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## Training and education

# Do automated real-time feedback devices improve CPR quality? A systematic review of literature



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### Abstract

**Aim:** Automated real-time feedback devices have been considered a potential tool to improve the quality of cardiopulmonary resuscitation (CPR). Despite previous studies supporting the usefulness of such devices during training, others have conflicting conclusions regarding its efficacy during real-life CPR. This systematic review aimed to assess the effectiveness of automated real-time feedback devices for improving CPR performance during training, simulation and real-life resuscitation attempts in the adult and paediatric population.

**Methods:** Articles published between January 2010 and November 2020 were searched from BVS, Cinahl, Cochrane, PubMed and Web of Science, and reviewed according to a pre-defined set of eligibility criteria which included healthcare providers and randomised controlled trial studies. CPR quality was assessed based on guideline compliance for chest compression rate, chest compression depth and residual leaning.

**Results:** The selection strategy led to 19 eligible studies, 16 in training/simulation and three in real-life CPR. Feedback devices during training and/or simulation resulted in improved acquisition of skills and enhanced performance in 15 studies. One study resulted in no significant improvement. During real resuscitation attempts, three studies demonstrated significant improvement with the use of feedback devices in comparison with standard CPR (without feedback device).

**Conclusion:** The use of automated real-time feedback devices enhances skill acquisition and CPR performance during training of healthcare professionals. Further research is needed to better understand the role of feedback devices in clinical setting.

**Keywords:** CPR quality, CPR training, Automated real-time feedback

## Introduction

Cardiac arrest is a sudden cessation of cardiac activity and circulation due to an electrical malfunction of the heart. Despite advances and development related to cardiopulmonary resuscitation in the last 10

years, a high incidence of cardiac arrest is still observed with low rates of survival to hospital discharge. The occurrence and survival rates vary extensively around the world with an estimate of 400,000 cases per year in the US and 300,000 occurrences in Europe.<sup>1,2</sup> A current report by the American Heart Association (AHA) demonstrated that emergency medical services respond to more than 347,000 adults

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and more than 7000 children (less than 18 years of age) with out-of-hospital cardiac arrest (OHCA) each year, while in-hospital cardiac arrest (IHCA) is estimated to occur in 9.7 per 1000 adult cardiac arrests (approximately 292,000 events annually) and 2.7 paediatric events per 1000 hospitalizations.<sup>3</sup> Survival to hospital discharge rates range between 2% and 18%, making cardiac arrest a worldwide health challenge with high rates of morbidity, mortality and associated costs.<sup>4,5</sup>

Appropriate cardiopulmonary resuscitation (CPR) is imperative to the perfusion of vital organs during a cardiac arrest, improving the chances of achieving return of spontaneous circulation (ROSC), survival from hospital discharge and appropriate neurological outcome. Good quality CPR is achieved by reaching the following quality metrics of chest compressions, established by current resuscitation guidelines: chest compression rate between 100–120 compressions per minute; chest compression depth of 4 cm for infants, 5 cm for children and 5–6 cm for adults; and complete chest recoil after each compression.<sup>6–9</sup> Despite advances in training, technology, simulation and dispatch assisted CPR, it has been demonstrated that CPR quality for lay people, basic life support (BLS) and advanced life support (ALS) rescuers is normally of suboptimal quality in both real-life resuscitation attempts, or simulated training, negatively impacting on survival to hospital discharge and patient neurological outcomes.<sup>5,10,11</sup>

Automated real-time feedback devices have been considered a potential tool to improve acquisition and retention of CPR skills, consequently enhancing the quality of CPR. A number of feedback devices have been developed to assist during CPR training and real-life resuscitation. The devices range from metronome only, which produces regular, metrical beats based on a prearranged frequency, to audiovisual feedback, based on quality data collected and measured during performance. The data from corrective feedback are processed in real-time according to resuscitation guidelines and result in visual information or voice messages/tones, enabling the rescuers to adjust their technique if needed.<sup>12,13</sup> These devices have been extensively reviewed and comparison between the effectiveness of metronomes, audiovisual devices, smartphone apps, portable devices and automated external defibrillator with CPR feedback have been previously published.<sup>14,15</sup>

Although previous studies have supported the usefulness of such devices during training, others have conflicting conclusions with regards to its efficacy during real-life CPR.<sup>16–21</sup> This systematic review of the literature aims to assess the effectiveness of artificial real-time feedback devices for improving CPR performance during training, simulation and real-life resuscitation attempts in the adult and paediatric population.

## Methods

The methodology, review and report of this systematic literature review was conducted between June and November 2020, following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.<sup>22</sup> No ethical approval was required.

### Study design and protocol

A comprehensive search of the published and unpublished literature was performed with the use of five electronic databases in order to identify eligible studies: Biblioteca Virtual em Saúde (BVS),

Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane, PubMed, and Web of Science. An experienced research librarian was consulted for the development of the search strategy, and the PICOS (participants, intervention, comparison, outcomes, and study design) framework was used to identify potential studies that could fit our eligibility criteria.

P – healthcare providers

I – use of automated real-time feedback devices during CPR training, simulation and real-life CPR (adult and paediatric population)

C – no automated real-time feedback devices during CPR training, simulation and real-life CPR

O – quality of simulated or real-life CPR based on chest compression rate, chest compression depth and residual leaning compliant with guidelines from the European Resuscitation Council (ERC)<sup>6,7</sup> and AHA<sup>8,9</sup>

S – randomised controlled trials (RCTs).

### Eligibility criteria

Inclusion criteria: articles published between January 2010 and November 2020 in adult and paediatric CPR training/simulation, and adult and paediatric real-life CPR, that fit our PICOS strategy. This timeframe was selected considering the recommendations launched in the 2010 Resuscitation Guidelines suggesting that “feedback devices improve CPR skill acquisition and retention and should be considered during CPR training for laypeople and healthcare professionals.”<sup>23,24</sup>

Exclusion criteria: animal studies, observational studies, smart devices, abstracts without full-text articles and unpublished studies.

### Search strategy and appraisal

The databases were searched following the pre-defined search strategy combining Boolean operators ‘AND’ and ‘OR’ with medical search headings and subheadings (e.g. MeSH) when applicable, as seen in Appendix I in Supplementary material. There was no restriction on language. Titles and abstracts from each source were reviewed by three researchers independently (DA, LT, TP), and references of all relevant articles were searched for additional studies. Initial sources that met eligibility criteria via title and abstract were subsequently analysed by the researchers. We searched for all RCT studies assessing the use of feedback devices during CPR training and real-life CPR (adult and paediatric population) in which compression rate, compression depth and/or residual leaning were an explicit outcome.

In order to facilitate the record and analysis of eligible sources, each study found during initial search, was added in a group in EndNote Desktop X9, where duplicates were removed. Subsequently, all the studies (minus duplicates) were transferred to an Excel spreadsheet according to the following: title, author, year of publication, country, type of study, number of participants, population, intervention, outcomes and results. From this spreadsheet, analysis of the studies was performed.

### Risk of bias

The risk of bias assessment was performed according to the criteria proposed in the Cochrane method, indicating high (H), low (L) or “some concerns”/uncertain (U).<sup>25</sup> This tool enables the assessment of the methodological rigour of studies based on a list of bias domains

and equivalent risk-of-bias judgement for a specific outcome. The included studies were assessed for randomisation, allocation concealment, blinding of participants, blinding of assessor, incomplete outcome data, selective outcome reporting and others, such as deviation from intended interventions (Appendix II in Supplementary material).

### Data synthesis and statistical analysis

PRISMA statement<sup>20</sup> was followed to create a four-phase flow diagram. Analysis was performed and synthesized in a descriptive way due to the differences in design, sample size, population and eligibility criteria of the studies included. This heterogeneity hindered us from performing statistical analysis of the data.

## Results

After the initial search, a total of 921 studies were found. Six additional records were identified through relevant references. Following removal of 200 duplicates, 727 sources were screened via titles and abstracts, resulting in 241 possible relevant studies. Conflicts in selection were resolved by discussion between the review authors. Upon full text analysis, 19 studies met inclusion criteria and were included in our review including 15 randomised controlled trials<sup>16,18,20,21,26,27,29–31,33,34,36–39</sup> and four randomised cross-over trials (RCOTs).<sup>17,28,32,35</sup> The flow chart of the search and selection process is presented in Fig. 1.

Due to the nature of the intervention, all the included studies had some degree of performance bias as the participants and/or assessors could not be blinded, meaning that the studies were at risk of detection bias. However, as the data were objective/

quantitative (rate, depth, residual leaning) and measured by a computer in most of the studies, the bias attributable to lack of blinding was assessed to be low, as seen in Appendix II in Supplementary material.

Each study used automated real-time feedback devices during CPR training, simulation or real CPR to analyse the performance of healthcare professionals for paediatric or adult population.

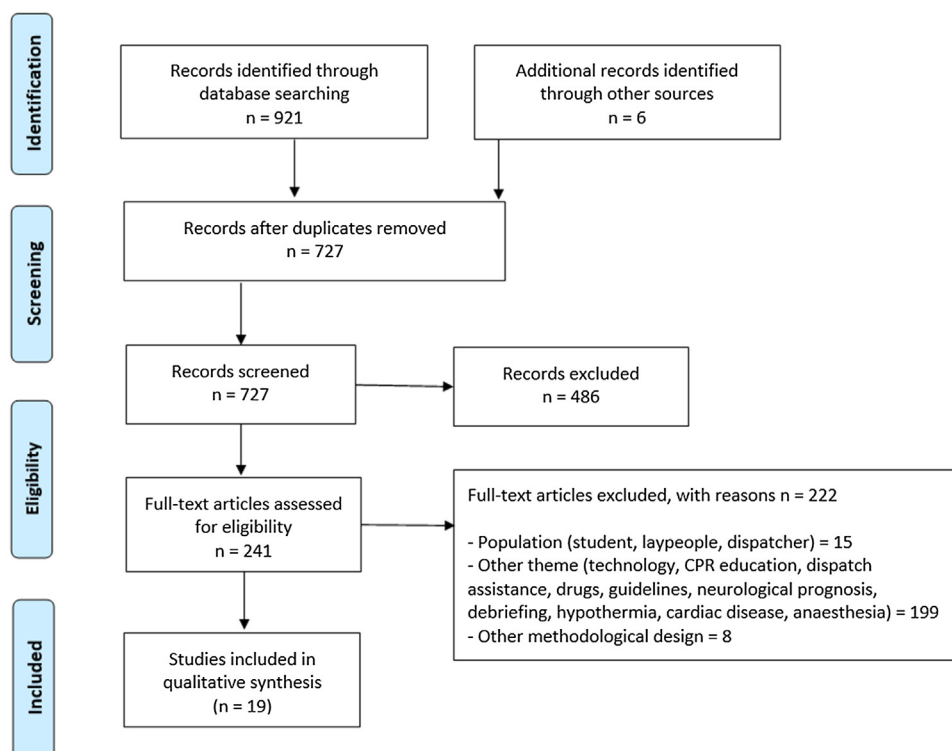
### Study characteristics

Due to the different elements included in this systematic review and the heterogeneity of the articles analysed, we classified the studies into three distinct groups: (a) the use of automated real-time feedback devices during paediatric CPR training, (b) the use of automated real-time feedback devices during adult CPR training and (c) the use of automated real-time feedback devices during real adult CPR performance. The researchers have not found any study about the use of feedback devices during real paediatric CPR performance. Cheng et al. (2015) and Lin et al. (2018) conducted their studies with 2 different populations and were, therefore, included twice in this review – in group “a” paediatric population and in group “b” adult population.

#### The use of automated real-time feedback devices during paediatric CPR training

Seven studies investigated the use of feedback devices during paediatric CPR training and/or simulated paediatric CPR as demonstrated in Table 1. Chest compression rate was analysed as outcome measure in 100% of the studies included in this group. Chest compression depth was observed in six studies (86%) and residual leaning in five studies (71%).

One study did not find significant improvement in overall chest compressions with the use of feedback device. Three studies



**Fig. 1 – PRISMA—Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement.**

**Table 1 – The use of automated real-time feedback devices during paediatric CPR training.**

Author	Country	Study type	Population	Intervention	Outcomes	Results
Austin et al., 2017	USA	RCT	70 healthcare providers (ALS or BLS)	Simulated paediatric CPR: feedback device (metro-nome) vs audiovisual vs standard CPR	Rate, depth and leaning *compliant with resuscitation guidelines	Not significant improvement with the use of audiovisual feedback device for any metric in comparison with standard CPR. Metro-nome increased rate but not significant improvement. Other metrics not significantly different.
Calvete et al., 2017	Spain	RCT	22 paediatricians	Simulated paediatric CPR: feedback device (visual) vs standard CPR	Rate, depth and leaning	Significant improvement in rate percentage in target (35.82% ( $\pm 37.54$ ) vs 67.09% ( $\pm 31.95$ ) $P = 0.024$ and depth percentage in target (48.86% ( $\pm 42.67$ ) vs 72.95% ( $\pm 20.25$ ) $P = 0.036$ . Leaning not significant
Cheng et al., 2015	Canada USA UK	RCT	324 CPR-certified health care professionals	Simulated paediatric CPR: feedback device (visual) vs standard CPR	Rate, depth and leaning *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate compliance by 40.1% (95% CI, 28.8%–51.3% ( $P < 0.001$ )) and depth compliance by 15.4% (95% CI, 6.6%–24.2% ( $P < 0.001$ )). Leaning was not significant.
Gregson et al., 2016	UK	RCOT	50 trained hospital staff	Simulated paediatric CPR: feedback device (visual) vs standard CPR	Rate *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate (108 (5) vs 120 (20)).
Lin et al., 2018	Canada	RCT	69 healthcare providers	Distributed training + feedback device (visual) vs standard CPR	Rate, depth and leaning *90% compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved (over 90% compliance) rate (%) mean (95% CI) 87 (78.3, 95.8) vs 62.3 (53.0, 71.5) $P < 0.001$ ; and leaning 91.5 (84.2, 98.8) vs 74.9 (67.2, 82.6) $P = 0.002$ . Depth improved but not significantly 96 (91.1, 100.0) vs 89.3 (84.0, 94.5) $P = 0.066$
Martin et al., 2013	UK	RCT	69 certified CPR providers	Simulated paediatric CPR: feedback device (audiovisual) vs standard CPR	Rate, depth and leaning *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate (92% vs 20%) $P < 0.001$ ; depth (99% vs 20%) $P < 0.001$ ; and leaning (99% vs 47%) $P < 0.001$ for the two-thumb technique. Feedback device compared with standard CPR significantly improved rate (87% vs 34%) $P < 0.001$ ; and depth (97% vs 21%) $P < 0.001$ ; leaning was not significantly different for the two-finger technique
Sutton et al., 2011	USA	RCT	69 BLS hospital-based providers.	Simulated paediatric CPR: standard CPR vs feedback device (audiovisual) only vs instructor combined with feedback device	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate compliance (96% vs 70%) $P = 0.02$ ; and depth compliance (100% vs 61%) $P = 0.01$ Feedback device combined with instructor compared with standard CPR significantly improved rate compliance (100% vs 48%) $P = 0.01$ ; and depth compliance (100% vs 78%) $P = 0.02$

demonstrated a significant improvement in each outcome measure when feedback device was used. Two studies found a significant improvement in rate and depth but not in residual leaning. And one study found a significant improvement in rate and residual leaning but not in depth.

#### *The use of automated real-time feedback devices during adult CPR training*

The use of automated real-time feedback devices during adult CPR training and/or simulated adult CPR was investigated in 11 studies (Table 2). Chest compression rate and chest compression depth were

analysed as outcome measures in 100% of the studies. Residual leaning was an outcome measure in four studies (36%).

Nine studies demonstrated a significant improvement in each outcome measure when feedback device was used. One study found a significant improvement in rate and depth but not in leaning, and one study demonstrated a significant improvement in depth but not in rate.

#### *The use of automated real-time feedback devices during real adult CPR performance*

Three studies investigated the use of feedback devices during real adult CPR performance as demonstrated in Table 3. Chest

**Table 2 – The use of automated real-time feedback devices during adult CPR training.**

Author	Country	Study type	Population	Intervention	Outcomes	Results
Aguilar et al., 2018	USA	RCT	98 healthcare providers	Simulated adult CPR: feedback device (audiovisual) vs standard CPR	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate (65% vs 37.9%) P = 0.008; and depth (17.9% vs 15%) P = 0.038
Buleón et al., 2016	France	RCOT	60 emergency rescuers	Simulated adult CPR: feedback device (visual) vs standard CPR	Rate, depth and leaning	Feedback device compared with standard CPR significantly improved rate (42% vs 21%) P < 0.001; depth (71% vs 57%) P = 0.03; and leaning (mean) (<1.5 kg vs >1.5 kg) P < 0.0001
Cheng et al., 2015	Canada USA UK	RCT	324 CPR-certified healthcare professionals	Simulated CPR: feedback device (visual) vs standard CPR	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate (95% CI, 28.8%–51.3%) P < 0.001; and depth (95% CI, 6.6%–24.2%) P < 0.001
Kornegay et al., 2018	USA	RCT	100 ACLS providers	Simulated adult CPR: feedback device (audiovisual) vs standard CPR	Rate, depth and leaning *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate (92.5% vs. 46.0%) P < 0.001; depth (86.5% vs 34%) P = 0.065; leaning was not significantly different (99% vs 99%) P = 0.3
Kurowski et al., 2015	Poland	RCT	167 paramedics	Simulated adult CPR: feedback device (visual + metronome "TrueCPR" vs standard	Rate and depth	Feedback device compared with standard CPR significantly improved rate (105.1 ( $\pm 4.7$ min <sup>-1</sup> ) vs 118.5 ( $\pm 14.2$ min <sup>-1</sup> ) P < 0.001; and depth (56.5 mm ( $\pm 4.7$ mm) vs 49.5 ( $\pm 8.8$ mm) P = 0.002
Lin et al., 2018	Canada	RCT	87 healthcare providers	CPR training: feedback device (visual) vs standard CPR training	Rate, depth and leaning *90% compliant with resuscitation guidelines	Feedback device compared with standard CPR training significantly improved (Mean (95% CI)) rate (92.7% (86.0, 99.4)) vs (78.0% (70.8, 85.1)) P = 0.003; depth (81.2% (72.3, 90.2)) vs (61.6% (51.6, 70.6)) P = 0.003; and leaning (97.4% (92.8, 100.0)) vs (86.5% (81.6, 91.4)) P = 0.002.
Tanaka et al., 2016	USA	RCOT	6 BLS – EMS; 6 ACLS - EMS	Simulated adult CPR: feedback device (audiovisual) with/without football shoulder pads vs standard CPR	Rate and depth	Feedback device compared with standard CPR training significantly improved depth (median [IQR], 13.8% [0.9–49.2] vs 69.6% [32.3–85.8] P = 0.0002 but do not significantly altered rate 17.1% [0–80.7] vs 59.2% [17.3–74.3] P = 0.50
Truszcwski et al., 2016	Poland	RCOT	140 nurses	Simulated adult CPR: feedback device (TrueCPR - visual + metronome) vs CPR-Ezy (audiovisual) vs standard CPR	Rate, depth and leaning	Feedback device (TrueCPR) compared with standard CPR significantly improved rate 110.2 ( $\pm 5.8$ ) vs 129.4 ( $\pm 22.4$ ) P < 0.001; depth 54.5 ( $\pm 9.5$ ) vs 44.6 ( $\pm 15.8$ ) P < 0.001; and leaning (%) 21.5 ( $\pm 9.7$ ) vs 31.6 ( $\pm 5.4$ ) P = 0.018 Feedback device (CPR-Ezy) compared with standard CPR significantly improved rate only 101.5 ( $\pm 4.8$ ) vs 129.4 ( $\pm 22.4$ ) P < 0.001
Wang et al., 2018	China	RCT	100 healthcare professionals	Simulated adult CPR: feedback device (audiovisual) vs standard CPR	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved rate 103.2 ( $\pm 21.0$ ) vs. 96.7 ( $\pm 25.8$ ) P = 0.026; and depth 5.54 ( $\pm 1.89$ ) vs 6.16 ( $\pm 1.88$ ) P = 0.016
Wu et al., 2019	China	RCT	191 physicians and nurses	Simulated adult CPR: feedback device (audiovisual) vs standard CPR	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved proportion of correct rate 88.3% (IQR, 72.2%–95.8%) vs 55.2% (IQR, 7.3%–89.9%) P < 0.00; and proportion of correct depth 83.8% (IQR, 68.7%–91.4%) vs 42.9% (IQR, 13.1%–66.5%) P < 0.001
Wutzler et al., 2015	Germany	RCT	63 healthcare professionals	Simulated adult CPR: feedback device (audiovisual) vs standard CPR	Rate and depth *compliant with resuscitation guidelines	Feedback device compared with standard CPR significantly improved percentage of compliant rate (82.7% $\pm$ 27.8) vs (70.5% $\pm$ 37.7) P = 0.039; and depth (54.8 $\pm$ 33.5%) vs (35.9 $\pm$ 30.6%) P = 0.003.

**Table 3 – The use of automated real-time feedback devices during real adult CPR performance.**

Author	Country	Study type	Population	Intervention	Outcomes	Results
Hostler et al., 2011	Canada USA	RCT	1586 OHCA episodes with attempted resuscitation by EMS	Real adult CPR: feedback device (audiovisual) vs standard CPR	Rate, depth and leaning	Feedback device compared with standard CPR significantly reduced rate (108 vs 103) $P < 0.001$ ; significantly increased depth (40 mm vs 38 mm) $P = 0.005$ ; and reduced the percentage of incomplete release (10% vs 15%) $P < 0.001$
Vahedian-Azimi et al., 2016	Iran	RCT	80 IHCA episodes	Real adult CPR: feedback device (audio) vs standard CPR	Rate and depth *compliant with resuscitation guidelines and based on a scale of 0 (lowest) to 10 (highest)	Feedback device compared with standard CPR significantly improved CPR quality (rate and depth compliant with guidelines) (Median [IQR]) (9 [8–10]) vs (5 [5–6]) $P < 0.0001$
Vahedian-Azimi et al., 2020	Iran USA	RCT	22 IHCA episodes	Real adult CPR: feedback device (audio) vs standard CPR	Rate and depth *compliant with resuscitation guidelines and based on a scale of 0 (lowest) to 10 (highest)	Feedback device compared with standard CPR significantly improved CPR quality (rate and depth compliant with guidelines) (mean ( $\pm$ SD)) 8.64 ( $\pm$ 0.7) vs 5.18 ( $\pm$ 0.6) $P = 0.0005$

compression rate and chest compression depth were analysed as outcome measures in every study (100%) and residual leaning in one study (33%). The outcome measures for the studies also included survival to hospital discharge and return of spontaneous circulation, which were not part of our outcomes therefore, not added to our analysis.

Each study demonstrated a significant difference in the outcomes measured when feedback devices were used.

## Discussion

The aim of this systematic review was to assess the effectiveness of using automated real-time feedback devices to improve CPR performance during simulation, training and real-life resuscitation in the adult and paediatric population. The studies analysed in this review used different types of feedback devices during CPR training and/or simulation and during real-life resuscitation attempts, for a range of professionals including BLS and ALS trained rescuers, nurses, doctors, ICU staff and emergency medical services.

It is established that effective chest compressions remain the cornerstone of successful cardiopulmonary resuscitation and are vital for patient survival to hospital discharge with good neurological recovery.<sup>3,5</sup> International guidelines reinforce the critical importance of the quality of manual chest compression metrics such as rate, depth and complete release of chest.<sup>3,6–9</sup> In an effort to enhance the quality of CPR performance and to improve acquisition and retention of CPR skills during training, several devices have been developed, including automated real-time feedback devices, that aim to inform rescuers about their CPR technique and/or guide them during a resuscitation attempt. The use of these devices during CPR training for laypeople and healthcare professionals are recommended by resuscitation guidelines to improve CPR skill acquisition and retention.<sup>40–42</sup>

CPR feedback technology ranges in complexity from a simple metronome to more complex devices able to offer information about performance, so that rescuers can make real time adjustments to their CPR technique. A metronome can produce regular, metrical beats based on a prearranged frequency. It can be set for a frequency

between 100–120 beats per minute, providing prompts to the rescuer to perform the appropriate rate of chest compressions in line with resuscitation guidelines. This type of device cannot assess the quality of the performance, which may impact the effectiveness of CPR.<sup>43</sup> An audiovisual feedback device, is capable of assessing performance in real-time, enabling the rescuers to adjust their technique if needed. These devices can be based on chest displacement and provide the rescuer with a visual feedback of their technique as well as a visual and audible representation of the correct range of compression depth, release of chest and compression rate (some may include duty cycle, hand position and ventilation feedback).<sup>13,18,31</sup>

An important aspect related to chest displacement and the accuracy of feedback devices with relation to compression depth particularly, is the surface where CPR is being delivered. If the patient is on a mattress, which is normally the case of in-hospital cardiac arrests, the compression depth may be overestimated by the feedback device, as the pressure applied to the patient's chest will cause the mattress to deform, dissipating the force through the patient's chest and the mattress under the patient.<sup>44–46</sup> This flaw could be addressed with the use of backboards under the patient when CPR is performed; using feedback devices with 2 accelerometers or sensors placed on the patient's chest and between the patient and the mattress so that the calculation of the exact compression depth is possible; deflecting the air mattress; or compressing the chest deeper than what is required on the floor.<sup>47–51</sup> These strategies can help rescuers to ensure adequate compression depth is achieved when CPR is performed on a mattress. Some studies in this systematic review have analysed CPR performance on a mattress<sup>21,30,34,39</sup> and the aspect of mattress deflection was acknowledged in most of them.<sup>21,34,39</sup>

With the great variety of automated real-time feedback devices available and the differences between their ability to provide feedback, results from their effectiveness for improving CPR performance during simulated training and real-life resuscitation can lead to dissimilar outcomes, as observed in many studies included in this systematic review.<sup>16–18,20,26,28,31</sup> Also, due to the complexity and heterogeneity of the study designs, sample sizes, methodological quality and outcome measures, the results can also vary extensively. As observed in this review, some studies demonstrated a significant improvement in chest compression performance for each metric

assessed during simulated CPR when automated real-time feedback devices were used irrespective of its design: metronome,<sup>17,34</sup> audio,<sup>21,39</sup> visual,<sup>17,27–29,32,34</sup> or audiovisual.<sup>18,30,31,36–38</sup> Contrastingly, other studies displayed significant changes in some metrics (e.g. rate and depth) but not in others (e.g. leaning) with the use of feedback devices.<sup>17,18,26,27,29,33,34</sup> And one study demonstrated no change in performance when comparing standard CPR with the use of feedback device.<sup>16</sup> (Cheng et al. (2015) and Lin et al. (2018) conducted their studies with two different populations and were, therefore, included twice in this review: in group “a” paediatric population and in group “b” adult population. We will call them 27a, 27b and 29a, 29b from this point going forward to differentiate between them). Despite the review process of a systematic review inevitably identifying studies that are diverse in their design, methodological quality, interventions used, population and outcome measures, it is important to note that this heterogeneity may have caused the substantial variation seen in the results.

Another important aspect observed in the studies explored in this review was related to how the outcome measures were reported, which may have impacted the differences seen in results. Data from 13 studies were presented using a percentage, which represented compliance with resuscitation guidelines.<sup>18,26,27a,27b,29a,29b–33,35,37,38</sup> All 13 studies had chest compression rate and chest compression depth as outcome measures and seven of those included residual leaning as well. Of the 13 studies presented using a percentage, 12 demonstrated a significant improvement in the percentage of compression depth compliant with resuscitation guidelines when a feedback device was used.<sup>18,26,27a,27b,29b,30–33,35,37,38</sup> 12 reported a significant improvement in the percentage of compression rate compliant with resuscitation guidelines when a feedback device was used.<sup>18,26,27a,27b,29a,29b–33,37,38</sup> And four studies demonstrated a significant improvement in the percentage of residual leaning compliant with resuscitation guidelines when a feedback device was used.<sup>18,29a,29b,32</sup> (Martin et al. (2013) concluded that residual leaning improved for the two-thumb technique but not for the two-finger technique during infant CPR). Reporting a percentage change from baseline, enables the researcher to present the results in relevant, accessible terms. However, this method can be considered statistically inefficient as it may not correct for imbalance between groups at baseline and it can create a non-normally distributed statistic from normally distributed data.<sup>52</sup> Another reporting method used in five studies analysed in this systematic review was presented using the values for each metric (i.e. 100–120 for rate, 50–60 mm for depth and <2.5 kg for residual leaning).<sup>17,20,28,34,36</sup> All of those studies included chest compression rate as an outcome measure, four included chest compression depth and two included residual leaning as outcome measure. All five studies reported an improvement in rate when automated real-time feedback device was used in comparison to standard CPR. Four reported an improvement in depth, however, in one of those studies,<sup>17</sup> this was just applicable with the use of a particular device (TrueCPR: visual + metronome) and not when CPR-Ezy (audiovisual) was used. And two studies demonstrated an improvement in residual leaning. Once more, Truszcwski et al. (2016) reported this result for TrueCPR only, not for CPR-Ezy. Lastly, two studies presented their results using a scale from 0 (lowest) to 10 (highest) and included compression rate and compression depth as their outcome measures.<sup>21,39</sup> In both

studies, the use of automated real-time feedback device improved performance for rate and depth in comparison with standard CPR.

Based on our review, the use of automated real-time feedback device in CPR training, simulation and real resuscitations attempts, resulted in improved acquisition of CPR skills and subsequent enhanced performance when compared to baseline or control groups in most of the studies. The outcome measures (i.e. rate, depth, leaning) significantly improved as a result of the use of feedback devices, irrespectively of the device used.<sup>17,18,20,21,27b,28,29b–32,34,36–39</sup> Conversely, other studies have demonstrated mixed effects, with results showing improvements in some of the outcome measures but not in others<sup>26,27a,29a,33,35</sup> or no improvement at all.<sup>16</sup> Although there was not a consistent improvement in CPR metrics across all studies, there is a significant body of evidence to support the use of automated real-time feedback devices (metronome, visual and/or audiovisual) to improve acquisition of CPR skills and enhance compliance of CPR performance with resuscitation guidelines. This conclusion is compatible with Kirkbright et al.<sup>53</sup> and Yeung et al.<sup>54</sup> who demonstrated in their systematic reviews, the benefits of using feedback devices to improve CPR skill acquisition, retention and enhance CPR performance.

Whilst it may be intuitive to assume that the use of automated real-time feedback devices will lead to improvements in cardiac arrest survival, it was not within the scope of this review to analyse patients' outcomes, therefore, further research such as the review conducted by Wang et al. (2020) is required to assess if the improvements in quality of CPR related to the use of feedback devices, translate into real life cardiac arrest outcomes. Investigating the relationship between the use of feedback devices and cardiac arrest patient outcomes, such as ROSC, short-term survival to hospital discharge and neurological outcome, Wang et al. (2020) analysed in their systematic review whether feedback devices can improve patient outcomes depending on the type of device used. The authors concluded that portable devices led to better outcomes when compared to AED-associated devices as they positively influenced the quality of CPR skills, positively impacting ROSC, neurological outcome and better quality of life post cardiac arrest.<sup>55</sup>

Nonetheless, because automated real-time feedback devices appear to enhance CPR quality during training and simulated management of cardiac arrest, the 2015 and 2020 American Heart Association resuscitation guidelines and European Resuscitation Council guidelines, recommend the use of feedback device as an adjunct to CPR training.<sup>40–42</sup> This recommendation is set alongside other strategies including deliberate practice, booster training sessions, spaced learning, or in-situ training, to enhance acquisition, retention and performance of CPR skills.

## Limitations

Our study has some limitations. Firstly, the majority of the studies included in this review used manikins in a simulated, controlled environment, which makes it difficult to replicate the results to a real-life cardiopulmonary resuscitation. Secondly, the studies selected prioritised RCTs and RCOTs. Therefore, relevant conclusions resulting from observational or other designs were not included in the analysis. Thirdly, the heterogeneity of feedback devices used in the studies, which provided different guidance to rescuers (metronome, visual, audio-prompts, corrective audiovisual) could have

impacted the results as variance in performance could be resulted from the type of feedback received.

## Conclusions

This review provides good evidence supporting the use of automated real-time feedback devices during CPR training and/or simulation in both adult and paediatric population as a strategy to improve CPR skill acquisition retention and improve performance in a simulated context. The evidence may also suggest that the use of feedback devices in clinical practice, as part of an overall strategy to improve the quality of CPR, could likewise be beneficial. However, considering some conflicting evidence in the results of the studies, further research is required to assess if the improvements in quality of CPR related to the use of automated real-time feedback devices translate into real life cardiac arrest outcomes.

## Conflict of interest

None.

## CRedit authorship contribution statement

DA, LT, TP, HP and ST have made substantial contributions to the conception, design of the study and final approval of the version to be submitted and have agreed to the Journal's submission policies.

DA, LT and TP have considerably contributed to the acquisition, analysis and interpretation of data.

DA, LT, TP, HP and ST have drafted the article and revised it critically for important intellectual content.

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## 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.resplu.2021.100108>.

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