CAN REAL-TIME FEEDBACK IMPROVE THE SIMULATED INFANT CARDIOPULMONARY RESUSCITATION PERFORMANCE OF BASIC LIFE SUPPORT AND LAY RESCUERS?

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ABSTRACT

Background: Performing high-quality chest compressions during CPR requires achieving of a target depth, release force, rate and duty cycle.

Objective: This study evaluates whether 'real time' feedback could improve infant CPR performance in Basic Life Support-trained (BLS) and Lay rescuers. It also investigates whether delivering rescue breaths hinders performing high-quality chest compressions. Thirdly, this study reports raw data from the two methods used to calculate duty cycle performance.

Methodology: BLS (n = 28) and Lay (n = 38) rescuers were randomly allocated to respective 'feedback' or 'no-feedback' groups, to perform two-thumb chest-compressions on an instrumented infant manikin. Chest compression performance was then investigated across 3 compression algorithms (compression only; 5 rescue breaths then compression only; 5 rescue breaths then 15:2 compressions). Two different routes to calculate duty cycle were also investigated, due to conflicting instruction in the literature.

Results: No-feedback BLS and Lay groups demonstrated <3% compliance against each performance target. The Feedback rescuers produced 20-fold and 10-fold increases in BLS and Lay cohorts respectively, achieving all targets concurrently in >60% and >25% of all chest compressions, across all 3 algorithms. Performing rescue breaths did not impede chest compression quality.

Conclusions: A feedback system has great potential to improve infant CPR performance, especially in cohorts that have an underlying understanding of the technique. The addition of rescue breaths – a potential distraction, did not negatively influence chest compression quality.

Duty cycle performance depended on the calculation method, meaning there is an urgent requirement to agree a single measure.

INTRODUCTION

Cardiopulmonary resuscitation (CPR) is often performed poorly by even well-trained rescuers [1-3]. A recent study of Advanced Paediatric Life Support (APLS)-certified instructors reported <1% conformity of simulated compressions, when compared concurrently to four infant-CPR performance metrics [4]. These metrics are:

- Compression depth: calculated as the antero-posterior chest deflection. Target = compression to one-third the external chest depth.
- Release force: cessation of chest compression to enable cardiac refill, defined as the minimum force associated with a clinically-significant increase in intra-thoracic pressure. Target = chest release force has previously been defined as <2.5kg.
- Compression rate: to achieve the optimal flow of oxygenated blood. Target = 100-120 min^{-1}
- Duty cycle: to achieve enough recoil (i.e. upwards movement of the chest wall) per compression cycle, to enable cardiac refill. Target = 30–50% recoil per cycle.

APLS rescuers were able to concurrently achieve the above 4 targets in 80% of all chest compression when provided with real-time ‘feedback’ [4]. Short-comings remained, however, including excessive rates, prolonged duty cycles and over- and under-compression [4-7]. Whilst delivery of technically optimal CPR can only produce approximately 50% cerebral and 15–25% coronary baseline blood flow levels [8-10], this correlates with a greater proportion of patients discharged without physiological or neurological deficits [11-13].

Ninety-three percent of infant cardiac arrests occur out-of-hospital [14]; hence, the non-expert population are those most likely to be faced with performing effective CPR. In the United Kingdom some of this community opt for Basic Life Support (BLS) training, providing a foundation of skills to achieve enhanced CPR performance. The International Liaison Committee on Resuscitation (ILCOR) specifies that chest compressions are most effective when interspersed with ventilations, or 'rescue breaths'; however, to maximise BLS performance, their training focusses exclusively on delivering accurate chest compressions, omitting breaths.

The duty cycle is not a measure used in the clinical performance of chest compression; however, it is frequently cited in CPR studies that emerge from the scientific community [4 5 15]. Two different equations exist for calculating this parameter [16]: (i) the 'area duty cycle' (ADC), defined as the ratio between the area under the chest compression curve and the area of one rectangle out-lining the compression-decompression curve; and, (ii) the 'effective compression time' (ECT), defined as the time from the beginning to the end of the compression divided by the total period for that compression-decompression event.

This study now aims to evaluate whether real-time feedback can be used to leverage improvement in CPR performance across BLS and Lay cohorts. It will also evaluate whether rescuers are distracted by delivering rescue breaths, negatively influencing compression quality. Thirdly, this study will compute duty cycle data via the two published techniques, to determine the extent of variation between these two methods.

METHODS

CPR compressions were performed on a modified infant training manikin (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway), representing a three-month-old, 5kg male infant (maximum chest compression-depth - 53mm) [5]. A novel accelerometer-based system was developed "in-house" to record chest compression performance and to provide real-time feedback. This system comprised two pads, each with an embedded accelerometer. One accelerometer was held against the manikin's back, whilst the other was positioned on the chest wall. Data from both accelerometers was then double-integrated, to calculate displacement. Displacement data from the rear accelerometer was then subtracted from the forward-positioned data, to isolate the relative chest movement. This corrected data was then plotted against time, producing a waveform that enabled quantification of compression parameters:

- **Chest compression depth**, by determining the maximum displacement relative to the reference datum.
- **Chest compression rate**, by determining the number of chest compressions recorded within a given time interval.
- **Compression duty cycle**, by determining the ratio of time taken to reach maximum compression, versus the time taken for the chest to return to the datum.
- **Chest release force**, by calculating the product of the minimum compression depth and the compressive resistance of the manikin chest ($2.1 Nmm^{-1}$) [18].

The manikin was temporarily fitted with an infra-red displacement sensor, to enable validation against an independent measurement of chest wall compression. The high correlation coefficients between the two plots, across 3 repeats, validated the accelerometer-based method (Supplementary Figure 1) [17].

These parameters were also immediately presented to the 'Feedback' rescuer cohorts, providing scope for them to improve their chest compression performance, enabled via in-house designed software (Figure 1). This describes:

- **Chest compression depth and release** was displayed as a trace. The green region described positive performance (i.e. one-third of the external chest AP diameter and complete decompression), the red region described over-compression and the white, under-compression.

- **Compression rate** was described by a flashing green indicator and a supplementary audible metronome.

- **Duty cycle** was not represented in the software; however, this was calculated retrospectively using both the ADC and ECT.

- **Number of breaths** was captured via a flow sensor, with its output integrated into the feedback software.

BLS-trained rescuers (n = 28) were recruited from a cohort of university healthcare students, whilst Lay rescuers (n = 38) were recruited from the general student population. The cohorts were asked to draw lots to achieve a random division between no-feedback (BLS- or Lay-) or feedback (BLS+ or Lay+) groups. All groups were tasked with performing two thumb (TT) CPR across 3 algorithms:

- **Chest-compressions only**, as taught in BLS. The 2015 ILCOR guidelines recommend this if rescuers are unwilling or unable to deliver rescue breaths. This technique is considered better than performing no CPR.

- **5 rescue breaths and then compression only**, were investigated to represent non-specialist training for those who wish to learn paediatric resuscitation [13].

- **5 rescue breaths then 15:2 compressions/breaths**, represents the current recommended ILCOR 2015 guidelines [13].

All rescuers performed all algorithms for 60s, in a randomized order and allowing for full recovery. BLS+ and Lay+ rescuers were given a 15s explanation of the feedback system. Compression performance data was then compared between the group that did, and did not, receive feedback. Overall compression quality was calculated as the proportion of compressions that achieved all four primary quality targets. Secondary outcome measures, such as insufficient or excessive rates, prolonged duty cycles, over and under compression depth and incomplete release forces, were also calculated. The unassisted and assisted groups' mean differences are reported with 95% confidence intervals. After testing for data normality, results were analysed by an independent Student's t-test by SPSS statistical software (SPSS 16.0, SPSS Inc., IL, USA). Statistical significance was considered at $p<0.05$ for all tests and all p-values were two-sided. A study sample size of 14 participants per group adequately detects a mean difference, 0.7 times the standard deviation of the differences, assuming data normality, providing a two-sided significance level of <0.05 and >80% power (calculated with G*Power 3.0.10 [19]).

RESULTS

A quantitative description of all data are presented in Tables 1 & 2, providing a statistical analyses of chest compression performance. Highlights of these data are described below.

Compression depth (Figures 2(a) &3(a)).

Continuous compressions only

BLS+ (85%) and Lay+ (88%) both represented statistically superior improvement ($p<0.001$) than the no-feedback performance (38% and 42% respectively). Approximately one-third of no-feedback compressions were too-shallow in both groups. Feedback led to reducing under-compression in both groups, whilst over-compression was almost eradicated (2% in both cohorts).

Five rescue breaths and then compression only

Forty-three percent of BLS- and 39% Lay- compressions achieved the target. BLS+ was near-double (81%) compliance, whilst Lay+ achieved 91%. The risk of over- and under-compressions also reduced in both cohorts.

Five rescue breaths and then 15:2 compression and breaths

This most complex technique was successfully performed in 45% of the BLS- compressions, with Lay- rescuers less accurate (37%). Both groups over-compressed during approximately one-quarter of all compressions. Eighty percent of BLS+ compressions and 85% of Lay+ were compliant with the target. Less than 5% were over-compressions, whilst under-compressions accounted for 16% of BLS+ and 10% of Lay+ compressions.

Release force (Figures2(b) &3(b))

Continuous compressions

Forty-five percent of all BLS- compressions achieved full release, versus 20% for Lay-. These performances were significantly better with feedback, with 90% of BLS+ and 75% of Lay+ compressions achieving the target.

Five rescue breaths and then compression only

Greater compliance of chest release forces was reported in the no-feedback groups (BLS-: 56%; Lay-: 32%), versus the equivalent compression-only performance. Feedback again achieved nearly 90% and 73% compliance in the BLS+ and Lay+ cohorts, respectively.

Five rescue breaths and then 15:2 compression and breaths

Nearly 60% of BLS- and 30% of Lay- compressions achieved the target release force. The feedback groups improved to 78% and 81%, respectively.

Compression rate (Figures 2(c) & 3(c))

Continuous compressions

BLS- participants achieved approximately 10% compliance, with two-thirds of compressions too-fast. Lay- rescuers were marginally better at performing successful compressions. BLS+ achieved 80% compliance with only 5% being too-fast, whilst 75% of Lay+ compressions achieved the desired rate.

Five rescue breaths and then compression only

Only 10% of BLS- and 13% Lay- compressions achieved the target rate, with most being too fast (BLS-: 64%; Lay-: 47%). The BLS+ group delivered 80% at the correct rate, with only 3% being too fast, whilst the Lay+ group achieved a similarly good performance (77%).

Five rescue breaths and then 15:2 compression and breaths

BLS- rescuers delivered 13% of compressions at the correct rate, versus 12% by Lay-. Feedback achieved very significant improvements, with the BLS+ group achieving 77% compliance and Lay+ 81%.

Compression duty cycle (Figures 2(d, e),3(d, e) & 4)

Duty cycle performance was calculated using the ADC and ECT, with both measures derived from the same dataset (Figure 4). ECT is found to provide a more positive measure of duty cycle performance, consistently scoring higher than ADC.

Continuous compressions

The BLS- and Lay- groups both achieved 16% success when the duty cycle was calculated using ADC. Feedback enabled BLS+ rescuers to achieve 87% compliance and Lay+ 37%. Calculating the ECT, BLS- achieved 38% and Lay- 42%, improving to 85% and 82% respectively.

Five rescue breaths and then compression only

A small proportion of BLS- compressions achieved the correct ADC duty cycle (16%) and even fewer Lay- (13%). A very significant difference is noted when considering the BLS+ group (85%), though again only a relatively modest improvement is evident in the Lay+ group (35%). By comparison, BLS- achieves 42% ECT compliance and 33% for Lay-. Feedback achieved 86% and 83% respectively.

Five rescue breaths and then 15:2 compression and breaths

Eighteen percent of ADC BLS-compressions achieved compliance in this more complex sequence, with the equivalent Lay- percentage slightly greater (22%). Whilst the Lay+ improvement with feedback doubles quality (41%), a four-fold increase is evident with BLS+ compressions (80%). BLS- (ECT) achieves 32% compliance and Lay- (ECT) 38%, increasing to 84% (BLS+) and 77% (Lay+) with feedback.

Overall Chest Compression Quality (Figure 4 & 5)

Feedback benefitted the overall compression quality across both cohorts and all CPR methods. It was noted that the BLS performance improved significantly across all algorithms, with ECT duty cycle measures consistently scoring highest quality. Feedback achieves approximately 20-times better compliance within the BLS cohort.

The Lay- group demonstrated similar performance to the equivalent BLS group, with overall compliance across the 3 algorithms consistently <3% (ADC) or <6% (ECT). Whilst feedback only achieves an approximately 30% increase in performance with the ADC calculation, ECT calculations record a further two-fold improvement (i.e. to 60% compliance), across each compression algorithm.

CPR Quality Measures	Continuous chest compressions only				5 Initial rescue breaths and CC only				5 Initial rescue breaths and 15:2			
	No Feedback group	Feedback group	Mean diff.	P-value	No Feedback group	Feedback group	Mean diff	P-value	No Feedback group	Feedback group	Mean diff	P-value
Chest Compression Depths												
Mean compression depth	40±4.7	41±1.2	-1	0.4	40.4±4.3	40±1.5	0.4	0.32	40±3.8	40.6±1.4	0.6	0.67
Median compression depth	42.4 [37, 44]	40.8 [40, 42]		0.36	41.2 [38, 43]	40 [40, 41]		0.37	40.5 [39, 44]	40 [39, 42]		0.68
Compression depth quality index	38.1 [10, 60]	85.4 [78, 90]		**<0.0001**	43.4 [29, 65]	81.4 [76, 88]		**<0.0001**	45.1 [35, 71]	80.1 [78, 85]		**<0.0001**
Under-compression	38.2	12.8		**<0.0001**	36	17.2		**<0.0001**	30.9	16.3		**<0.0001**
Over-compression	23.7	1.8		**<0.0001**	20.6	1.4		**<0.0001**	24	3.6		**<0.01**
Chest Release Forces												
Mean release force	2.2±0.8	1.3±0.7	1.1	**<0.001**	2.1±0.9	1.4±0.7	0.7	**<0.01**	2±0.9	1.45±0.7	0.55	**<0.05**
Median release force	2.07 [1.7, 2.8]	1.0 [0.9, 2]		**<0.01**	2.5 [1.5, 2.7]	1.3 [1, 2]		**<0.001**	2.1 [1.7, 2.5]	1.4 [1.2, 2.2]		**<0.05**
Release force quality index	45.4 [0.9, 2]	89.6 [80, 97]		**<0.001**	56.1 [43, 91]	87.1 [78, 96]		**<0.001**	58.1 [56, 84]	77.7 [72, 88]		**<0.001**
Complete Release force index	4.2	24		**<0.0001**	7.9	29		**<0.0001**	9.8	18.9		**<0.0001**
Chest Compression Rates												
Mean compression rate/min	136±38	110±6	26	**<0.01**	135±35	109±6	26	**<0.01**	142±38	107±6.4	35	**<0.0001**
Median compression rate/min	140 [100, 171]	108 [104, 116]		**<0.001**	131 [99, 165]	107 [105, 116]		**<0.001**	155 [99, 176]	105 [102, 112]		**<0.0001**
Compression rate quality index	9.3 [0, 35]	80.5 [74, 88]		**<0.001**	10.9 [0, 24]	80.5 [67, 83]		**<0.001**	13.7 [0, 36]	77.6 [64, 80]		**<0.0001**
Compression rate- too fast	66.4	4.8		**<0.0001**	63.6	3.2		**<0.0001**	52.7	13.3		**<0.0001**
Compression rate- too slow	24.3	14.7		0.36	25.5	16.3		0.24	33.6	9.1		**<0.001**
Duty Cycle (ADC)												
Mean duty cycle	55±5.6	44.7±3.5	10.3	**<0.0001**	56.3±5.9	45.4±3.9	10.9	**<0.0001**	55.7±5.2	46.5±3.5	9.2	**<0.0001**
Median duty cycle	53 [52, 57]	42.9 [42, 45]		**<0.0001**	55.3 [53, 59]	43.6 [42, 46]		**<0.0001**	54 [51, 60]	44.9 [43, 49]		**<0.0001**
Duty cycle quality index	15.5 [2, 33]	87.4 [68, 97]		**<0.0001**	16.4 [2, 28]	85.1 [66, 98]		**<0.0001**	18.5 [3, 31]	79.2 [67, 94]		**<0.0001**
Prolonged DC	84.4	12.6		**<0.0001**	83.6	14.9		**<0.0001**	81.4	20.8		**<0.0001**

Duty Cycle (ECT)												
Mean Duty cycle	47.6±8.7	44.6±4.9	3	0.22	47±7	44.5±4.4	2.5	0.21	46.2±7.9	42.5±5.3	3.7	0.11
Median Duty cycle	49.4 [46, 52]	46.9 [42, 48]		0.35	48.5 [48, 51]	46.2 [40, 49]		0.27	48.4 [44, 50]	48.4 [40, 47]		0.14
Duty cycle quality index	38.4 [23, 73]	84.9 [78, 91]		**<0.0001**	41.5 [29, 66]	86.4 [60, 86]		**<0.0001**	32.4[18, 65]	84.3 [62, 85]		**<0.0001**
Prolonged DC	61.6	15.1		**<0.0001**	58.5	13.6		**<0.0001**	67.6	15.7		**<0.0001**

CPR mean quality measures are presented as mean ± standard deviation. Median and quality indices are presented as median measures (upper and lower quartile range).

Difference between feedback and no feedback groups are presented as mean difference (95% confidence interval). independent samples Student's T test.

P-values are calculated using two-sided independent samples Student's T test.

Table 1:BLS rescuers CPR simulated performances quality measures and quality indices between the no-feedback and feedback groups, for the two Duty Cycle calculations

CPR Quality Measures	Continuous chest compressions only				5 Initial rescue breaths and CC only				5 Initial rescue breaths and 15:2			
	No Feedback group	Feedback group	Mean diff.	P-value	No Feedback group	Feedback group	Mean diff.	P-value	No Feedback group	Feedback group	Mean diff.	P-value
Chest Compression Depths												
Mean compression depth	40±3.5	41±1.5	1	0.26	40.5±4	41±1	0.5	0.52	41±4	42±1	1	0.29
Median compression depth	40 [38, 42]	41 [40, 42]		0.33	42 [39, 43]	41 [40, 42]		0.33	42 [40, 44]	42 [42, 43]		0.41
Compression depth quality index	42.3 [41, 85]	88 [84, 98]		**<0.001**	39 [41, 48]	91.7 [86, 96]		**<0.0001**	36.8 [34, 81]	84.9 [74, 91]		**<0.001**
Under compression	37.5	9.7		**<0.0001**	41	5.7		**<0.0001**	39.9	10.1		**<0.0001**
Over compression	20.2	2.3		**<0.001**	20	2.6		**<0.0001**	23.3	5		**<0.0001**
Chest Release Forces												
Mean release force	3.6±0.7	2±0.4	1.6	**<0.0001**	4±4	2.1±0.4	2.9	**<0.05**	3.7±2.1	2.1±0.5	1.6	**<0.001**
Median release force	3.7 [3.1, 4]	2.1 [2, 2.4]		**<0.0001**	3.4 [3.1, 4.7]	2.2 [2.1, 2.5]		**<0.01**	3.4 [3.1, 4.2]	2.1 [1.9, 2.4]		**<0.001**
Release force quality index	20.1 [14, 28]	74.9 [59, 76]		**<0.05**	32.1 [21, 45]	73 [66, 78]		**<0.05**	28.6 [2, 30]	80.9 [64, 88]		**<0.01**
Complete Release force index	1.4	47		**<0.0001**	2.1	46		**<0.0001**	2.4	41		**<0.0001**
Chest Compression Rates												
Mean compression rate/min	101±46	107±11.5	6	0.58	106±51	107±10	1	0.93	98±40	105±11	7	0.46
Median compression rate/min	86 [64, 124]	101 [101, 114]		0.41	83 [69, 145]	102 [101, 114]		0.34	96 [72, 118]	100 [97, 115]		0.79
Compression rate quality index	12.2 [4, 17]	75.2 [63, 81]		**<0.01**	13 [4, 24]	77 [61, 79]		**<0.01**	11.6 [6, 15]	81 [55, 87]		**<0.001**
Compression rate-too fast	42	23.3		**<0.01**	47	18.5		**<0.01**	45.4	12		**<0.001**
Compression rate-too slow	45.8	1.5		**<0.001**	40	4.5		**<0.01**	43	7		**<0.0001**
Duty Cycles (ADC)												
Mean duty cycle	73±6	60±5	13	**<0.0001**	72±6	60±4	12	**<0.0001**	69±4	59±5	10	**<0.0001**
Median duty cycle	77 [68, 78]	62 [56, 63]		**<0.0001**	73 [68, 76]	61 [57, 63]		**<0.0001**	69 [67, 71]	61 [55, 63]		**<0.0001**
Duty cycle quality index	16.1 [0, 5]	36.8 [18, 28]		**<0.001**	12.8 [8, 34]	34.7 [10, 31]		**<0.001**	22 [0, 10]	40.8 [14, 39]		**<0.001**
Prolonged DC	83.9	63.1		**<0.01**	87.2	65.3		**<0.001**	78	59.1		**<0.001**
Duty Cycles (ECT)												
Mean Duty cycle	53.7±8.4	46±6	7.7	**<0.0001**	52.9±10	46.5±6.5	6.4	**<0.05**	52.7±7.7	47±7.6	5.7	**<0.05**

Median Duty cycle	52.9 [50, 56]	45.2 [43, 49]	**<0.0001**	51.5 [50, 55]	42.2 [42, 52]	**<0.05**	51.2 [48, 55]	46 [42, 53]	**<0.05**
Duty cycle quality index	42.1 [21, 51]	81.6 [72, 91]	**<0.0001**	32.7 [7, 57]	82.5 [73, 93]	**<0.0001**	37.7 [33, 66]	77.2 [71, 86]	**<0.0001**
Prolonged DC	57.9	18.4	**<0.0001**	67.3	17.5	**<0.0001**	62.3	22.8	**<0.0001**

CPR mean quality measures are presented as mean ± standard deviation. Median and quality indices are presented as median measures (upper and lower quartile range).

Difference between feedback and no feedback groups are presented as mean difference (95% confidence interval). independent samples Student's T test.

P-values are calculated using two-sided independent samples Student's T test.

Table 2:Lay rescuers CPR simulated performances quality measures and quality indices between the no-feedback and feedback groups, for the two Duty Cycle calculations

DISCUSSION

This study identified that providing feedback significantly improved BLS and Lay CPR performance.

Chest Compression Depth

Both no-feedback groups achieved 37 - 42% success across all 3 methods, which was better than the APLS-trained clinicians [4]. The BLS+ and Lay+ groups recorded approximately 2-fold increases in chest compression performance, with an only marginal decrease with increasing rescue breaths. By comparison, APLS+ achieved 99% when performing compression-only [4]. Thirty to forty per cent of all no-feedback compressions were too-shallow (BLS-: 31-38%; Lay-: 38-41%), which is consistent with health care providers [3 20 21]. The BLS+ group achieved an under-compression rate of 13–17%, whilst the Lay+ group reduced the proportion to <10%. The significant reduction in over-compressions to <5% in all provider groups, from c. 20% of compressions, reduces intra-thoracic trauma risk [22 23].

Chest Release Force

Adequate chest release was achieved in approximately one-half of all BLS- compressions and c.25% of Lay- performance. The Lay+ group achieved approximately 75% compliance across the three algorithms, which equated to a 2.3 to 3.8-fold improvement. The BLS+ group achieved >85% compliance for release across all algorithms, which is approaching the performance of APLS rescuers [4].

Chest Compression Rate

The BLS- group were 2.5-times more likely to over-compress than the Lay- cohort, possibly due to their previous training highlighting the particularly negative association between sluggish rates and positive outcome [1]; however, this appears to encourage rescuers to instead compress too-quickly. Over-compression (>130/min) has also been reported in other simulated infant-CPR performance [5 24 25], whilst another reported lower rates [1]. Rate was successfully regulated by feedback, with both groups consistently achieving>75% across all methods and peaking at 81% compliance. This is again approaching the APLS+ group (92%) [4].

Duty Cycle

Data presented in this study are the first that quantifies infant CPR DC performance using the ADC and ECT methodologies. The BLS- and Lay- groups achieved comparable performance (c. 15%) to APLS- when calculated via ADC (the method used in [4]); however, ECT indicated ~40% compliance across all 3 algorithms. The BLS+ (ADC) group achieved >79%, whilst the Lay+ lack of experience meant they achieved only a modest improvement, as they appeared unable to achieve the correct compression 'rhythm'. BLS+ (ECT) produced similar performance metrics to the BLS+ (ADC) group; however, Lay+ (ECT) was two-fold greater than Lay+ (ADC). Such a lack of correlation between the two calculations is consistent with an adult-based study[16], meaning there risks potential confusion when describing the performance most effective at optimising blood flow during CPR (i.e. given that the exact same compressions have been quantified very differently by these two methods). The ECT technique is the most readily available clinical method, as it is recorded and reported by the CPR quality monitoring defibrillator [26]. In addition, 2010 AHA guidelines recommend the ECT technique for measuring DC performance during CPR [27]. Despite ADC producing lower metrics than ECT, it may be over-reporting compliant performance as it did not discriminate between those DC waveforms that had a quick compression and slow decompression, versus those with a slow compression and quick decompression. Hence, both accurate (i.e. 30-50%

active compression) and inaccurate (i.e. 50-70% active compression) chest compressions were considered successful.

Feedback was identified to achieve dramatic improvement when considering the performance of the 4 parameters across all algorithms, for both the BLS and Lay cohorts. The similar performance of Lay- and BLS- warrants further investigation, as BLS training appears to account for little additional ability without feedback. Underlying BLS expertise was realised when twinned with feedback, up-lifting performance by 20-fold and approaching that of the expert APLS+ rescuers [4]. A 10-fold increase was achieved in the Lay+ group, increasing from 3% to c.25%. Only modest variation existed across the 3 algorithms, indicating that performing ventilations - which have great physiological importance, does not appear to negatively affect compression performance and so should be championed by the relevant bodies.

In using an infant manikin in a non-emergency scenario, this study may be reporting performance that does not accurately reflect the genuine rescuer response. Additionally, this experimental setup had a pre-defined optimal compression depth, negating the need for the rescuer to judge the external chest dimension and then calculate one-third of this measure. Relying on the rescuer to calculate this value and then define it in the software will delay the start, and potentially decrease the initial accuracy of, 'real-life' chest compressions. Conversely, feedback systems for adult CPR benefit from a standardised compression depth, meaning that APLS performance would not be exposed to these risks within a clinical setting. The data reported here does strongly suggest, however, that infant-CPR can be significantly improved in the BLS and Lay populations with the provision of an easily accessible feedback platform, for the non-expert CPR rescuer. These data also indicate that modification to the existing BLS training programme may be needed, to positively influence rescuer performance.

CONCLUSION

Significant improvements in infant CPR performance can be achieved by supplementing BLS training with real-time feedback. A more modest upward trend was identified when providing feedback to Lay rescuers, confirming a need for such a system to be widely available. This study also revealed that the combination of rescue breaths and chest compressions did not negatively influence overall compression quality. The physiological advantage afforded by the provision of these breaths means that, based on this evidence, future guidelines should consider further advocating the 15:2 ratio for infant CPR. Thirdly, these data have highlighted the potential for confusion when calculating the duty cycle, meaning there is an urgent need to identify and then universally adopt a single measure.

WHAT IS ALREADY KNOWN

- Lay and BLS infant CPR performance is expected to be inferior versus APLS-trained clinicians
- Simulated infant CPR performed poorly by APLS-trained clinicians
- ‘Real-time’ feedback is known to improve performance of adult CPR

WHAT THIS STUDY ADDS

- That providing ‘real-time’ feedback has the potential to significantly increase the CPR quality performed by BLS and Lay rescuers
- Future guidelines should consider further advocating the 15:2 ratio for infant CPR.
- An urgent requirement exists for a single duty cycle measure

AUTHOR CONTRIBUTIONS

- JK was responsible for data acquisition and analysis, drafting and approving the final manuscript.
- PT was responsible for the study design, data analysing, drafting and approving the final manuscript.
- IM was responsible for the study design, data analysing, drafting and approving the final manuscript.
- MJ was responsible for the study design, data acquisition and analysing, drafting and approving the final manuscript

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