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Review

Methods to teach schoolchildren how to perform and retain cardiopulmonary resuscitation (CPR) skills: A systematic review and meta-analysis

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Abstract

Background: Worldwide, bystander CPR rates are low; one effective way to increase these rates is to train schoolchildren; however, the most effective way to train them is currently unknown.

Methods: This systematic review and meta-analysis of randomized controlled trials (RCTs) and observational studies, evaluated whether CPR training for schoolchildren, using innovative teaching modalities (nonpractical, self, or peer-training) versus standard instructor-led training, resulted in higher quality CPR, self-confidence and short-term (≤3 months post-training) or long-term (>3 months post-training) retention of CPR skills.

Results: From 9793 citations, 96 studies published between 1975 and 2022 (44 RCTs and 52 before/after studies) were included. There were 43,754 students, average age of 11.5 ± 0.9 (range 5.9–17.6) and 49.2% male. Only 13 RCTs compared practical vs. nonpractical training (n = 5), self- vs. instructor-led training (n = 7) or peer- vs. instructor-led training (n = 5). The observed statistically significant differences in mean depth and rate of compressions between children with hands-on practical training and those without were not clinically relevant. Regardless of training modality, compression depth was consistently suboptimal. No differences were observed in CPR skills immediately or ≤ 3 months post-training, between children who were self- or peer-trained vs. instructor-led. Due to lack of data, we were unable to evaluate the impact of these novel training modalities on student self-confidence.

Conclusion: Although innovative training modalities are equally effective to instructor-led training when teaching schoolchildren CPR, compression depth was frequently suboptimal. Recommendations on standardized training and evaluation methods are necessary to understand the best ways to train children.

Keywords: Cardiopulmonary resuscitation, Automated external defibrillators, Training, Education, Schoolchildren

Introduction

Two of the most important factors for improving survival from sudden cardiac arrest (SCA), are cardiopulmonary resuscitation (CPR) and early defibrillation using an automated external defibrillator (AED).[1] SCA victims are almost twice as likely to survive, if they receive bystander CPR before Emergency Medical Services (EMS) arrival.[2] Worldwide, bystander CPR rates range between 6% and 70%.[3,4] One effective way to increase rates of bystander CPR is to train schoolchildren. Countries like Denmark, who have mandated CPR training in schools for decades, have shown a doubling in the rate of bystander CPR after five years, and a threefold improvement in survival following SCA over ten years.[5]

Recent scientific position statements from the International Liaison Committee on Resuscitation (ILCOR) and the European Resuscitation Council (ERC) recommend mandating CPR training for all schoolchildren, starting as early as possible. [6,7] Training children in CPR is effective at improving their skills and knowledge.[8] Beyond learning practical skills, children can also act as multipliers and transmit information to other family members.[9–11] Furthermore, learning CPR at a young age, may help children develop self-confidence in their ability to perform it.[12] This can help to facilitate the development

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of practical skills, as they become more capable of performing physical maneuvers and make them more likely to help in emergency situations as adults.[13,14]

As there are many barriers to implementing CPR training in schools,[14] investigating whether innovative training modalities (i.e. nonpractical, self- or peer-based training), are as effective as traditional, instructor-led methods, could provide guidance as to whether these strategies can be used to increase implementation of CPR training in schools.[12]

Previous reviews have narratively described the best method(s) for training children how to perform CPR[7,8,15–17] however, few have meta-analyzed this data, due to the diversity of the literature. The objective of this systematic review and meta-analysis was to examine if CPR training using innovative training modalities, resulted in higher quality CPR and/or retention of CPR skills compared to standard instructor-led training among schoolchildren.

Methods: We conducted this systematic review and meta-analysis in accordance with the Cochrane Handbook for Systematic Reviews of Interventions[18] and followed the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) statement for meta-analysis in health care interventions (PRISMA Checklist, Supplemental Appendix Table S1).[19] This review was registered on PROSPERO (International prospective register of systematic reviews) ID: CRD42019139005.

Eligibility criteria: We included all randomized controlled trials (RCTs) and observational studies, where schoolchildren (ages 4–18) were taught CPR. We included studies that trained both children and adults if we could separate their data. We excluded studies with children < age 4 and that had only adults (i.e. age > 18).

Search strategy and study selection: A search strategy was developed by an experienced information specialist (TK), in close collaboration with the lead author (KA). The following bibliographic databases were searched from inception to May 24, 2023: Medline (Ovid), the Cochrane Central Register of Controlled Trials (Ovid), CINAHL Plus with Full Text (EBSCO), Embase (Ovid), Web of Science, and ERIC (ProQuest). A combination of subject headings and text words were used for each of the main search concepts: CPR, education and schoolchildren, which were combined using Boolean operators. No year/language restrictions were placed on the searches. The initial Medline search strategy was peer reviewed by another information specialist using the PRESS checklist.[20] An example search strategy is available in Supplemental Appendix 1. The final search results were exported into EndNote, and duplicates were removed by the information specialist. Ongoing trials were identified using the World Health Organization International Clinical Trials Registry Platform and ClinicalTrials.gov. Experts were contacted to inquire about additional studies and unpublished data.

Eight reviewers working in pairs independently examined the titles, abstracts, and full-text articles retrieved by the search, in Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia). We included studies for full-text review based on agreement between two reviewers or when there was disagreement or uncertainty. Data from multiple reports of the same study were linked together and used to supplement information obtained from the primary report. We examined citations of included studies to identify additional studies not identified in the electronic search. A priori, we decided to include single arms of RCTs that did not directly compare our outcomes of interest in the observational analyses.

Data extraction: Eight reviewers working in pairs used standardized forms created in Covidence to independently perform data extraction, in duplicate, with discrepancies resolved through consensus. We abstracted data on both study characteristics and individual participants: study variables included author and year of publication, location, design, setting, number of participants, description of the intervention, reported outcomes, time points measured and length of training. Participant characteristics included average age, average height, average weight, proportion male sex and the proportion with any prior CPR training.

Endpoints and subgroup analyses

The primary analysis evaluated whether CPR training in schoolchildren (population) using practice (comparison) (defined as any training with a hands-on component) compared to CPR training using no practice (intervention), resulted in higher quality CPR (i.e. mean rate, mean depth), self-confidence and short ($\leq$3 months post-training) or long term retention (>3 months post-training) of CPR skills (outcomes). Secondary analyses compared differing modalities of CPR training to evaluate their impact on CPR skills, self-confidence and retention. Specifically, we compared traditional instructor-led CPR training to self-training and peer-training formats. Instructor-led training was defined as, any training led by instructors and involving any format (i.e. didactic lecture, teaching by video, etc). Additionally, instructors could be of any background (i.e. certified instructors, teachers, healthcare professionals, etc). We used the ILCOR definition of self-training: "as any form of digital (e.g. video, phone application [app] based, internet based, game based, virtual reality, augmented reality) education or training for BLS that can be completed without an instructor".[17] We defined peer-training as any format of education or training for CPR that was led by peers, but may also have included a teacher facilitator.

Planned subgroup analyses included evaluating the effect of age, sex and teaching modality on CPR performance. Sensitivity analyses were planned to evaluate potential sources of bias resulting from variability in studies.

Risk of bias and quality assessment: Risk of bias for RCTs was assessed using the Cochrane Collaboration Risk of Bias 1.0 tool, as "low risk," "high risk of bias," or "unclear" for the following measures: adequacy of sequence generation, adequacy of allocation concealment, adequacy of blinding for participants, study personnel and outcome assessors, completeness of outcome data for each primary and secondary outcome, selective outcome reporting, and other potential sources of bias (i.e. funding).[21] As all of the observational studies were interrupted time series, we used the Cochrane Effective Practice and Organization of Care (EPOC) tool[22] to assess risk of bias for the following domains: intervention independent of other changes, shape of the intervention effect pre-specified, intervention unlikely to affect data collection, knowledge of the allocated interventions adequately prevented during the study, incomplete outcome data adequately, selective outcome reporting and other risks of bias. Risk of bias tables were completed independently by the 8 reviewers in pairs and compared for consensus.

Statistical analysis: We used inverse-variance random-effects models to compare CPR outcomes (mean depth, mean rate, % correct depth, % correct rate and % correct hand position) and self-confidence, incorporating for heterogeneity between studies. Data were pooled at consistent time points across studies immediately post-training, ≤3 months' post-training (short term retention) and >3 months' post-training (long term retention) to measure differences between training modalities (i.e. practical training vs. nonpractical training).

Weighted mean differences with confidence intervals were calculated for continuous outcomes and we calculated the odds ratio (OR) for binary data, using Review Manager (RevMan) Version 5.3.5 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2014) software. For data that were unavailable numerically, we used approximations based on graphic output. For studies reporting only medians and interquartile ranges, means and standard deviations were estimated.[23] Point estimates with 95% confidence intervals are reported. We did not perform funnel plots due to the limited number of RCTs included in each analysis.

We evaluated studies for heterogeneity using the χ^2 test for homogeneity with an alpha = 0.10 and the I^2 statistic to quantify inconsistency.[24] I^2 values of 0%–40% were considered as not important, 30%–60% as moderate heterogeneity, and 75%–100% as considerable heterogeneity.[24]

For data from cohort studies and single arms of RCTs, we pooled proportions of CPR outcomes with binary data including, % correct depth, % correct rate and % correct hand position and % improved self-confidence. We pooled means of CPR outcomes with continuous data, including mean compression depth and mean compression rate. Similar to the analyses of RCTs, data were pooled at consistent time points across studies and between training modalities. Generated forest plots provide graphical representation of the results, without estimates, due to considerable heterogeneity, particularly with the proportional meta-analyses. We used the metaprop, metamean, and forest functions in R version 1.4.1106 (R Foundation for Statistical Computing, Vienna, Austria) to analyze the study data.

Results

Literature search and study selection

We identified 9793 records. After removing 1679 duplicates, 8114 records were screened by title and abstract, 296 full-text articles were assessed for eligibility and 96 studies were included (Fig. 1).

Study characteristics

A total of 43,754 students were included in the 96 studies (44 RCTs,[25–28,28–67] 30 uncontrolled before/after studies[68–97] and 22 controlled before/after studies[98–119], ranging from 30 to 6352 students per study. Studies spanned the globe, including Europe, North America, Asia, the Middle East and New Zealand and were published between 1975 and 2022. Supplemental Table S2 summarizes the included study characteristics.

Student characteristics

The average weighted age of the students was 11.5 ± 0.9 (range 5.9–17.6) with 49.2% male (Table 1). Only 4 studies included students with age < 10.[69,99,102,107] The average weighted height and weight of the students were 158.5 ± 8.1 cm and 46.3 ± 8.9 kg, respectively. Almost 30% of the students had prior CPR training before participation.

Risk of bias

Most RCTs had low risk of bias for 6 of 7 categories (Supplemental Fig. S1A) with description of the allocation sequence being unclear in more than 60% of the included studies. With the uncontrolled/controlled before and after studies, the majority had low risk of bias in 6/7 categories, with the exception of other bias (Supplemental Fig. S1B).

Outcomes and sensitivity analyses

Of the 44 RCTs, only 13 directly compared practical vs. nonpractical training (n = 5)[28,51,55,62,67], self-training vs. instructor-led training (n = 7)[28,32,34,51,55,61,67] or peer-training vs. instructor-led training (n = 5)[27,56,57,59,61]. We treated the remaining RCTs (n = 31)[29,54,56,21,22,25–27,31–46,48–50,59–62] as one arm cohorts and combined them with the uncontrolled before/after studies (n = 30)[68–97] and controlled before/after studies (n = 22)[98–119] to perform the same comparisons (Supplemental Appendix 2). Most studies did not report their data according to age or sex, so we could not assess the effect of these variables on CPR metrics. Where applicable, we examined the effect of different training modalities on outcomes.

Primary analysis – Instructor-led practical versus NonPractical training RCTs

For the primary analysis, two RCTs[28,67] compared the mean depth and mean rate of compressions performed by children immediately post-training, who received hands-on practical training versus those without any practical training. There was no statistically significant difference in the mean compression depth immediately post-training (Fig. 2), however, there was high heterogeneity, likely due to the differing ages of the children included in both studies (15 vs. 12.5 years) and proportion male (81% vs. 44%). In contrast, there was a significant, non-clinical difference in the mean compression rate immediately post-training (MD = −9.30 [−12.31, −6.29], I^2 = 0%, p < 0.00001, two trials, n = 164), favouring nonpractical training over practical training (Fig. 2). No studies reported self-confidence immediately post-training.

Short term retention (≤3 months) RCTs

The same two RCTs[28,67] compared the mean depth and mean rate of compressions performed by children ≤ 3 months post-training, who received hands-on practical training versus those without any practical training. There was a statistically significant difference in the mean compression depth (MD = 2.20 [0.92, 3.48], I^2 = 0%, p = 0.004, 2 trials, n = 158) favouring practical training (Fig. 3). Conversely, there was a significant, non-clinical difference in short-term mean compression rate (MD = −5.21 [−8.73, −1.70], I^2 = 0%, p = 0.004, 2 trials, n = 158) favouring nonpractical training (Fig. 3). Three different RCTs evaluated the impact of practical versus nonpractical training on the proportion of children with correct depth, correct rate and correct hand position of compressions, ≤3 months post training.[51,55,62] There was no observed difference in the percentage of students with correct depth or correct rate of compressions between students who completed practical vs. nonpractical training (Fig. 4), however, heterogeneity was also high. Neither age nor sex were reported consistently in these studies, so we could not determine if these had any effect. In contrast, there was a significant improvement in the percentage of students with correct hand position (OR = 1.67 [1.10, 2.54], I^2 = 0%, p = 0.02, 2 trials, n = 392) favoring practical training vs. nonpractical training (Fig. 4).

Only one RCT reported self-confidence[51]; in this study, students who received video-based instruction with hands-on practice and mobile-assisted feedback had the highest self-confidence scores

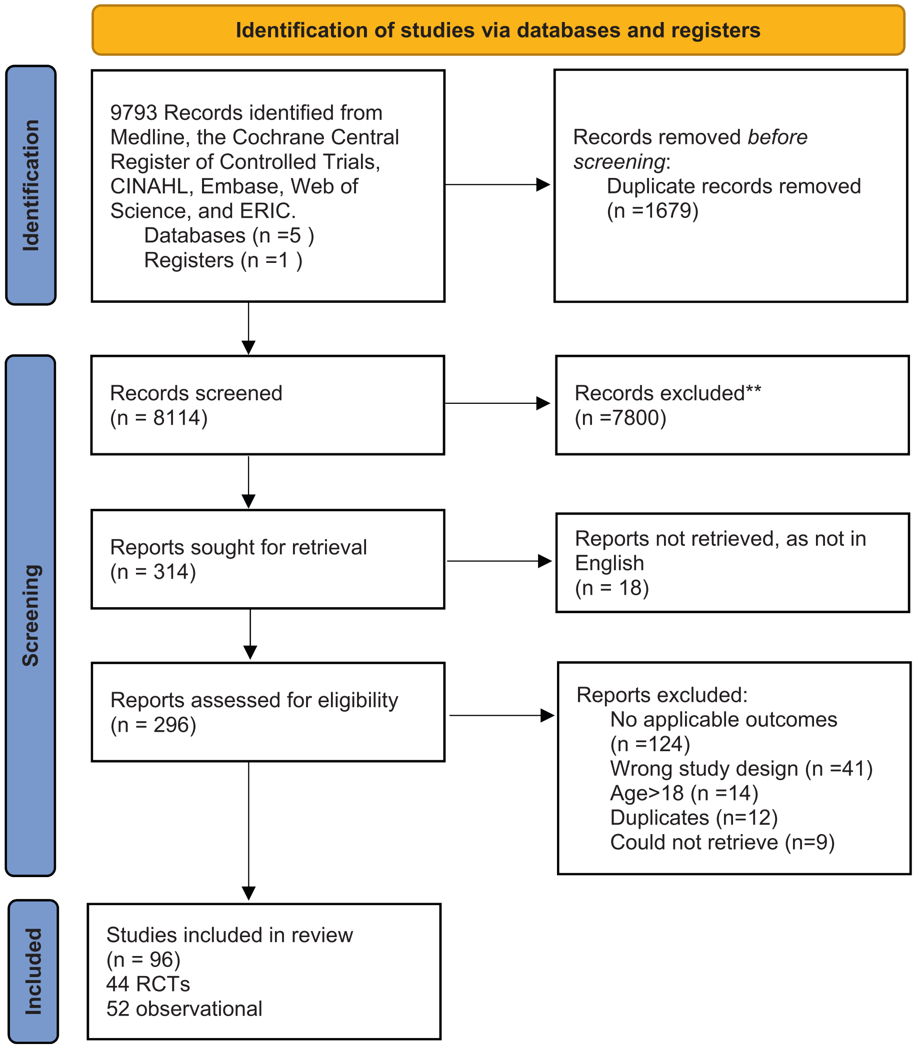

Fig. 1 – PRISMA Flow Diagram.

one-week post training, in comparison to students who received only one or neither of these interventions.

There were an insufficient number of RCTs that reported long-term retention outcomes, preventing meta-analysis.

Secondary analyses – Self-training versus instructor-led training RCTs

Five RCTs[31,32,34,61,67] compared CPR skills immediately post-training for children who were self-taught versus those who received traditional instructor-led training. Methods of self-learning included video instruction or using an online application with (n = 4)[32,34,61,67] or without hands-on practice (n = 2).[28,67] There were no observed differences in the mean depth, mean rate, percent correct depth, percent correct rate or percent correct hand position of compressions between children in either group post-training (Figs. 5 and 6). Heterogeneity was high in both mean compression depth and rate post-training. Removing studies based on age or proportion male did not affect the I^2 value for mean compression rate post-training; however, for mean compression depth post-training, removing the study[67] with the youngest participants completely eliminated the heterogeneity. Subgrouping the type of training by hands-on training vs. without, seemed to eliminate the heterogeneity in mean compression rate post-training (Supplemental Appendix 1: Supplemental Fig. S2).

Two RCTs[51,55] compared CPR skills ≤ 3 months post-training and two RCTs compared CPR skills > 3 months post-training[61,67], for children who were self-taught (video based training with hands-on practice (n = 2) and online app without hands on practice (n = 2)), versus those who received traditional instructor-led training. Similar findings were observed in both short term and long-term retention outcomes (Figs. 5 and 6, with the exception of correct hand position. There was a significantly higher proportion of children with correct hand position in those who were instructor-led trained in comparison to children who were self-trained (OR 0.63 [0.40, 0.99], I^2 = 3%, p = 0.05, 2 trials, n = 392), ≤ 3 months of initial training. Only one study reported self-confidence, preventing meta-analysis.

Peer-trained versus instructor-led trained – RCTs

Five RCTs compared CPR metrics immediately post-training in children who were trained by peers versus those who received traditional instructor-led training.[27,56–57,59,61] In all 5 studies, students were taught by peers, which included hands-on practice. No differ-

Table 1 – Student characteristics.

Author, Year	Number of Children Analyzed	Mean Age of Children	Mean Height of Children (cm)	Mean Weight of Children (kg)	Male Sex N (%)	Number of Children with any Prior CPR Training N (%)
Abelairas-Gomez 2014	721	12.5	156.3 ± 7.9	51.5 ± 10.9	361 (50.1)	NR
Abelairas-Gomez 2021	472	10.0 ± 2.0	NR	NR	NR	NR
Abelsson 2020	50	17.0 ± 1.0	NR	NR	20 (40.0)	NR
Akiteru 2022	88	9.1 ± 1.7	134.9 ± 12.2	34.8 ± 10.4	41 (46.6)	NR
Aloush 2018	121	NR	NR	NR	40 (33.3)	18 (14.9)
Andresen 2012	195	13.8	NR	NR	100 (51.3)	0 (0)
Barsom 2020	40	16.0	NR	NR	20 (50.0)	NR
Banfai 2018	118	5.9 ± 0.5	121.3 ± 1.0	21.1 ± 0.5	47 (39.8)	0 (0)
Banfai 2017	582	10.2 ± 2.0	146.9 ± 13.1	38.7 ± 9.9	265 (45.5)	75 (12.9)
Banfai 2019	524	9.7 ± 1.9	NR	NR	236 (45.0)	524 (100)
Beard 2015	87	11.1 ± 2.6	151.0 ± 16.7	44.4 ± 12.2	45 (51.7)	0 (0)
Beck 2015	937	13.9 ± 1.1	168.1 ± 9.6	55.4 ± 11.6	439 (46.9)	111 (12.6)
Berthelot 2013	82	10.6 ± 0.5	NR	NR	47 (57.3)	6 (7.4)
Beskind 2016	159	14.9 ± 0.9	NR	NR	146 (81.5)	33 (18.4)
Bohn 2012	280	NR	NR	NR	223 (51.5)	0 (0)
Borovnik Lesjak 2022	611	13 ± 1	NR	NR	53 (45.7)	NR
Brown 2018	795	15.0	NR	62.9	386 (48.5)	795 (100.0)
Chamdawala 2021	220	16.0 ± 0.5	170.5 ± 9.5	63 ± 13.5	123 (55.9)	47 (21.4)
Chang 2022	385	10.5 ± 0.5	NR	NR	180 (46.8)	96 (25)
Chan 2017	112	10.3	142	37.4	81 (72.3)	NR
Cons-Ferreiro 2022	160	10.7 ± 0.6	150.6 ± 11.7	46.2 ± 12.2	170 (55.2)	78 (23.5)
Contri 2016	36	17.3 ± 1.5	NR	NR	17 (47.2)	NR
Cuijpers 2016	144	14.4 ± 0.6	NR	NR	82 (56.9)	NR
Damvall 2022	982	NR	NR	NR	NR	NR
Desailly 2017	97	NR	NR	NR	NR	NR
Doucet 2019	165	NR	NR	NR	81 (43.8)	113 (71.9)
Dumcke 2021	365	13.7 ± 0.8	NR	NR	193 (52.9)	77 (21.1)
Fleischhackl 2009	162	13.8 ± 2.6	160.0 ± 16.3	61.8 ± 27.9	NR	0 (0)
Gabriel 2019	210	17.0 ± 1.5	NR	NR	126 (60.0)	0 (0)
Greer 2010	122	13.5	NR	NR	47 (38.5)	NR
Han 2021	62	17.0 ± 0.6	NR	NR	13 (20.9)	50 (80.6)
He 2018	360	11.6 ± 0.5	153.1 ± 6.7	44.6 ± 8.2	180 (50.0)	0 (0)
Hill 2009	85	11.1	148.5	40.8	37 (43.5)	85 (100.0)
Hori 2016	6352	14.3 ± 1.7	NR	NR	4966 (78.2)	1423 (22.4)
Isbye 2007	72	13.0	NR	NR	45 (62.5)	0 (0)
Iserbyt 2013	111	13.0 ± 0.8	NR	NR	NR	0 (0)
Iserbyt 2014	128	16.9 ± 0.7	NR	NR	25 (18.1)	NR
Iserbyt 2021	235	13.0 ± 1.0	NR	NR	72 (30.6)	0 (0)
Jones 2007	157	11.6 ± 0.3	149.2 ± 8.5	43.2 ± 11.8	74 (47.1)	NR
Kalluri 2018	267	NR	NR	NR	NR	47(17.6)
Kaweenuttayanon 2017	275	15.4 ± 1.6	163.0 ± 8.0	58.0 ± 13.6	118 (42.9)	16 (58.2)
Kelley 2006	33	13.6	NR	NR	17 (51.5)	8 (24.2)
Kesici 2021	130	14.0	NR	NR	NR	23 (14.7)
Kherbeche 2017	52	13.2	160	54.7	28 (53.8)	0 (0)
KimSe 2011	439	NR	NR	NR	271 (59.2)	NR
Kłosiewicz 2021	402	9.5 ± 2.5	142.0 ± 11.7	39.8 ± 16.4	202 (50.2)	0 (0)
Lanzas 2022	318	16.4 ± 0.5	NR	NR	140 (44.0)	246 (77.4)
Lester 1997	233	11.5	NR	NR	128 (54.9)	81 (34.8)
Li 2018	489	12.6 ± 1.1	NR	NR	547 (50.1)	170 (15.6)
Lorem 2008	102	11.9 ± 0.04	NR	NR	39 (38.2)	63 (61.8)
Lorem 2010	145	NR	NR	NR	NR	51 (35.2)
Martinez-Isasi 2021	62	11.9 ± 0.5	149.6 ± 7.0	45.0 ± 10.9	27 (43.5)	NR
Martinez-Isasi 2022	567	10.0 ± 2.0	NR	NR	295 (52.0)	NR
Martins 2022	102	11.72 ± 0.75	151.62 ± 3.59	53.27 ± 4.67	48 (47.1)	NR
Mathew 2020	617	13.4 ± 0.3	150.8 ± 3.8	39.5 ± 2.8	351 (56.9)	50 (8.1)
Meissner 2012	98	14.6 ± 1.4	170.8 ± 7.0	58.1 ± 0.1	57 (43.2)	44 (33.3)
Metelmann 2021	200	14.6	NR	NR	95 (48.2)	121 (60.5)
Mpotos 2017	265	15 ± 1.6	169.3 ± 2.0	56.1 ± 1.5	156 (58.4)	11 (4.2)
Napp 2020	808	14.9 ± 0.9	167.3 ± 9.3	55.9 ± 10.5	375 (46.1)	277 (36.5)

(continued on next page)

Table 1 (continued)

Author, Year	Number of Children Analyzed	Mean Age of Children	Mean Height of Children (cm)	Mean Weight of Children (kg)	Male Sex N (%)	Number of Children with any Prior CPR Training N (%)
Naqvi 2011	30	13.4 ± 1.7	144.2 ± 8.1	50.0 ± 11.8	11 (36.6)	NR
Nord 2016	1061	13.0	NR	NR	579 (47.0)	363 (29.5)
Nord 2017 #1	432	13.0	NR	NR	213 (49.3)	124 (28.7)
Nord 2017 #2	587	13.0	NR	NR	283 (48.2)	152 (25.9)
Oliveira 2022	104	13.9	156.2 ± 0.1	55.7 ± 13.8	38 (36.5)	0 (0)
Onan 2019	77	17.5	NR	NR	NR	NR
Otero-Agra 2019 #1	196	11.1 ± 1.5	148.9 ± 10.0	44.2 ± 10.5	71 (36)	0 (0)
Otero-Agra 2019 #2	489	13.5 ± 1.2	163.0 ± 8.9	56.8 ± 12.4	246 (50.3)	0 (0)
Oulego-Erroz 2011	59	13.5	NR	NR	NR	0 (0)
Paglino 2017	203	NR	NR	NR	NR	NR
Paglino 2019	622	16.8 ± 1.4	169.9 ± 9.4	61.6 ± 11.9	277 (44.5)	NR
Ramesh 2022	414	14.2 ± 0.5	158.5 ± 8.5	48.9 ± 10.9	227 (54.8)	NR
Reder 2006	779	NR	NR	NR	424 (54.4)	534 (68.6)
Sabihah 2020	36	16.0	NR	NR	NR	1 (2.8)
Santomauro 2018	320	16.4 ± 2.0	164.3 ± 8.1	65.2 ± 10.0	154 (48.1)	8 (2.5)
Schmitz 2015	201	15.1 ± 1.6	NR	NR	94 (46.8)	201 (100)
Schuffelen 2015	108	15.9 ± 0.8	NR	NR	55 (50.9)	NR
Semeraro 2017	50	16.0 ± 1.0	NR	NR	49 (75.0)	0 (0)
So 2020	128	13.5 ± 0.5	NR	NR	35 (27.3)	0 (0)
Suss-Havemann 2020	600	12.0 ± 1.0	160.5 ± 8.2	47.0 ± 8.7	286 (47.7)	42 (7.0)
Suwanpairoj 2020	313	10.1	NR	NR	NR	NR
Tanaka 2020	54	17.6 ± 0.6	167.2 ± 7.9	59.7 ± 9.1	40 (74.1)	28 (51.9)
Uhm 2010	71	11.6 ± 0.6	151.6 ± 6.5	44.5 ± 9.3	45 (63.4)	NR
Uzendu 2021	77	NR	NR	NR	NR	38 (49.4)
Vanderschmidt 1975	400	15.0	NR	NR	NR	NR
Vanderschmidt 1976	216	15.0	NR	NR	NR	216 (100.0)
VanRaemdonck 2014	165	15.5	NR	NR	165 (100.0)	0 (0)
Vetter 2016	412	15.9 ± 1.3	NR	NR	150 (36.4)	NR
Wang 2021	198	11.8 ± 0.5	152.8 ± 7.3	41.9 ± 8.7	97 (49.0)	64 (32.3)
Watanabe 2017	41	NR	NR	NR	NR	1 (2)
Weidenauer 2018	322	10.0	145.7	40.8	141 (43.8)	147 (45.6)
Wingen 2018	424	15.0 ± 0.6	NR	NR	207 (48.8)	177 (41.7)
Yeow 2021	118	16.0	NR	NR	68 (57.6)	1 (0.8)
Yeung 2017	81	12.5	NR	NR	36 (44.4)	NR
Younas 2006	59	14.5	NR	NR	NR	34 (57.6)
Zalewski 2016	235	NR	NR	NR	87 (37.0)	NR
Zeleke 2019	160	12.0	NR	NR	NR	160 (100.0)

ences were observed when comparing the proportion of children with percent correct depth, percent correct rate and percent correct hand position in compressions, immediately post-training in those who received peer-training versus those who received traditional instructor-led training (see Supplemental Appendix 1: Supplemental Fig. S3). No retention or self-confidence data were available for comparison from the RCTs.

Observational data

Due to the considerable heterogeneity of the cohort and single arm RCT data, we did not conduct formal meta-analyses of proportional or continuous CPR outcomes; however, we did generate forest plots to graphically summarize the data. (Supplemental Appendix 2).

Discussion

We performed a comprehensive systematic review and meta-analysis, evaluating the impact of innovative training modalities on the performance and retention of CPR skills in schoolchildren. We observed some statistically significant, but non-clinical differences in mean depth and mean rate of compressions, both immediately post-training and ≤3 months, between groups that were provided practical training and those without. No differences were observed when comparing CPR skills between children who were trained using traditional instructor-led methods versus those who were self or peer-trained. The exception to this was children who were trained by instructors had better short-term retention of correct hand position in comparison to those who did not receive any practical training or were peer or self-trained. Due to lack of data, we were unable to meta-analyze self-confidence measures.

ILCOR recently performed a systematic review of CPR and AED self-training using digital formats in both adults and children[17,120] and demonstrated comparable outcomes for most CPR skills immediately post-training and up to 1 year later.[120] Similar results were observed when comparing instructor-led training with hands-on practice to digital training without hands-on practice. They recommended that either method could be used to teach adults and high school children (>10 years of age) CPR knowledge and skills, as long as they incorporated hands-on practice and manikins with feedback

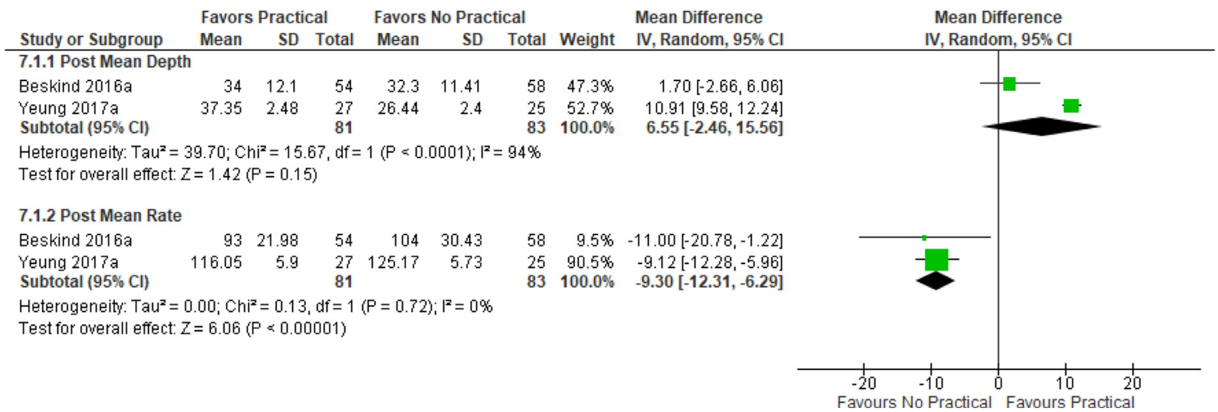

Fig. 2 – Randomized Controlled Trials - Mean depth and mean rate by Practical vs NonPractical training – post-training.

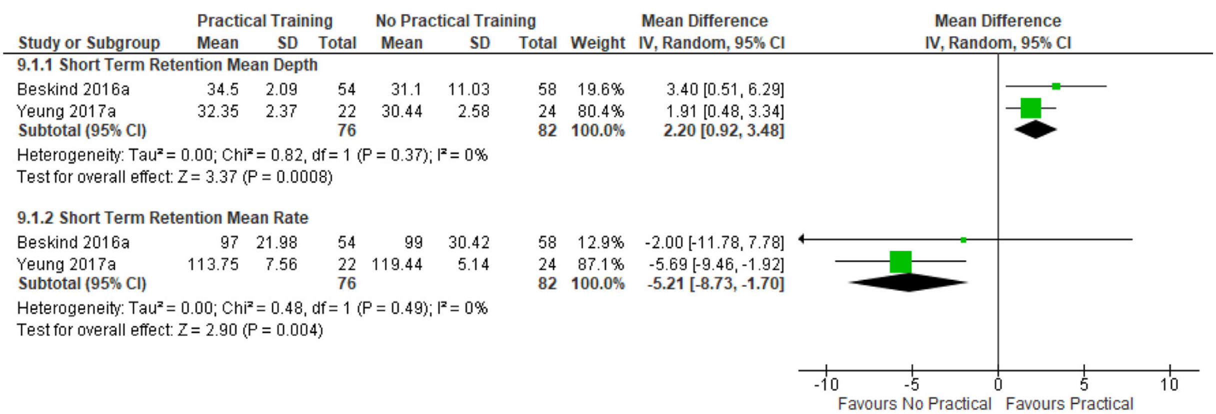

Fig. 3 – Randomized Controlled Trials - Mean depth and mean rate by Practical vs NonPractical training – short term retention.

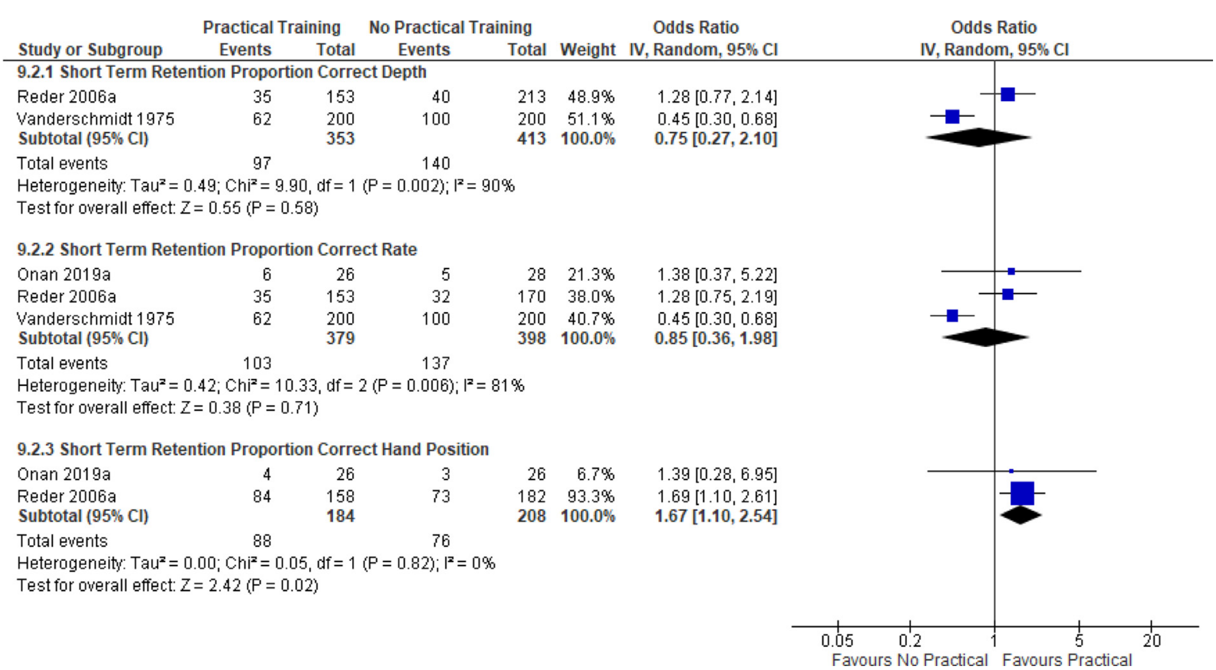

Fig. 4 – Randomized Controlled Trials - Proportion correct depth, rate, hand position Practical vs NonPractical training - short term Retention.

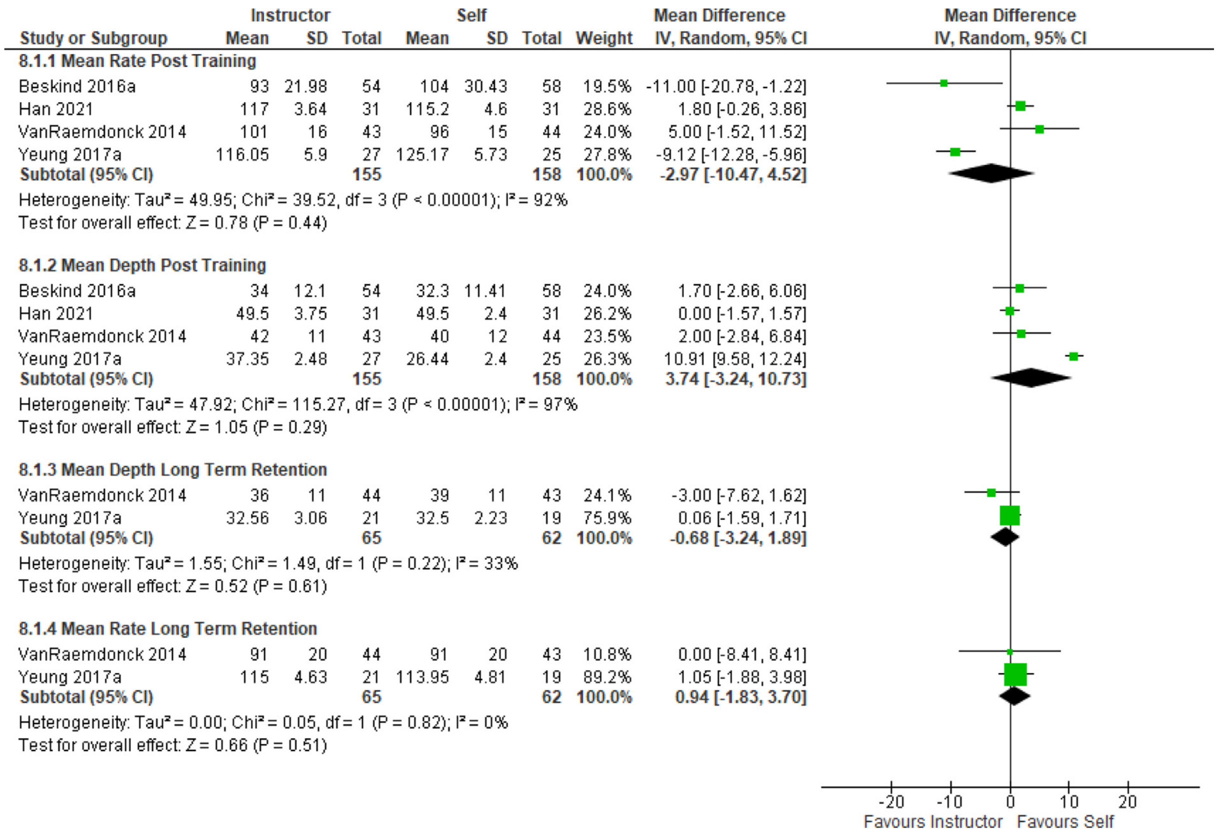

Fig. 5 – Randomized Controlled Trials - Mean depth, rate by self vs. instructor-led training – post-training and long term retention.

devices.[17] Since children are known to act as multipliers, sending students home with digital self-training kits, could be an effective and cost-savings method to train both students and adults, especially in under-resourced areas.[11]

In contrast to another recent systematic review,[15] we did not find a difference in CPR skills, between children who were self-taught using digital training methods compared to those who were instructor-led. Regardless of who trained them or training modality, children consistently did not compress deep enough, although compression rate remained on target. Lim et al. evaluated the effectiveness of technology-based CPR training on adolescents' CPR skills and knowledge and found that overall, instructor-led training improved CPR skills in adolescents (ages 12–18), while the use of self-directed learning produced less optimal skills.[15] Our results likely differ, because we included a broader age range and we defined "standard training" as instructor-led, in any format (i.e. in person, by video, etc), while their definition included only instructor-led training without a technology component. We also did not differentiate between self-training with or without hands-on practice, which may have led to the equivalency result.

Yet this raises an important point; current CPR training methods fail to teach children how to compress deeply enough. This is problematic, as optimal compression depth and rate are well correlated with survival from SCA.[121,122] The use of CPR feedback devices or manikins that are easier to compress, may help children to achieve guideline targets for compression depth. Very few of the studies that we reviewed, evaluated the effect of feedback devices on CPR performance. Chamdawala et al. compared the use of real-time visual feedback on high school students' CPR performance and retention, to those taught without it.[29] They found that post-training, students taught with real-time feedback had significantly higher compression scores, including depth, at both baseline and retention testing, compared to those without it. In both groups however, CPR depth remained well below recommended guidelines. More research is clearly needed to help determine how we can help children to achieve optimal CPR performance.

Additionally, the lack of standardization on how these training courses are taught and evaluated, poses a significant barrier to determining the most effective method to teach children. Due to the wide variation in teaching methods, type of instructor, ages of the children trained and forms of evaluation, most systematic reviews on this topic have been limited to narratively describing them, as authors were unable to meta-analyze the results.[120,123] This was clearly evident when we attempted to synthesize the results from the observational studies and one arm RCTs. Visual inspection of the forest plots showed that mean depth and mean rate of compressions were consistent across studies, yet those that reported the proportion with correct rate, depth or hand position during compressions were extremely variable, potentially due to observer bias. This highlights the pressing need for recommendations on how to objectively measure the impact of training schoolchildren how to perform CPR, which ideally should include knowledge, skills and some measurement of self-confidence or willingness to help.

A novel finding from our systematic review was that there were no differences in CPR skills between children who were trained by their peers versus those who were instructor-led. To the best of our knowl-

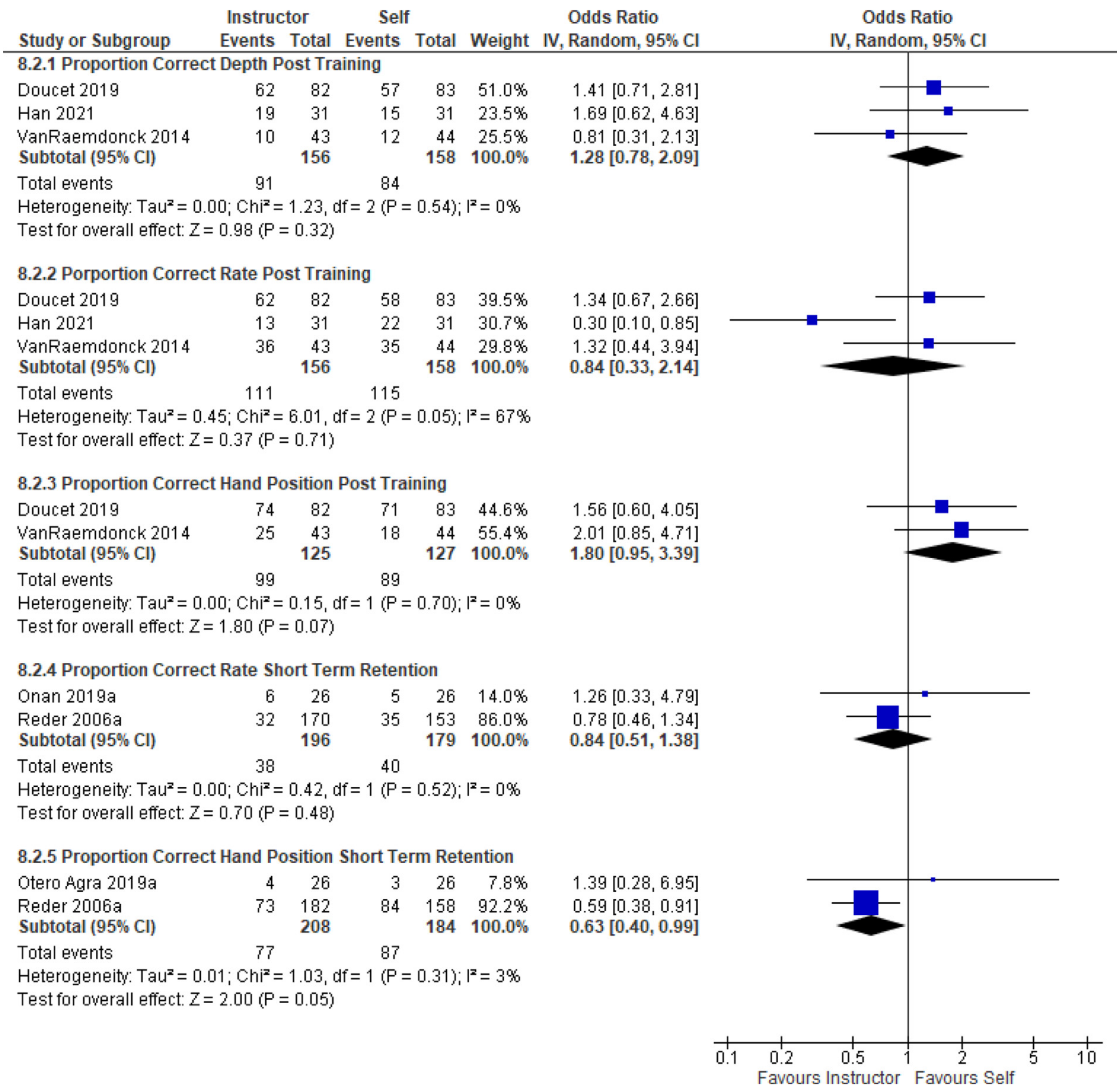

Fig. 6 – Randomized Controlled Trials - Proportion correct depth, rate, hand position by self vs. instructor-led training – post-training and short term retention.

edge, no other systematic review has evaluated this training modality in comparison to instructor-led courses. Numerous studies across health disciplines have found that peer trainers are equally effective as teachers, and can help boost students' self-confidence.[124,125] In the context of first aid and CPR training, a 2010 study by Carruth et al. used a train-the-trainer model for high school students to teach their peers first aid and risk reduction in rural communities.[126] Peer trainers reported improved self-confidence in teaching and that students were more comfortable asking questions, because they were peers and not "traditional" instructors. Using a peer trainer method may help facilitate implementation of CPR training programs in schools, as schoolteacher's willingness to teach, is often tied to their own perceived CPR proficiency level.[14] Additionally, it may be more cost effective and sustainable than hiring certified instructors, which are often cited as a major barrier for schools.[127]

Limitations

As other reviews have noted, there was a high degree of heterogeneity in the training programs and how outcomes were measured.[8,15,120] We attempted to explore the causes of this heterogeneity in the RCTs, by examining the effect of age, sex and training modality on CPR performance, but we were limited by the small number of studies reporting them. Additionally, roughly half of the studies included in the final meta-analysis had high risk of bias due to incomplete outcome data. Furthermore, many of the studies we found were observational and spanned a period of almost 50 years. Guidelines on optimal CPR performance and approaches to CPR training have changed substantially since then, thus insight from those studies may not align with present day practice. Lastly, we only included studies written in English.

Conclusion

Our review observed that innovative approaches, such as peer and self-based CPR training are equally effective as instructor-led methods when teaching schoolchildren. While there were statistically significant differences noted in mean depth and rate of compressions between children provided opportunities to engage in practical training and those without, these differences were not clinically relevant. Due to extensive heterogeneity between observational studies, we were unable to meta-analyze the impact of these novel training methods on student self-confidence. Best practice guidance on standardized training and evaluation methods is necessary, in order to consistently and effectively train schoolchildren in CPR.

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CRediT authorship contribution statement

Katherine S. Allan: Conceptualization, Methodology, Data curation, Writing – original draft, Investigation, Supervision, Writing – review & editing. **Bianca Mammarella:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Mika'il Visanji:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Erinda Moglica:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Negin Sadeghlo:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Emma O'Neil:** Data curation, Methodology, Writing – review & editing. **Tiffany T. Chan:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Teruko Kishibe:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Theresa Aves:** Conceptualization, Methodology, Data curation, Writing – original draft, Investigation, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2023.100439.

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