EUROPEAN RESUSCITATION COUNCIL

Review

Associations between cardiopulmonary resuscitation (CPR) knowledge, self-efficacy, training history and willingness to perform CPR and CPR psychomotor skills: A systematic review

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Abstract

Aim: To determine whether training history (including number of times and duration since last training), knowledge, self-efficacy or willingness are associated with cardiopulmonary resuscitation (CPR) psychomotor skills.

Methods: Eight databases were systematically searched from January 2005 to February 2018 for articles that involved adult layperson participants and explored an association between training history, knowledge, self-efficacy or willingness and CPR psychomotor skills or survival outcomes after real CPR attempts.

Results: Thirty-four articles with a total of 35,421 participants were included. CPR training was found to improve psychomotor skills, compared to no training, and any previous training was associated with better skills, compared to no previous training, however only the use of a popular song promoted meaningful retention of a specifically targeted skill, compared to standard training methods. Skills deteriorated within 3 months, then plateaued from 3 to 6 months. Self-efficacy was weakly associated with skill level, however knowledge was not associated with skill level. No studies assessed the association between willingness and psychomotor skills.

Conclusion: All laypeople should attend an instructor-led CPR training session with real-time or delayed feedback to improve CPR skills. Training sessions should utilise combinations of validated skill-specific training strategies, preferably including popular songs and feedback to help ensure skills retention. Refresher training, which focusses on skills and self-confidence rather than knowledge, should be undertaken every 3–6 months, although this timeframe needs further validation. All future studies assessing CPR psychomotor skills should adhere to a standardised reporting outcome list (proposed in this paper) to ensure consistency and comparability of results.

Keywords: Cardiopulmonary resuscitation, CPR, Psychomotor skills, Training, Education, Retention, Self-efficacy, Knowledge, Willingness, Survival

Introduction

Rationale

Survival to discharge from out-of-hospital cardiac arrest (OHCA) globally is estimated at 5.6%.[1] High-quality cardiopulmonary resuscitation (CPR) improves patient survival,[2] however CPR by laypeople may be suboptimal, limiting effectiveness.[3,4] In 2005, the International Liaison Committee on Resuscitation (ILCOR) emphasised chest compressions and simplified CPR guidelines, recommending a 30:2 compression-ventilation ratio (except for neonates).[5]

Previous reviews found CPR psychomotor skills deteriorate within 2–6 weeks, with other studies showing some skill retention for 6–12 months,[6–8] however, these reviews were based on pre-2005 guidelines and simplification of guidelines should improve laypeople's skill retention if the rationale for the change holds true. While ILCOR reviewed timing for basic life support (BLS) retraining in 2010 and 2015, most studies included used pre-2005 guidelines, or health professional or health student participants.[9,10] A comprehensive review of post-2005 literature focussing on laypeople has not been published.

ILCOR's 2005 review found no studies that specifically investigated the association between knowledge of correct CPR technique and psychomotor skills.[11] A 2013 review found knowledge is not associated with advanced life support (ALS) psychomotor skills in health care providers.[12] CPR psychomotor skills and knowledge deteriorate at different rates,[13] possibly contributing to discrepancy between written test scores and practical skills. CPR knowledge is commonly collected in research investigating population-level OHCA response abilities.[14–16] To the authors' knowledge, the association between CPR knowledge and psychomotor skills in laypeople has not been reviewed since 2005.

The association between CPR psychomotor skills and either self-efficacy or willingness to perform CPR has not been previously reviewed. As bystander CPR is associated with survival after OHCA,[17,18] it is important to identify whether people willing to perform CPR have adequate psychomotor skills. Investigating an association between self-efficacy and psychomotor skills could assist in developing educational strategies to improve skills.

Objectives

The objective was to systematically review the extent to which self-efficacy/confidence, willingness, training history and knowledge are each associated with CPR psychomotor skills in adult members of the general population (excluding health professionals and student health professionals). The outcomes of interest were performance indicators in simulated or actual out-of-hospital CPR attempts, including human assessor judgments, digital mannequin-generated data, and survival rates. Data must have been collected during or after 2005 and published in a peer-reviewed publication.

Methods

Protocol and registration

The protocol for this review is registered with PROSPERO (CRD42018059577). Explanations for differences between the protocol and final review are presented in Appendix 1.

Eligibility criteria

Participants

Members of the general public aged 18 years or older. Studies with health professionals or student health professionals were excluded, including students without previous CPR training, as they may have higher levels of education and motivation to learn CPR skills. Neonatal or infant CPR was excluded.

Interventions

Included studies needed to address training, willingness, self-efficacy or knowledge. Training included any activity designed to improve CPR performance, training history, number of times trained, and time since last training. Willingness was defined as a person's perceived likelihood (or probability) of performing CPR in a future scenario. Choices made in real resuscitation scenarios were excluded. Self-efficacy was a person's self-confidence, or perceived ability to perform a task correctly, based on Bandura's concept of self-efficacy.[19] Knowledge was a person's understanding of the theory and/or technique of CPR.

Comparators

Studies had to attempt to make an association between relevant interventions and outcomes. Comparison groups could include different: levels of willingness, self-efficacy or knowledge; time since last training; number of times trained; or training interventions.

Outcomes

The primary outcomes were nine measures of CPR performance, assessed using a mannequin or in an actual resuscitation attempt: compression rate, compression depth, compression-ventilation ratio, duration of interruptions to chest compressions, chest recoil, correct hand placement, proportion of correct compressions, ventilation volume and overall score. Secondary outcomes were return of spontaneous circulation (ROSC) and survival rates after resuscitation attempts.

Component and aggregate scores for non-CPR BLS skills (e.g. checking danger, response, airway, breathing) were excluded as these may be considered cognitive, rather than psychomotor tasks, so may be acquired through different training methods and retained for different time periods, compared to CPR psychomotor skills.

Study designs

Peer-reviewed analytical studies presenting original primary data of CPR psychomotor ability in out-of-hospital settings were eligible for inclusion. Studies of CPR performed in hospitals, nursing homes or general practices, and animal studies, were excluded.

Information sources

MEDLINE, Scopus, EMBASE, the Cumulative Index of Nursing and Allied Health (CINAHL), the Cochrane Central Register of Controlled Trials (CENTRAL), PsycInfo, Informit and Web of Science were used. Databases were searched from 1 January 2005 to 10 February 2018 (date of search) to ensure studies used post-2005 CPR guidelines.[5]

Database searches were supplemented by retrieving and screening references cited by Part 3 and Part 8 of ILCOR's 2015 International Consensus on CPR and Emergency Cardiovascular Care Science With Treatment Recommendations (CoSTR),[9,20] and summary of ILCOR's 2017 CoSTR.[21] References cited by included studies were retrieved and screened.

Search

The search strategy was designed in MEDLINE, using combinations of medical subject heading (MeSH) and free-text searches, then translated to equivalent searches in other databases (Appendix 2). The search strategy was reviewed by a librarian to consider whether all possible relevant search term combinations were included (i.e. to maximise sensitivity) and ensure that the search strategy correctly reflected review objectives (i.e. the search strategy was valid).

Study selection

Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework,[22] duplicates were removed, then title and abstract screening were performed by one author (MR). After level 1 screening, full-text articles were independently assessed by two reviewers (MR and LS) using a standardised study selection form (Appendix 3) and disagreements resolved through discussion, or by involving a third reviewer (RF).

Data collection process

Data was independently extracted by two authors (MR and LS) using a standardised data extraction form (Appendix 4).

Data items

Participant variables extracted include: number of participants, age, sex and training history. It was noted whether ethnicity, level of education, or participant anthropometry were reported. Study characteristic variables include: study design, country, whether single-centre or multi-centre, and inclusion and exclusion criteria. For studies assessing training interventions, assessment details extracted include: duration, mannequin, guideline and method of assessment.

Where no assessment guideline was reported, the guideline current at time of training, data collection, study submission for publication, or study publication (in priority order) was used. It was assumed that the source of training materials reflected whether American Heart Association (AHA) or European Resuscitation Council (ERC) guidelines were used. If the training material source was unclear, the year of the guideline used was extracted, as AHA and ERC guidelines were identical for most outcome measures.

For training intervention and retention studies, intervention groups, number of participants, training facilitation method, training duration and time between intervention and assessment were extracted. For studies evaluating self-efficacy, knowledge, and willingness, groups representing different magnitudes of each variable and number of participants were extracted.

Outcome data extracted include pre-test, post-test, effect size and statistical significance data for compression rate, compression depth, percentage of correct compressions, duration of interruptions, chest recoil, hand placement, ventilation volume, correct compression-ventilation ratio, overall skills, and survival rates (to discharge, ROSC, 1-month).

Risk of bias in individual studies

The Cochrane Risk of Bias tool was used to appraise randomised controlled trials (RCTs) and quasi-RCTs.[23] The McMaster Critical Review Form for Quantitative Studies was used to appraise pre-test/post-test and cross-sectional studies.[24] A quality assessment, rather than formal risk of bias assessment, of non-RCTs was performed, as it was predicted that the quality of non-RCTs would be highly variable and that a quality assessment, incorporating a less formal risk of bias assessment, would better differentiate the quality of non-randomised studies, and allow sources of bias to be identified. Risk of bias and quality were assessed by a single reviewer (MR).

Summary measures

Mean differences (MD), median differences and differences of proportions were used as summary measures for training intervention and retention studies. No summary measures were used for studies evaluating knowledge, willingness or self-efficacy.

Synthesis of results

Results were synthesised in a narrative analysis. Studies assessing the effect of a training intervention were grouped according to intervention type. For studies assessing retention of skills, analyses were grouped by time interval since training. A meta-analysis was not performed due to significant clinical heterogeneity of results and small numbers of studies assessing some outcomes of interest.

Risk of bias across studies

Publication bias could not be assessed using a funnel plot due to significant clinical heterogeneity of the studies and the absence of a single outcome variable reported in all studies, so a narrative analysis of publication bias was performed.

Results

Study selection

A total of 12,796 records were retrieved and 4,782 duplicates removed. Title and abstract screening of 8,014 articles was performed, with 7,822 excluded, leaving 192 articles for full-text assessment (Fig. 1). After full-text screening, 34 articles were included.[25–58]

Study characteristics

Characteristics of included and excluded studies are summarised in Appendices 5 and 6.

Sixteen studies assessed training interventions,[25,28,31–33,37–41,44,45,48–50,52] fifteen studies assessed skill retention and training interventions,[26,27,29,30,34,36,42,43,46,47,51,53,56–58] two studies assessed self-efficacy,[35,54] and one study assessed knowledge.[55] Seven studies excluded participants with previous training,[34,36,39,41,43,57,58] two excluded participants with training less than two years ago,[27,44] and three studies excluded participants with training less than five years ago.[42,50,53] Twenty studies used a mannequin to assess CPR skills,[25–27,29,31–34,38–42,44–48,50,53] six studies used a checklist,[30,37,43,49,51,58] six studies used both a mannequin and checklist,[36,52,54–57] and two studies assessed survival after real CPR attempts.[28,35]
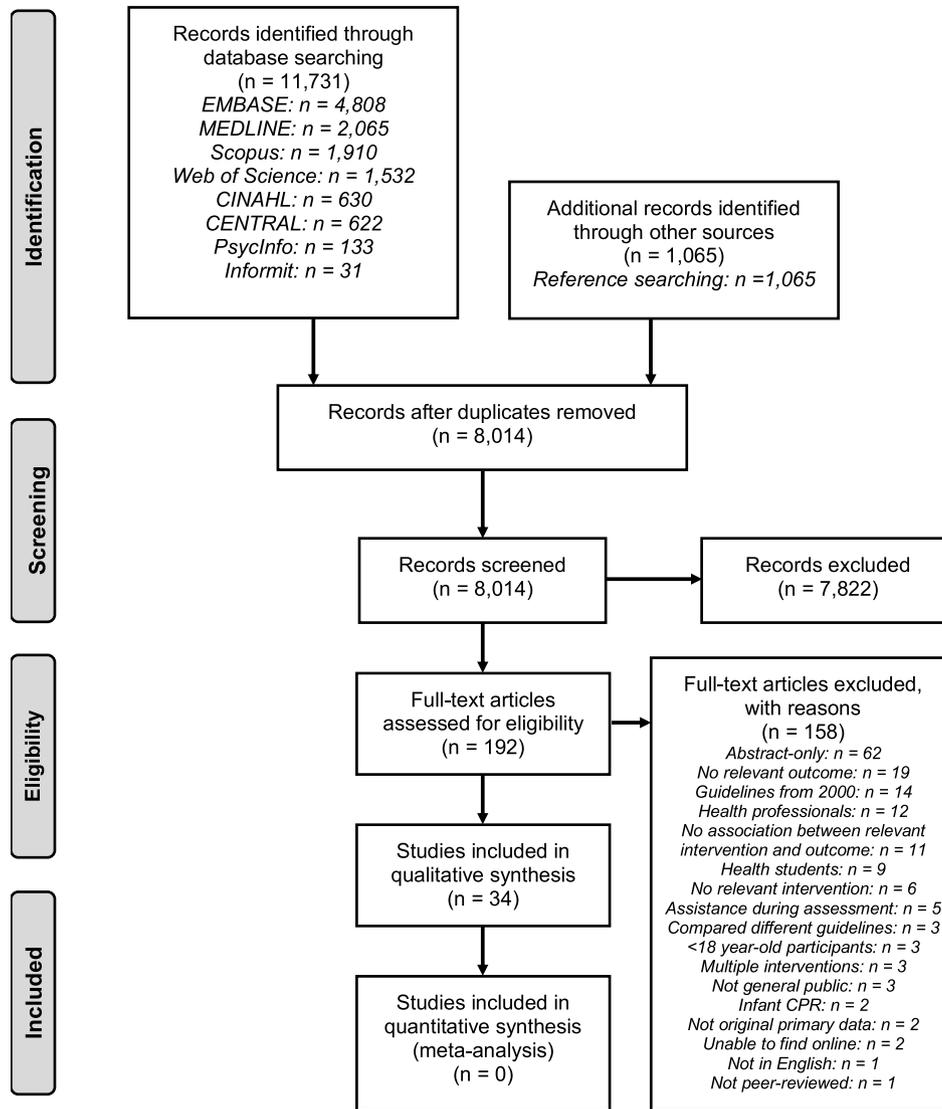
Fig. 1 – PRISMA flow diagram for the review.

Risk of bias within studies

Twenty-one RCTs were appraised (Table 1, Appendix 7).[25–27,31–34,36,39,41,42,44,46–48,50,51,53,56–58] Twenty studies had a low risk of detection bias, as digital mannequins were used to measure outcomes, or outcome assessors were blinded.[25–27,31–34,36,39,41,42,44,46–48,50,51,53,57,58] Fifteen studies had a high risk of performance bias due to participants,[44,47,48,58] or participants and instructors,[25,26,33,34,36,42,50,51,53,56,57] not being blinded to the intervention participants received. Twelve studies had an unclear risk of selection bias, as the method of random sequence generation was unclear.[27,31,33,34,39,41,42,44,47,48,50,57] Nine studies were at high risk of selective reporting bias, due to not reporting all relevant variables generated by digital mannequins,[27,31,39,48] not reporting outcomes indicated to have been recorded,[34,58] reporting continuous variables as categorical outcomes,[50,51] or not reporting an entire data set collected.[26] Thirteen non-RCTs were appraised (Table 2, Appendix 8).[28–30,35,37,38,40,43,45,49,52,54,55] Eleven studies did not justify sample

size,[29,30,37,38,40,43,45,49,52,54,55] and five did not address reliability and/or validity of outcome measures.[30,37,43,49,54] There was a risk of co-intervention primarily in population-based studies (e.g. assessing media interventions).[28,35,37,40,52] All studies were of high or moderate quality, except three that were low-quality.[43,45,55]

Results of individual studies

Intervention studies

Face-to-face methods (instructor-led, feedback and peer-led methods). Instructor-led training substantially improved average compression rates (MD:16.6bpm, $P < 0.0001$), but only slightly improved compression depth (MD:4.5–6.7 mm, $P < 0.0001$), compared to pre-testing (Table 3).[45] Concordantly, additional real-time or delayed feedback substantially improved compression depth compared to both pre-testing (MD:6–18.8 mm, $P < 0.05$)[41] and instructor-led training (MD:9.1–11.2% more compressions with correct depth, $P = 0.012$),[39] while compression rate remained unchanged.[39,41] Using

Table 1 – Summary of risk of bias assessment for RCTs using the Cochrane Risk of Bias Tool.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other sources of bias (other bias)
Jones et al. 2007 [25]	-	-	-	+	?	?	-
Nishiyama et al. 2008 [26]	+	+	-	+	+	-	+
Bobrow et al. 2011 [27]	?	?	?	+	?	-	+
Godfred et al. 2013 [31]	?	?	?	+	+	-	?
Van Tulder et al. 2015 [32]	+	+	?	+	+	+	?
Lee et al. 2016 [33]	?	?	-	+	?	+	+
Charlier et al. 2016 [34]	?	+	-	+	+	-	?
Boet et al. 2017 [36]	+	+	-	+	+	+	?
Baldi et al. 2017 [39]	+	?	?	+	+	-	+
Saraç 2017 [41]	?	?	?	+	+	?	-
Hong et al. 2016 [42]	?	?	-	+	?	?	+
Panchal et al. 2014 [44]	+	?	-	+	?	+	+
Ettl et al. 2011 [46]	+	-	+	+	-	?	-
Iserbyt et al. 2009 [47]	?	?	+	+	+	?	+
Nishiyama et al. 2009 [48]	+	?	-	+	+	-	+
Mancini et al. 2009 [50]	?	?	-	+	?	-	+
Chung et al. 2010 [51]	+	+	-	+	?	-	+
Hafner et al. 2015 [53]	+	-	-	+	+	+	+
Saraç et al. 2010 [56]	+	+	-	?	?	+	?
Iserbyt et al. 2014 [57]	+	?	-	+	+	+	?
Papadimitriou et al. 2010 [58]	+	+	-	+	-	-	+

popular songs instead of metronomes (MD:−12 to 5.2bpm, P < 0.002)[42,53] and traditional order of course content (median difference 12bpm, P < 0.05)[46] improved compression rates. Real-time or delayed feedback improved proportions of adequate compressions (MD:52.5–60.4%, P < 0.05),[41] adequate ventilations (MD:45.3–64.4%, P < 0.05),[41] compressions with complete chest recoil (difference 14.9–17.1%, P < 0.001)[39] and compressions with correct hand positioning (MD:5–6.1%, P < 0.001),[39] compared to pre-testing and instructor-led training.

In one study, peer-led learning improved compression rate, compared to instructor-led (MD:3–9bpm, P = 0.014),[57] however this effect was inconsistent,[34,47] and it worsened ventilation performance (MD:151–206 mL, P < 0.005).[57]

Video-instruction methods. Brief video-instruction improved compression rates, compared to no training (median difference 19–37.5bpm, P < 0.05),[27,44] and was equivalent to instructor-led training (Table 3).[25] Although compression depth improved in one study (median difference 11–18mm, P < 0.001),[27] two studies showed no

improvement,[31,44] and self-training videos were modestly inferior to instructor-led training (MD:−9 mm, 6.5% fewer participants performing correct depth, P < 0.01).[25,51] Video-instruction reduced durations of interruptions, compared to pre-testing (median difference −27 s, P < 0.05),[44] and improved proportion of compressions with correct hand placement, compared to no training (median difference 16.2%, P = 0.001).[31] However, instructor-led training was slightly more effective at reducing duration of interruptions (MD:−3 s, P = 0.018)[25] and increasing proportion of participants with correct hand placement (difference 5.6%, P < 0.01).[51] SMS reminders to watch a video improved the proportion of compressions with correct hand positioning (MD:29.6%, P = 0.004).[29]

Media and web-based training methods. Media campaigns and brief commercials slightly improved absolute compression rate (median difference 7bpm, P = 0.034)[40] and compression depth (median difference 2–6 mm, P < 0.05),[38,40] however modestly increased the proportion of participants performing compressions with correct rate (difference 22%, P = 0.019)[37] and depth (difference 20%, P = 0.012).[37] Only people who noticed the media campaign improved compression rate.[40] Compared to pre-testing, media campaigns may worsen ventilation performance (MD:−105 mL, P < 0.001).[40]

Online training was less effective than traditional instruction in teaching compression rate (MD:−9bpm, P ≤ 0.05),[50] compression depth (MD:−11.5 mm, 17% fewer participants with correct depth, P < 0.05)[50,56] and ventilation volume (MD:9% fewer ventilations with correct volume, P ≤ 0.05).[50] There was a slight increase in proportion of compressions with complete chest recoil (MD:6%, P ≤ 0.05),[50] concordant with the decrease in compression depth.

Survival-to-discharge. The adjusted odds-ratio (AOR) for community-level survival-to-discharge following OHCA was 1.20 (95% CI 1.07–1.33) per 10% increase in the proportion of a population having CPR training with a mannequin and 1.10 (95% CI 1.04–1.15) per 10% increase in the proportion of a population having ever had CPR training.[35]

Skills retention
Compression rate and depth skills were retained at 2 months, 18 weeks and 6 months,[27,42,56] although compression rate was only retained at 6 months in a popular song-instructed group (MD:20bpm, P < 0.0001; Table 4).[42] However, the proportion of participants with correct rate and compression-ventilation ratio decreased until 3 months (cumulative MD:−16% to −18% at 1 month, P < 0.05; cumulative MD:−29% to −32% at 3 months, P < 0.05 compared to 1 month), then plateaued from 3 to 6 months (cumulative MD:−40% to −43% at 6 months, P > 0.05 compared to 3 months).[58] Duration of interruptions substantially deteriorated by 1 month (MD:51.6 s, P < 0.05),[26] however ventilation skills were unchanged at 18 weeks,[56] and chest recoil and hand positioning were unchanged at 6 months.[42]

Using popular songs improved retention of compression rate skills at 6 weeks (MD:−9bpm, 31% more people with correct rate, P < 0.014) and 6 months (MD:−14.8bpm, 50.2% more people with correct rate, P < 0.0001), compared to metronomes (Table 5).[42,53] Conversely, online self-instruction resulted in poorer retention of compression rate (MD:−13.7bpm, P < 0.05), compression depth (MD:−10 mm, P < 0.05), proportion of adequate compressions (MD: −54%, P < 0.01) and proportion of adequate ventilations (MD: −18.9%, P < 0.01), however ventilation volume improved (MD: −406 mL, P < 0.01).[56] Peer-led training resulted in excess ventilation

Table 2 – Summary of quality appraisal of non-RCTs using the McMaster Critical Appraisal Tool for Quantitative Studies.

Study	Study Design	Was the purpose stated clearly?	Was relevant background literature reviewed?	Was the sample described in detail?	Was sample size justified?	Were the outcome measures reliable?	Were the outcome measures valid?	Intervention was described in detail?	Contamination was avoided?	Cointervention was avoided?	Results were reported in terms of statistical significance?	Were the analysis methods appropriate?	Clinical importance was reported?	Drop-outs were reported?	Conclusions were appropriate given study methods and results?	Adjusted Total[a]	Quality Assessment[b]
Tanigawa et al. 2011[28]	Cohort	Y	Y	Y	Y	Y	Y	N/A	N/A	N	Y	Y	N	Y	Y	10/12	High
Ahn et al. 2011[29]	Case-control	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y	Y	N	10/14	Moderate
Anderson et al. 2012[30]	Cross-sectional	Y	Y	Y	N	U	U	N/A	N/A	U	Y	Y	Y	N/A	Y	7/11	Moderate
Ro et al. 2016[35]	Ecological study	Y	Y	Y	Y	Y	Y	N/A	N/A	N	Y	Y	Y	N/A	Y	10/11	High
Benoit et al. 2017[37]	Before and after	Y	Y	Y	N	U	U	Y	Y	N	Y	Y	Y	Y	Y	10/14	Moderate
Beskind et al. 2017[38]	Before and after	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	12/13	High
Plunien et al. 2017[40]	Before and after	Y	N	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	N	10/14	Moderate
Hasani et al. 2015[43]	Before and after	Y	Y	N	N	U	U	N	Y	U	Y	Y	N	N	N	5/14	Low
Hirose et al. 2014[45]	Before and after	Y	N	N	N	Y	Y	Y	Y	Y	Y	N	Y	N	Y	9/14	Low
Kumawat et al. 2013[49]	Before and after	Y	Y	Y	N	Y	U	N	U	Y	Y	Y	Y	Y	Y	10/14	Moderate
Wiese et al. 2008[52]	Cohort	Y	N	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	11/14	Moderate
De Vries et al. 2007[55]	Cohort	N	Y	N	N	Y	Y	Y	Y	Y	N	N	N	Y	N	7/14	Low
Mahony et al. 2008[54]	Cross-sectional	Y	Y	Y	N	Y	U	N/A	Y	N/A	N	N	Y	Y	Y	8/11	Moderate

N = No, U = not addressed, Y = Yes, N/A = not applicable.

a Maximum score is 14. A denominator of less than 14 indicates that some questions were deemed not applicable and were excluded from the total possible score for that study.

b An adjusted total with 0–2 points deducted was considered "High" quality, 3–4 points deducted was "Moderate" quality, and 5 or more points deducted was "Low" quality.

Table 3 – Summary of results from studies assessing the effect of interventions on psychomotor skills.

Study	Control/Pre-test	Intervention/Post-Test	# Control/Pre-test	# Post-test	Beats/minute^ (Compression rate)	% of compressions with correct rate^	% of participants with correct rate^^	Millimetres^ (Compression depth)	% of compressions with correct depth^	% of participants with correct depth^^	% Correct / adequate compressions^	% of participants with correct / adequate compressions^	Duration of interruptions to compressions (s)^	% of compressions with complete chest recoil^	% of participants with complete chest recoil^^	% of compressions with correct hand placement^	% of participants with correct hand placement^^	Mean tidal volume (mL)^	% of breaths with adequate/correct volume^	% of participants with adequate/correct volume^^	% correct compression-ventilation ratio^^	Overall skills (any method)
Video-instruction																						
Jones et al. 2007 [25]	Pre-test	Self-training DVD	24	40	8			0					-1	0		6		581			42	
	Instructor-led	Self-training DVD	40	40	-1			-9					3	3		-1		-41			-2	
Bobrow et al. 2011 [27]	No training	UBV	51	47	34			11	73.3													
	No training	Brief video	51	49	33			12	78.8													
	No training	Brief video + practice	51	46	37.5			18	88.4													
Godfred et al. 2013 [31]	No training	Video-instruction COCPR	135	185	8	12.3		1	0.55							16.2						
	No training	Video-instruction Full CPR	135	119	19	19.5		2.5	8.2							14.5						
	Video-instruction Full CPR	Video-instruction COCPR	185	119	-11	-7.2		-1.5	0.27							1.7						
Hasani et al. 2015 [43]	Pre-test	T2: Educational film	112	112																		↑
Nishiyama et al. 2009 [48]	Pre-test	Instructor-led	87	87									-36.4									
	Pre-test	DVD in advance + instructor-led	96	95									-26.9									
	Instructor-led	DVD in advance + instructor-led	87	95									1									
Panchal et al. 2014 [44]	No training	UBV	47	48	19			6					-27									
Chung et al. 2010 [51]	TCI	VSI	132	124			4.4			-6.5	-3.6						-5.6			-2.6		~
Feedback																						
Baldi et al. 2017 [39]	Course without feedback	Course + 1min with mannequin feedback	150	150	-2				11.2					14.9		5						↑
	Course without feedback	Course + 10min with mannequin feedback	150	150	-1				9.1					17.1		6.1						↑
Saraç 2017 [41]	Pre-test	Male Control - CPR without feedback	9	9	0.4			0.1			-0.3							178.8	15.5			
	Pre-test	Female Control - CPR without feedback	16	16	-7.1			4.3			4.1							91.2	6.2			
	Pre-test	Male AC - real-time feedback	10	10	-8.1			6.4			52.5							-354	51.7			
	Pre-test	Female AC - real-time feedback	17	17	4			18.8			59.6							-118.3	53.9			
	Pre-test	Male AT-KR - printed report feedback	9	9	10.3			10.2			60.4							-90	45.3			
	Pre-test	Female AT-KR - printed report feedback	15	15	4.4			6			54.5							-42.7	64.4			
Peer-led																						
Charlier et al. 2016 [34]	Instructor-led	Jigsaw (Ven)	40	49	0			3								0		82				
	Instructor-led	Jigsaw (CC)	40	48	-2			-4								0		120				
Iserbyt et al. 2009 [47]	Control - Task cards	Task cards + peer evaluation	38	38	-7.6			-0.7			-4.3					-9.6		-20.7	4.1			
	Pre-test	Task cards	38	38	63.4			23.3			45.8					51		521	7			
Iserbyt et al. 2014 [57]	TBI	RBI	55	60	9			1			2					-2		206	-4			
	TBI	RNI	55	60	3			0			-6					-5		151	-2			
Instructor-led																						
Jones et al. 2007 [25]	Pre-test	Instructor-led	23	40	20			9					0	-8		10		386			48	
Nishiyama et al. 2008 [26]	CPR	COCPR	107	106							17.6											
Lee et al. 2016 [33]	Level 1 (COCPR)	Level 2 (COCPR)	121	119	-2			1	19.3		15.7			0	0							
	Level 3 (CPR)	Level 4 (CPR)	124	121	-1			4	23.6		43.5			-2	0				57	-5			
Hasani et al. 2015 [43]	Pre-test	T1: Interactive lecture with human model	112	112																		↑
	Pre-test	T3: Workshop, lecture	113	113																		↑

Study	Control/Pre-test	Intervention/Post-Test	# Control/ Pre-test	# Post-test	Beats/minute^	% of compressions with correct rate^	% of participants with correct rate^^	Millimetres^	% of compressions with correct depth^	% of participants with correct depth^^	% Correct / adequate compressions^	% of participants with correct / adequate compressions^	Duration of interruptions to compressions (s)^	% of compressions with complete chest recoil^	% of participants with complete chest recoil^^	% of compressions with correct hand placement^	% of participants with correct hand placement^^	Mean tidal volume (mL)^	% of breaths with adequate/correct volume^	% of participants with adequate/correct volume^^	% correct compression-ventilation ratio^^	Overall skills (any method)
	Pre-test	T4 = Workshop, lecture, human model, educational film, reference book	113	113																		↑
Hirose et al. 2014 [45]	Pre-test	Instructions + practice on mannequin	109	109	16.6			5.4	29.7				-0.84									
Ettl et al. 2011 [46]	Standard course design	Intervention group	27	39	-12			2										116				
Kumawat et al. 2013 [49]	Pre-test	Training + demo with models	30	30																		↑
Number of times trained																						
	Pre-test	First time participants	95	95	21.8			6.7	33.4				-1.53									
	Pre-test	Second time participants	59	59	10.9			4.5	27.7				-0.08									
Hirose et al. 2014 [45]	First time participants (pre-training)	Second time participants (pre-training)	95	59	13.2			1.4	7.6				-1.54									
Wiese et al. 2008 [52]	No previous training + course	Previous training + course	48	52	4							25.6	-8.3							23.4		↑
Media																						
	Pre-test	Media campaign	500	500	4			6														
Plunien et al. 2017 [40]	Media campaign - subgroup - those who did not notice campaign	Media campaign: Subgroup - noticed campaign	111	308	7			3										-105				
Benoit et al. 2017 [37]	Pre-test	Brief video on TV in ED	50	50			22			20							14					
Beskind et al. 2017 [38]	Pre-test	UBV in commercial break	45	51	5			2					-24									
Miscellaneous																						
Van Tulder et al. 2015 [32]	AHA depth instruction	ERC instruction	55	55				-4		-23.6												
Boet et al. 2017 [36]	Time-based	Mastery learning	22	27	1	0.7		1		6.7							0					
Hong et al. 2016 [42]	Metronome	Popular song	65	71	5.2	8.7		1.2	21.5	-3.3				-1.1		-10.5						
Mancini et al. 2009 [50]	Traditional instruction	Online self-training	63	59	-9					-12	-17	-6		6		0	-7		-9	-4		↓
Hafner et al. 2015 [53]	Metronome	Bee Gees	46	50	-12	9		-3.8				4.4										
Saraç et al. 2010 [56]	Traditional instruction	Case-based	28	30	-0.49			-0.35				2.74						53	2.33			
	Traditional instruction	Web	28	28	-11.7			-11.5				-61.9						-519	-28.9			
Papadimitriou et al. 2010 [58]	Group B	Group A	239	241			-1										0			-2	-1	
Ahn et al. 2011 [29]	No reminder	Video-reminded	40	40	0			1.2					-0.7			29.6		250				
de Vries et al. 2007 [55]	No training	Online self-training	2	16	42.1	58.8		26.1	58.8					-6.7		87.5		200		13.3	93.8	

Green shading = statistically significant, yellow shading = not statistically significant, no shading = statistical significance not assessed, ↓ = decrease, ↑ = increase, ¯ = no difference.

AC = augmented concurrent group, AHA = American Heart Association, AT-KR = augmented terminal knowledge of results group, BLS = basic life support, CC = chest compressions, COCPR = compression-only CPR, CPR = cardiopulmonary resuscitation, DVD = digital video disc, ED = emergency department, ERC = European Resuscitation Council, min = minute(s), mL = millilitres, RBI = reciprocal/BLS instructor group, RNI = reciprocal/non-BLS instructor group, s = seconds, T1 = Training group 1, T2 = Training group 2, T3 = Training group 3, T4 = Training group 4, TBI = traditional/BLS instructor group, TCI = traditional classroom instruction, TV = television, UBV = ultra-brief video, Ven = ventilations, VSI = video self-instruction, # = number of participants.

volume, compared to instructor-led training (MD:169–175 mL, P = 0.002), at 3 weeks.[57] SMS reminders to watch a short video only improved the proportion of compressions with correct hand placement (MD:29.6%, P = 0.004) at 3 months.[29] Smaller group sizes, more practice time and modified course structure slightly decreased compression rate skill retention (MD:−12bpm, P < 0.05), compared to instructor-led training.[46]

The AOR for community-level survival-to-discharge following OHCA was 1.15 (95% CI 1.06–1.26) per 10% increase in the proportion of a population having CPR training within the last two years.[35]

Number of times trained
Compression depth (MD:13.2bpm, P < 0.05),[45] interruptions to compressions (MD:−8.3 s, P < 0.05),[52] and proportions of

Table 4 – Summary of results from studies assessing retention of psychomotor skills at different time periods after training. All skills are compared to those immediately after training.

Time Period	Study	Intervention	# Control/Pre-test	# Post-test	Compression rate (bpm)^	% of people with correct rate^^	Compression depth (mm)^	% of compressions with correct depth^	% of participants with correct depth^^	% Correct/adequate compressions^	Duration of interruptions to compressions (s)^	% of compressions with complete recoil^	% of compressions with correct hand placement^	% of participants with correct hand placement^^	Mean tidal volume (mL)^	% of breaths with adequate/correct volume^	% of participants with adequate/correct volume^^	% correct compression-ventilation ratio^	Overall skills (any method)
2 wks	Iserbyt et al. 2009 [47]	Control group	38	38	-9.3		-1.5			-17.1			-11.1		59.8	-3.6			
		Intervention group	38	38	-8.7		-2.1			-8.8			-2.1		-26.8	-4.4			
3 wks	Iserbyt et al. 2014 [57]	RBI	60	60	-5		-7			-2			-7		-36	1			
		RNI	60	60	-7		0			4			2		13	0			
		TBI	55	55	0		-1			0			0		-5	0			
1 mth	Papadimitriou et al. 2010 [58]	Group A	241	147		-16												-25	
		Group B	239	156		-18												-24	
	Nishiyama et al. 2008 [26]	CCOCPR	106	104						-14.7									
		CPR	107	104						-6.1	51.6								
6 wks	Hafner et al. 2015 [53]	Metronome	46	42	-1	4	1			-2.1									
		Bee Gees	50	46	2	26	1			-8.3									
2 mths	Bobrow et al. 2011 [27]	UBV	47	48	-2		2	-6.8											
		Brief video	49	50	-2.5		0.5	-0.1											
		Brief video + practice	46	45	-9.5		-2	-3.6											
3 mths	Ahn et al. 2011 [29]	Face-to-face, no reminder	40	40	12.8		-3.9						1.6	-29.6	-295				
		Face-to-face, reminder SMS	35	35	13		-0.8						1.7	3.7	-118				
	Papadimitriou et al. 2010 [58]	Group A	241	147		-29*												-40*	
		Group B	239	156		-32*												-40*	
4 mths	Boet et al. 2017 [36]	Time-based	22	20	2.5	-5	9.5		30						-5				
		Mastery learning	27	23	4	-8.7	5		17.4						-8.7				
18 wks	Saraç et al. 2010 [56]	Traditional	28	28	-1.17		0.36			-12.3						-58	-7.64		
		Case-based	30	30	2.54		-0.67			-13.8						-90	-15.5		
		Web	28	28	-3.35		1.78			-4.3						55	2.4		
6 mths	Hong et al. 2016 [42]	Metronome	65	61	22.6	-45.9	-0.8	-1.4	-3.3				0	-0.6					
		Popular song	71	68	2.6	-4.4	-2.2	-21.1	-4.4				1.1	-6.6					
12 mths	Papadimitriou et al. 2010 [58]	Group A	241	147		-40**												-52**	
		Group B	239	156		-43**												-51**	
	Chung et al. 2010 [51]	TCI	132	75	-20.6				0	1.8					-4		1.7		~
		VSI	124	55	-4				2.9	6.3					2		5.6		↑
	Hasani et al. 2015 [43]	T1: interactive lecture	112	25															↓
		T2: educational film	112	25															↓
		T3: Workshop using lecture	113	25															↓
		T4 = Workshop using lecture, human model, educational film, reference book	113	25															↑

Green shading = statistically significant, yellow shading = not statistically significant, no shading = statistical significance not assessed, ↓ = decrease, ↑ = increase, ~ = no difference, ^ = mean or median differences, ^^ = difference in proportions, * = P < 0.05 compared to 1 month, ** = P > 0.05 (NS) compared to 3 months. BLS = basic life support, bpm = beats per minute, COCPR = compression-only CPR, CPR = cardiopulmonary resuscitation, mL = millilitres, mm = millimetres, mth(s) = month(s), RBI = reciprocal/BLS instructor group, RNI = reciprocal/non-BLS instructor group, s = seconds, SMS = short messaging service (text message), T1 = Training group 1, T2 = Training group 2, T3 = Training group 3, T4 = Training group 4, TBI = traditional/BLS instructor group, TCI = traditional classroom instruction, UBV = ultra-brief video, VSI = video self-instruction, wks = weeks, yrs = years, # = number of participants.

participants with correct compressions (25.6% difference, P = 0.0058),[52] correct ventilations (23.4% difference, P = 0.0062),[52] and overall "effective" CPR (22.3% difference, P = 0.0038)[52] were improved in participants with previous training, compared to without training. Irrespective of previous training, participants improved compression rate (MD:10.9–21.8bpm, P < 0.05) and depth (MD:4.5–6.7 mm, P < 0.0001) after training.[45]

Self-efficacy and knowledge

The AOR for community-level survival-to-discharge following OHCA was 1.08 (95% CI 1.03–1.13) per 10% increase in community-level self-efficacy and 1.06 (95% CI 1.03–1.10) per 10% increase in community CPR awareness rates.[35] Yet, mannequin studies reported no associations between knowledge, self-rated confidence or self-rated competence with psychomotor skills.[54,55]

Risk of bias across studies

There was a high risk of publication and reporting bias. There were 62 non peer-reviewed abstracts, of which ten had a corresponding peer-reviewed full-text article,[59–67] suggesting high risk of bias towards significant results. No attempt was made to search, or correlate study protocols with full-text publications, thus proportion of completed, yet unpublished, studies is unknown. Only peer-reviewed publications in English were considered. By handsearch-ing the reference lists of included articles, risk of citation bias

Table 5 – Summary of results from studies assessing the effect of interventions on psychomotor skills at retention testing.

Time Period	Study	Control/ Pre-test	Intervention/Post-test	# Control/ Pre-test	# Post-test	Compression rate (bpm)^	% of people with correct rate^^	Compression depth (mm)^	% of compressions with correct depth^	% of people with correct depth^	% Correct / adequate compressions^	Duration of interruptions to compressions (s)^	% of all compressions with complete recoil^	% of compressions with correct hand placement^^	% of people with correct hand placement^^	Mean tidal volume (mL)^	% of breaths with adequate/correct volume^	% of people with adequate/correct volume^^	% correct compression–ventilation ratio^^	Overall skills (any method)
2 wks	Iserbyt et al. 2009 [47]	Control - Task cards	Task cards + peer evaluation	38	38	-7		-1.3			4			-0.6		-107.3	8.8			
3 wks	Iserbyt et al. 2014 [57]	TBI	RBI	55	60	4		-5			0			-9		175	-2			
		TBI	RNI	55	60	-4		1			-2			-3		169	-3			
1 mth	Charlier et al. 2016 [34]	Instructor-led	Jigsaw (Ven)	40	49	0		3						0		82				
		Instructor-led	Jigsaw (CC)	40	48	-2		-4						0		120				
	Nishiyama et al. 2008 [26]	CPR	CCOCPR	104	104						9	-51.6								
	Papadimitriou et al. 2010 [58]	Group B	Group A	156	147		1												-2	
6 wks	Hafner et al. 2015 [53]	Metronome	Bee Gees	42	46	-9	31	-3.8				-1.8								
2 mths	Bobrow et al. 2011 [27]	UBV	Brief Video, no practice	40	49	2		-0.5			12.2									
		UBV	Brief Video, practice	40	48	-3		3			18.3									
3 mths	Papadimitriou et al. 2010 [58]	Group B	Group A	156	147		2												-1	
	Ahn et al. 2011 [29]	No reminder	Reminder	40	35	0		1.2						-0.7	29.6	250				
4 mths	Boet et al. 2017 [36]	Time-based	Mastery learning	20	23	2.5	-3	-3.5				-5.9			-3.7					
18 wks	Saraç et al. 2010 [56]	Traditional	Case-based	28	30	3.2		-1.4			1.3					21	-5.5			
		Traditional	Web	28	28	-13.7		-10.0			-54					-406	-18.9			
6 mths	Papadimitriou et al. 2010 [58]	Group B	Group A	156	147		2												-2	
	Ettl et al. 2011 [46]	Standard	Intervention design	27	39	-12		2								116				
	Hong et al. 2016 [42]	Metronome	Popular song	61	68	-14.8	50.2	-0.2	1.8	-4.4			0	-16.5						
	Chung et al. 2010 [51]	TCI	VSI	75	55	12.2					-3.6	0.9			0.4			1.3		~
12 mths	Hasani et al. 2015 [43]	T1	T2	25	25															↓
		T1	T3	25	25															↑
		T1	T4	25	25															↑

Green shading = statistically significant, yellow shading = not statistically significant, no shading = statistical significance not assessed, ↓ = decrease, ↑ = increase, ‾ = no difference, ^ = mean or median differences, ^^ = difference in proportions.

BLS = basic life support, bpm = beats per minute, CC = chest compressions, COCPR = compression-only CPR, CPR = cardiopulmonary resuscitation, mL = millilitres, mm = millimetres, mth(s) = month(s), RBI = reciprocal/BLS instructor group, RNI = reciprocal/non-BLS instructor group, s = seconds, T1 = Training group 1, T2 = Training group 2, T3 = Training group 3, T4 = Training group 4, TBI = traditional/BLS instructor group, TCI = traditional classroom instruction, UBV = ultra-brief video, Ven = ventilations, VSI = video self-instruction, wks = weeks, # = number of participants.

favouring certain schools of thought was high. For example, Iserbyt authored all studies assessing peer-led interventions (Table 3) and 19 of 178 authors of included studies authored multiple articles. Fourteen studies were at high risk of selective reporting bias (Table 1, Appendix 7 and 8),[26,27,30,31,34,39,40,43,48–52,58] possibly towards favourable and significant results. There was also a high risk of time-lag bias towards favourable findings, as only articles spanning 13 years were included. Risk of location bias was low, as studies represented various Asian, European and American settings.

Discussion

Summary of evidence

Any method involving practical training improves psychomotor skills. However, we found combining instructor-led training with real-time or delayed feedback likely results in the greatest improvements in laypeople's CPR skills, consistent with findings from a previous systematic review.[68] Video-instruction methods have similar effectiveness to instructor-led training, however instructor-led training is slightly superior in improving compression depth and hand placement, and minimising interruptions.[25,51] Therefore, video-instruction could be an acceptable alternative to face-to-face training in geographically isolated or low-resource settings. Online training was similar or slightly inferior to instructor-led training, consistent with a subgroup analysis within a recent systematic review and meta-analysis.[69] The slight skill improvements resulting from media campaigns should be balanced with the costs of these strategies.

An optimal retraining interval could not be determined, due to the small number of studies and lack of reported statistical significance. The largest and only retention study reporting statistical significance at more than one time period demonstrated that skills deteriorated over 3 months, then plateaued,[58] however smaller studies showed skill retention at 6 months.[42,56] This is consistent with previous studies, which have demonstrated BLS and ALS skill deterioration in health professionals (including students) between 3 and 12 months.[70–75] More large, high-quality, longitudinal studies are required to confirm an optimal time for refresher training.

Training with a popular song prevented deterioration of compression rate skills and was the only intervention that predictably improved retention of a specific target skill.[42,53] The combination of mental imagery coupled with motor stimuli and song familiarity likely enhances sensorimotor synchronisation, which improves accuracy of beat timing.[76] Only three studies used training strategies targeting specific CPR component skills,[32,42,53] making it difficult to identify which particular strategies within packaged interventions were effective. As part-whole teaching techniques improve performance of high-complexity, low-organisation tasks,[77]

including CPR, future research should validate single component interventions for skill retention, then combine multiple skill-specific teaching strategies.

Previous CPR training was associated with higher skills and survival-to-discharge rates, compared to no training, consistent with findings from hospital employees.[78] Repetition promotes psychomotor skill development through use-dependent plasticity, operant reinforcement, savings, and adaptation,[79] and distributed practice improves motor skill acquisition and retention.[80,81] These findings suggest that laypeople should be trained at least once (e.g. linked to driver licensing)[82] to improve psychomotor skills. Increasing the number of times laypeople undertake CPR training, using a distributed practice model,[80,81] may have additional benefit, but further studies are required to confirm this hypothesis.

Self-efficacy may be associated with improved skills, although evidence is weak. One large, high-quality ecological study found a small, statistically significant association,[35] however a small, moderate-quality study showed no association.[54] Previous studies in health professionals and students also have varied results.[83–85] This inconsistency is likely due to different study populations, study designs and training methods, and more large, high-quality studies could clarify findings.

Knowledge was not associated with skills, however quality of evidence was low and more studies are required. Previous systematic reviews have noted that skills deteriorate faster than knowledge,[13,71] suggesting minimal association. Contemporary teaching recommendations for complex psychomotor skills recognise that psychomotor tasks involve knowledge and skill sub-parts,[86] suggesting that skills will always deteriorate more rapidly than knowledge, creating the mismatch found in this and other reviews.[13,71] This mismatch suggests that refresher training should focus on the skills sub-components of the overall CPR psychomotor task, rather than knowledge.

There was broad agreement between simulated CPR performance indicators and real-life CPR outcomes. Any CPR training improved both survival-to-discharge rates and CPR performance on a mannequin. Survival-to-discharge rates improved with more recent training, broadly consistent with trends from mannequin studies. However, while skills on mannequins deteriorated over 3–6 months,[42,56,58] survival-to-discharge rates were only categorised relative to a 2-year cut-off point,[35] preventing a direct comparison. Although self-efficacy and knowledge were not

associated with psychomotor skills in mannequin studies, they were weakly associated with survival-to-discharge rates.[35] High-quality CPR is associated with improved survival.[20] Since mannequins objectively record CPR parameters, mannequin data should correlate with patient outcomes. However, the authors are not aware of any study that has directly compared mannequin-rated CPR performance with real-life patient outcomes. The data from this review provides very weak and indirect evidence suggesting a possible association, which requires further exploration, between these factors.

As ILCOR previously noted,[9] significant heterogeneity of training interventions, outcome measures and retention time periods exist, and this prevented a meta-analysis in this review. We recommend that a consistent set of outcomes, assessing the salient CPR skills emphasised by ILCOR, AHA and ERC guidelines,[20,87,88] be reported by all studies assessing CPR psychomotor skills (Table 6). We believe outcome measures should not be aggregated, as specific components performed well or poorly cannot be identified, preventing targeted interventions.

Strengths and limitations

The strengths of this review are that eight databases, rather than the three used by ILCOR,[9] were searched using a very sensitive strategy and that quantitative results were reported for each salient component of CPR. This review also attempted to minimise heterogeneity by limiting inclusion criteria to studies using the simplified, generally similar, post-2005 CPR guidelines.[5,20,87–93]

This review concurrently used objective mannequin-recorded outcomes and subjective human assessor judgments of observable behaviours, through checklist-based outcomes. There is only a weak (if any) correlation between mannequin and human judgments of psychomotor skills,[94] and assessor judgments may differ significantly from mannequin data,[95] however there is greater agreement for very good and very poor performances.[96] Assessors have been shown to de-emphasise certain process skills and performance sequence errors,[97] which may affect concordance with mannequin data. Due to the small number of data points using checklist-based data that required comparison with mannequin-based data for any given outcome measure and the absence of any validated techniques for adjusting the data prior to comparison, we considered subjective and objective data equivalent without adjustment.

Table 6 – Recommended sets of reportable outcomes for studies assessing CPR psychomotor skills, when skills are assessed by a mannequin and human assessor.

Reportable outcomes when CPR skills are assessed by a mannequin	Reportable outcomes when CPR skills are assessed by a human assessor
Average[a] compression rate (beats per minute)	Percentage of participants who performed CPR at the correct rate
Average[a] compression depth (millimetres)	Percentage of participants who performed CPR with the correct depth
Average[a] duration of interruptions to chest compressions (seconds)	Percentage of participants who minimised interruptions to chest compressions
Average[a] percentage of compressions performed with complete chest recoil (%)	Percentage of participants who achieved complete chest recoil
Average[a] percentage of compressions performed with correct hand placement (%)	Percentage of participants with the correct hand placement
Average[a] tidal volume (millilitres)[b]	Percentage of participants providing adequate breaths[b]
	Percentage of participants using the correct compression-ventilation ratio[b]

CPR = cardiopulmonary resuscitation.
[a] Mean (parametric data) or median (non-parametric data).
[b] Only applicable for CPR with ventilations.

As most studies assessing skill retention did not report statistical significance, the absence of a meta-analysis resulted in conclusions about skill retention being based on a minority of potential studies. Further, the narrative analysis of the data assumes that all training with the same delivery method is the same, however specific content and teaching styles may be significant confounding factors.

Some studies did not report which guideline participants were assessed against and assumptions were made about relevant guidelines and target skill ranges. As only three guideline time periods (2005, 2010, 2015) were used, these assumptions were likely accurate.

Few studies assessed number of times trained, self-efficacy, knowledge and willingness, limiting the confidence of conclusions.

Conclusions

CPR training, particularly instructor-led training with real-time or delayed feedback, improves psychomotor skills. Any previous training was associated with better skills, compared to no training, however only the use of a popular song promoted meaningful retention of a specifically targeted skill. In the highest-quality retention study, skills deteriorated within 3 months, then plateaued from 3 to 6 months. Self-efficacy may be weakly associated with skills, however knowledge was not associated with skills. No studies assessed the association between willingness and psychomotor skills. Overall, laypeople should attend at least one CPR training session, utilising combinations of validated skill-specific training strategies. Refresher training should focus on psychomotor skill performance and improving self-confidence, and should be undertaken every 3–6 months. More high-quality studies are required and all future studies assessing CPR psychomotor skills should adhere to a list of standardised reporting outcomes for consistency and comparability of results.

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Conflicts of interest

MR was a volunteer with St John Ambulance (Queensland) at the time of writing. He did not receive any monetary payments from St John Ambulance for his services, but has attended St John CPR and first aid courses for free. RF and LS do not have any conflicts of interest to declare.

Acknowledgments

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.2019.03.019.

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