM, Krantz BE, Weigelt JA. ATLS: a foundation for trauma training. A Emer Med 1999;34:233–7.
4. Jewkes F, Phillips B. Resuscitation training of paediatricians. Arch Dis Child 2003;88:118–21.
5. O'Donnell CP, Gibson AT, Davis PG. Pinching, electrocution, ravens' beaks, and positive pressure ventilation: a brief history of neonatal resuscitation. Arch Dis Child Fetal Neonatal Ed 2006;91:F369–73.
6. Thompson BM, Rice T, Jaffe J, Aprahamian C, Horwitz L, Torphy D. "PALS for life!" A required trauma-oriented pediatric advanced life support course for pediatric and emergency medicine housestaff. Ann Emerg Med 1984;13:1044–7.
7. Ly N, McCaig LF. National hospital ambulatory medical care survey: 2000 outpatient department summary. Adv Data 2002;1–27.
8. Maio RF, Garrison HG, Spaite DW, et al. Emergency medical services outcomes project I (EMSOP I): prioritizing conditions for outcomes research. Ann Emerg Med 1999;33:423–32.
9. Merchant RM, Yang L, Becker LB, et al. Incidence of treated cardiac arrest in hospitalized patients in the United States. Crit Care Med 2011;39:2401–6.
10. Minei JP, Schmicker RH, Kerby JD, et al. Severe traumatic injury: regional variation in incidence and outcome. Ann Surg 2010;252:149–157.
11. Morrison LJ, Neumar RW, Zimmerman JL, et al. Strategies for improving survival after in-hospital cardiac arrest in the United States: 2013 consensus recommendations: a consensus statement from the American Heart Association. Circulation 2013;127:1538–63.
12. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 2008;300:1423–1431.
13. Perlman JM, Wyllie J, Kattwinkel J, et al. Part 11: Neonatal resuscitation: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2010;122:S516–38.
14. Rea TD, Eisenberg MS, Sinibaldi G, White RD. Incidence of EMS-treated out-of-hospital cardiac arrest in the United States. Resuscitation 2004;63:17–24.
15. Richmond S, Wyllie J. European resuscitation council guidelines for resuscitation 2010 section 7. Resuscitation of babies at birth. Resuscitation 2010;81:1389–99.
16. Roger VL, Go AS, Lloyd-Jones DM, et al. Heart disease and stroke statistics–2011 update: a report from the American Heart Association. Circulation 2011;123:e18–e209.
17. Stiell IG, Nesbitt LP, Pickett W, et al. The OPALS major trauma study: impact of advanced life-support on survival and morbidity. CMAJ 2008;178:1141–52.
18. Vaillancourt C, Stiell IG. Cardiac arrest care and emergency medical services in Canada. Can J Cardiol 2004;20:1081–90.
19. Canada HSFo. Advanced cardiac life support (ACLS) provider course. 2014.
20. Surgeons ACo. Advanced trauma life support (ATLS). 2014.
21. Society CP. Neonatal resuscitation program. 2014.
22. Mosley C, Dewhurst C, Molloy S, Shaw BN. What is the impact of structured resuscitation training on healthcare practitioners, their clients and the wider service? A BEME systematic review: BEME Guide No. 20. Med Teach 2012;34:e349–85.
23. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 2005;293:305–10.
24. 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.
25. Lum ME, Galletly DC. Resuscitation skills of first year postgraduate doctors. N Z Med J 1989;102:406–8.
26. Mundell WC, Kennedy CC, Szostek JH, Cook DA. Simulation technology for resuscitation training: a systematic review and meta-analysis. Resuscitation 2013;84:1174–83.
27. 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.
28. Wik L, Kramer-Johansen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. JAMA 2005;293:299–304.
29. Cheng A, Nadkarni VM, Mancini MB, et al. Resuscitation education science: educational strategies to improve outcomes from cardiac arrest: a scientific statement from the American Heart Association. Circulation 2018;138:e82–e122.
30. Mancini ME, Soar J, Bhanji F, et al. Part 12: Education, implementation, and teams: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2010;122: S539–81.
31. Yang CW, Yen ZS, McGowan JE, et al. A systematic review of retention of adult advanced life support knowledge and skills in healthcare providers. Resuscitation 2012;83:1055–60.
32. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.
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. Meaney PA, Topjian AA, Chandler HK, et al. Resuscitation training in developing countries: a systematic review. Resuscitation 2010;81:1462–72.
35. Plant N, Taylor K. How best to teach CPR to schoolchildren: a systematic review. Resuscitation 2013;84:415–21.
36. Rakshasbhuvankar AA, Patole SK. Benefits of simulation based training for neonatal resuscitation education: a systematic review. Resuscitation 2014;85:1320–3.
37. Soar J, Mancini ME, Bhanji F, et al. Part 12: education, implementation, and teams: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2010;81:e288–330.
38. Sullivan N. An integrative review: instructional strategies to improve nurses' retention of cardiopulmonary resuscitation priorities. Internat J Nurs Educ Scholarsh 201512:.
39. 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.
40. Yeung J, Okamoto D, Soar J, Perkins GD. AED training and its impact on skill acquisition, retention and performance—a systematic review of alternative training methods. Resuscitation 2011;82:657–64.
41. Cartledge S, Bray JE, Leary M, Stub D, Finn J. A systematic review of basic life support training targeted to family members of high-risk cardiac patients. Resuscitation 2016;105:70–8.
42. Dempsey E, Pammi M, Ryan AC, Barrington KJ. Standardised formal resuscitation training programmes for reducing mortality and morbidity in newborn infants. Cochrane Database Syst Rev 2015;Cd009106.
43. Mohammad A, Branicki F, Abu-Zidan FM. Educational and clinical impact of Advanced Trauma Life Support (ATLS) courses: a systematic review. World J Surg 2014;38:322–9.
44. Pammi M, Dempsey EM, Ryan CA, Barrington KJ. Newborn resuscitation training programmes reduce early neonatal mortality. Neonatology 2016;110:210–24.
45. Reisman J, Arlington L, Jensen L, Louis H, Suarez-Rebling D, Nelson BD. Newborn resuscitation training in resource-limited settings: a systematic literature review. Pediatrics 2016138:.

46. Magill R. defining and assessing learning. Motor learning and control: concepts and applications. New York, NY: McGraw Hill. 248-264.
47. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. JAMA 2011;306:978–88.
48. Higgins JP, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ (Clin Res Ed) 2011;343:d5928.
49. Reed DA, Cook DA, Beckman TJ, Levine RB, Kern DE, Wright SM. Association between funding and quality of published medical education research. JAMA 2007;298:1002–9.
50. Bender J, Kennally K, Shields R, Overly F. Does simulation booster impact retention of resuscitation procedural skills and teamwork? J Perinatol 2014;34:664–8.
51. Demaria Jr. S, Bryson EO, Mooney TJ, et al. Adding emotional stressors to training in simulated cardiopulmonary arrest enhances participant performance. Med Educ 2010;44:1006–15.
52. Lo BM, Devine AS, Evans DP, et al. Comparison of traditional versus high-fidelity simulation in the retention of ACLS knowledge. Resuscitation 2011;82:1440–3.
53. Matterson HH, Szyld D, Green BR, et al. Neonatal resuscitation experience curves: Simulation based mastery learning booster sessions and skill decay patterns among pediatric residents. J Perinatal Med 2018;46:934–41.
54. Schwid HA, Rooke GA, Ross BK, Sivarajan M. Use of a computerized advanced cardiac life support simulator improves retention of advanced cardiac life support guidelines better than a textbook review. Crit Care Med 1999;27:821–4.
55. Settles J, Jeffries PR, Smith TM, Meyers JS. Advanced cardiac life support instruction: do we know tomorrow what we know today? J Contin Educ Nurs 2011;42:271–9.
56. Stross JK. Maintaining competency in advanced cardiac life support skills. JAMA 1983;249:3339–41.
57. Wayne DB, Butter J, Siddall VJ, et al. Simulation-based training of internal medicine residents in advanced cardiac life support protocols: a randomized trial. Teach Learn Med 2005;17:210–6.
58. Devine LA, Donkers J, Brydges R, Perelman V, Cavalcanti RB, Issenberg SB. an equivalence trial comparing instructor-regulated with directed self-regulated mastery learning of advanced cardiac life support skills. Simulation Healthc: J Soc Simulation Healthc 2015;10:202–9.
59. Ali I, Cohen R, Reznick R. Demonstration of acquisition of trauma management skills by senior medical students completing the ATLS Program. J Trauma 1995;38:687–91.
60. Kaczorowski J, Levitt C, Hammond M, et al. Retention of neonatal resuscitation skills and knowledge: a randomized controlled trial. Fam Med 1998;30:705–11.
61. Ali J, Cohen R, Adam R, et al. Teaching effectiveness of the advanced trauma life support program as demonstrated by an objective structured clinical examination for practicing physicians. World J Surg 1996;20:1121–5 discussion 5–6.
62. Delasobera BE, Goodwin TL, Strehlow M, et al. Evaluating the efficacy of simulators and multimedia for refreshing ACLS skills in India. Resuscitation 2010;81:217–23.
63. Nimbalkar A, Patel D, Kungwani A, Phatak A, Vasa R, Nimbalkar S. Randomized control trial of high fidelity vs low fidelity simulation for training undergraduate students in neonatal resuscitation. BMC Res Notes 2015;8:636.
64. Jensen ML, Lippert F, Hesselfeldt R, et al. The significance of clinical experience on learning outcome from resuscitation training-a randomised controlled study. Resuscitation 2009;80:238–43.
65. Krogh KB, Hoyer CB, Ostergaard D, Eika B. Time matters - realism in resuscitation training. Resuscitation 2014;85:1093–8.
66. Sutton RM, Niles D, Meaney PA, 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: J Soc Crit Care Med World Fedal Pediatr Intensive Crit Care Societies 2011;12:e116–21.
67. Siegel LL, Kahana MJ. A retrieved context account of spacing and repetition effects in free recall. J Exp Psychol Learn, Memory, Cogn 2014;40:755–64.
68. LeBlanc VR, McConnell MM, Monteiro SD. Predictable chaos: a review of the effects of emotions on attention, memory and decision making. Adv Health Sci Educ: Theory Pract 2015;20:265–82.
69. Phelps EA. Human emotion and memory: interactions of the amygdala and hippocampal complex. Curr Opinion Neurobiol 2004;14:198–202.
70. Marsch SC, Muller C, Marquardt K, Conrad G, Tschan F, Hunziker PR. Human factors affect the quality of cardiopulmonary resuscitation in simulated cardiac arrests. Resuscitation 2004;60:51–6.