Bournemouth University

Faculty of Health and Social Sciences

Can a novel infant CPR retraining strategy result in longer skill retention?

Debora Almeida

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Abstract

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The overall aim of this thesis was to create a novel, tailored, competence-based strategy to infant cardiopulmonary resuscitation (iCPR) retraining, with the ultimate goal of maximising retention of iCPR skills and potentially, improve survival rates after cardiac arrest.

To interpret real changes in iCPR performance, consistency and variability of simulated iCPR skills were investigated through a within-day and between-day reliability study. Intraclass Correlation Coefficient, Standard Error of Measurement and Minimal Detectable Change were used. The results demonstrated that iCPR skills are highly repeatable and consistent, indicating that changes in performance after training can be considered real skill decay or improvement, and not variability in human performance. However, when the metrics are transformed in quality indices, large changes are required to be confident of real change.

Differences in performance between dominant hand (DH) and non-dominant hand (NH) during simulated iCPR, and how perception of fatigue may affect performance, were also investigated. A randomised study was conducted, and the results indicated no significant differences in performance with DH versus NH for any iCPR metric. However, perception of fatigue is higher in NH and is related to compression rate and residual leaning, but with no effect on quality of performance. Based on the results, individuals

performing iCPR can offer similar quality of infant chest compressions, regardless of the hand used.

To investigate iCPR skill acquisition and retention, a prospective, longitudinal, interventional study with 118 participants was conducted. The results indicate that, despite individuals requiring different amounts of input and time (four to 28 minutes after initial training) to achieve iCPR competence, the retention of those skills was as high as 96% at follow-up. This suggests that the optimal reinforcement schedule is highly likely to vary depending on the individual achieving iCPR competence. It may be argued that this tailored, competence-based retraining model, can potentially reduce training costs overall, enhance iCPR performance, and in consequence, may improve the chances of survival after infant cardiac arrest.

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List of Abbreviations

AED	Automated External Defibrillators
AHA	American Heart Association
ALS	Advanced Life Support
ANOVA	Analysis of Variance
APLS	Advanced Paediatric Life Support
AR	Augmented Reality
ARTF	Automated Real-time Feedback
ATLS	Advanced Trauma Life Support
AV	Atrioventricular
BLS	Basic Life Support
BU	Bournemouth University
CCD	Chest Compression Depth
CCR	Chest Compression Rate
CI	Confidence Interval
cm	Centimetre
CoSTR	Consensus on Science with Treatment Recommendations
CPR	Cardiopulmonary Resuscitation
DAQ	Data Acquisition Unit
DC	Duty Cycle
DH	Dominant Hand
EMS	Emergency Medical Services

EPALS	European Paediatric Advanced Life Support
EPLS	European Paediatric Life Support
ERC	European Resuscitation Council
HIV	Human Immunodeficiency Virus
ICC	Intra-class Correlation Coefficient
iCPR	Infant Cardiopulmonary Resuscitation
IHCA	In-hospital Cardiac Arrest
ILCOR	Liaison Committee on Resuscitation
IQR	Inter-quartile Range
Kg	Kilogram
LabView	Laboratory Virtual Instrument Engineering Workbench
MATLAB	Matrix Laboratory
MDC	Minimal Detectable Change
MeSH	Medical Subject Headings
Min	Minutes
mm	Millimetre
NCAA	National Cardiac Arrest Audit
NH	Non-dominant Hand
ODP	Operating Department Practice
OHCA	Out-of-hospital Cardiac Arrest
PALS	Paediatric Advanced Life Support
PC	Personal Computer
pCPR	Paediatric CPR
PEA	Pulseless Electrical Activity
PhD	Doctor of Philosophy
PHPLS	Pre-hospital Paediatric Life Support
PICOST	Population, Intervention, Control, Outcomes, Study design and Timeframe
PILS	Paediatric Immediate Life Support
QI	Quality Indices

RCT	Randomised Controlled Trial
RCUK	Resuscitation Council UK
REF	Research Excellence Framework
RL	Residual Leaning
ROSC	Return of Spontaneous Circulation
RTF	Real-time Feedback
SA	Sinoatrial
SD	Standard Deviation
SEM	Standard Error of Measurement
SPSS	Statistical Package for the Social Sciences
TF	Two-finger
TFT	Two-finger Technique
TT	Two-thumb
TTT	Two-thumb Technique
UK	United Kingdom
UREC	University's Research Ethics Committee
USA	United States of America
VAS	Visual Analogue Scale
VF	Ventricular Fibrillation
VR	Virtual Reality
VT	Ventricular Tachycardia
WHO	World Health Organization

Acknowledgments

I have been through a lot of life changes during my PhD journey which made me a much stronger and resilient person. I am very lucky to have wonderful children who support me no matter what life brings; a beautiful and supportive family who gently pushes me into the right direction; amazing and reliable friends who back me up each step of the way; and a strong network of people who have encouraged and supported me throughout my research journey. Two special mentions to make: the first one is to my supervisors Jon Williams, Carol Clark, Ursula Rolfe and Mike Jones who supported me throughout the development and completion of this thesis. Thank you for your contributions, encouragement and most importantly, for believing in my potential. The second special mention is to the participants of my studies. Without your willingness to help, this research would not have been possible. A massive thanks to all of you :-)

Chapter 1 Introduction

1.1 Background

"CPR is for the person with a heart and brain too good to die." Peter Safar (1924-2003)

Cardiac arrest is a significant worldwide public health problem, with high rates of morbidity and low rates of survival (Nolan *et al.* 2018, Wong *et al.* 2019). In the paediatric population, the burden caused by cardiac arrest is considered higher when compared to adults, due to the potentially larger number of lost years of life per individual (Atkins *et al.* 2009, Karamaien 2010, Sutton *et al.* 2015), and the financial implications caused by long-term healthcare, related to morbidity in those who survive (Ronco 1995, Duncan 2009).

The incidence and survival rates of cardiac arrest vary significantly between different regions around the world. There is an estimate of 300,000 cardiac arrests per year in Europe and 400,000 cardiac arrests in America (Atwood *et al.* 2005, Bardai *et al.* 2011, Go *et al.* 2014, Benjamin *et al.* 2019). In the UK, over 30,000 out-of-hospital cardiac arrests (OHCA) and 24,000 in-hospital cardiac arrests (IHCA) happen each year, with the paediatric population representing around 20% of these occurrences (Nolan *et al.* 2014). The majority of paediatric cardiac arrest events (44-64%) happens in infants (children between one and 12 months of age) (Nitta *et al.* 2011, Atkins 2012) and this group represents the lowest survival rates (1.4-3.7%) when compared to older children (3.6-9.8%) or adolescents (8.9-16.3%) (Bardai *et al.* 2011, Atkins 2012, Rajan *et al.* 2015).

High-quality infant cardiopulmonary resuscitation (iCPR) is a life-saving technique performed to sustain perfusion of vital organs, in an attempt to increase the chances of survival with good neurological outcome after a cardiac arrest. It consists of chest compressions combined with appropriate ventilations (Safar *et al.* 1961, Laerdal Medical 2016, AHA 2018a). Two techniques have been established for iCPR performance and are based on the number of rescuers present during the arrest: the two-finger technique (TFT) for the lone rescuer (Fig. 1-1) and the two-thumb (or encircling) technique (TTT) for two or more rescuers (Fig. 1-2). Both techniques and their effectiveness have been investigated by several studies (Todres and Rogers 1975, Dorfsman *et al.* 2000, Whitelaw *et al.* 2000, Udassi *et al.* 2009, Smereka *et al.* 2017, Millin *et al.* 2020) and will be further explained in Chapter 2, Section 2.3.4.

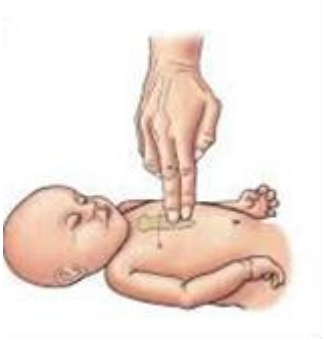

Figure 1-1 **Two-finger Technique (NCA 2022)**

Figure 1-2 **Two-thumb Technique (NCA 2022)**

The overall aim of both iCPR techniques is to achieve the correct quality of chest compressions, established by current resuscitation guidelines. They include chest compression depth (CCD) of 1/3 of the anteroposterior chest diameter or approximately 4cm for an infant; chest compression rate (CCR) between 100–120 compressions per minute; complete chest recoil after each compression to avoid residual leaning (RL) and allow blood to return to the heart before the next compression; and compression duty cycle (DC) of 50% (the percentage of time spent in compression vs relaxation) (Maconochie *et al.* 2015, Atkins *et al.* 2015, Topjan *et al.* 2020, Skellett *et al.* 2021). Added to chest compressions, high-quality rescue breaths are of paramount importance during infant cardiac arrest due to its common respiratory failure aetiology, including respiratory diseases, choking or drowning. For this reason, current guidelines recommend five initial rescue breaths before initiating chest compressions in an infant in cardiac arrest (Topjan *et al.* 2020, Skellett *et al.* 2021).

Despite high-quality iCPR being crucial to improving patient outcome after a cardiac arrest, evidence shows that iCPR performance is normally suboptimal for both lay rescuers and trained professionals, reducing the chances of survival (Martin *et al.* 2013a, Wallace *et al.* 2013, Sutton *et al.* 2015, Niles *et al.* 2017, Nolan, *et al.* 2018, Talikowska *et al.* 2020). The reason for poor quality seems to be caused by many factors, including initial skill learning; variability in human performance; retention and decay of skills after training; finger or hand strength; fatigue during performance; use of feedback devices during training/retraining and/or real-life iCPR attempts; and frequency of iCPR retraining (Ochoa *et al.* 1998, Botelho *et al.* 2016, Buléon *et al.* 2016, Kim *et al.* 2016, Almeida *et al.* 2020, Reynolds *et al.* 2020). All these aspects

have been investigated throughout this research and the results are described in this thesis.

Current CPR training varies significantly, but normally comprises of participation in an instructor-led session every one or two years. The requirements to gain certification include engaging in the session; demonstrating a safe performance, normally visually assessed by the instructor; and/or completing a self-assessment questionnaire (Jones *et al.* 2015, Cheng *et al.* 2020, Lockey *et al.* 2021). However, despite participation and achievement of the intended learning outcomes of the course, a large body of evidence demonstrates that trainee's iCPR skills performance immediately after training is consistently poor, and the skills deteriorate within weeks to months after training (Niles *et al.* 2017, Kleinman *et al.* 2018, Saad *et al.* 2019, Lockey *et al.* 2021), raising the question as to whether the current retraining strategy is effective. Although it has been recognised that frequent updates distributed over time are an important mechanism in an attempt to reduce skill decay and potentially improve the quality of iCPR (Sutton *et al.* 2011, Lin *et al.* 2018, Anderson *et al.* 2019, Cheng *et al.* 2020, Lockey *et al.* 2021, Oermann *et al.* 2022), the ideal timeframe is yet to be established.

1.2 Research Aims and Objectives

The overall aim of this research was to create a novel, competence-based strategy to iCPR retraining. In order to achieve this, further two aims were selected and included:

(i) to explore the quality of chest compressions during simulated iCPR performance.

(ii) to investigate retention and decay of chest compression skills during iCPR performance.

Although the author recognises the importance of ventilations during iCPR, the focus of this research was on the chest compression aspect of resuscitation. Therefore, from this point onwards, the abbreviation iCPR should be considered as chest compressions during iCPR.

To achieve the above aims, the following objectives were identified to inform the research design and processes:

1. To measure simulated iCPR performance delivered by healthcare students based on CCD, CCR, RL, and DC to establish quality of iCPR performance.
2. To determine the degree of correlation and agreement between repeated measures for CCD, CCR, RL, and DC to establish consistency and variability of simulated iCPR performance.
3. To investigate differences in performance between the dominant hand (DH) and non-dominant hand (NH) during simulated iCPR.
4. To assess perception of fatigue during simulated iCPR for the DH and NH and its relationship with performance.
5. To determine how long it takes to master iCPR skills so that individuals become competent.
6. To determine for how long iCPR skills remain effective.
7. To create a tailored strategy of retest and retraining of simulated iCPR skills to maximise retention of the skills.

1.3 The Research Development

The initial vision that originated my PhD was based on the concept that, despite strong evidence that CPR retraining every 12 months is not effective to the maintenance of high-quality CPR skills, this timeframe is still applied and recommended by current guidelines. At present, paediatric CPR retraining for lay people or highly trained healthcare professionals happens on a yearly basis or every two years, even though evidence suggests that the quality of performance is poor just after weeks or a few months after training.

With this in mind, a retraining strategy was envisaged where trainees would master their iCPR skills after initial training and maximise the retention of those skills by a short reinforcement over a period of time, determined by their performance. This strategy could potentially enable them to deliver a high-quality iCPR when needed. Skill mastery and subsequent retention of skills can be achieved with repeated exposure, where improved accuracy and consistency result in internalisation and automation of the motor procedure (Murphy *et al.* 2002, Sullivan *et al.* 2008), iCPR skills in this case. Therefore, to retain the skills and achieve automation, it was important to determine the appropriate amount of reinforcement needed, and the rate that the stimulus should be re-exposed for maintenance of skills.

My philosophical belief originates from the principle that concepts can be tested through experiments and analysis of data for the creation of new knowledge. This is based on positivism, a philosophical underpinning that emphasizes the importance of empirical evidence, objective data, and scientific methods in understanding the world. It suggests that knowledge must be based on specific concepts that can be

verified through prespecified and strict design, statistical analysis, and quantitative approaches (Polit and Beck 2010). Positivism argues that subjective experiences, opinions, values, and beliefs cannot be trusted as reliable sources of knowledge and are open to biases in the research results. Therefore, the positivist researcher aims to be as neutral and independent from the research participants as possible (Park *et al.* 2020). Moreover, this paradigm recognises that accurate knowledge or certainty of answers is not fully achievable, therefore the use of probabilistic evidence with a high degree of likelihood is applied into study designs.

I have considered the qualitative aspects of my research topic when designing the experiments. It included rescuers' experiences in performing iCPR, opinions on feedback strategies, perceptions of quality of iCPR performance, and views on frequency of training. However, based on my philosophical beliefs, I concluded that an objective, pragmatic approach would enable me to answer my research questions in a more relevant, accurate way.

The steps taken to develop this research are outlined below:

- **Step 1 - Literature review (Chapter 2 – Section 1)**

The first step was to perform a literature review to advance my understanding and establish current knowledge gaps related to CPR. Through the literature review, it was evident that there is a robust amount of research on adult CPR, however, there is a lack of sufficient evidence on paediatric CPR, particularly infants (under the age of one year). Since infant cardiac arrest and resuscitation present many challenges (e.g. infrequent occurrences, making it difficult to maintain the skills; substantial public health problems due to high rates of morbidity and mortality; low adherence

to resuscitation guidelines; highly stressful medical emergency; lowest survival rates), the decision to focus this research on the infant population seemed pertinent.

- **Step 2 – Choice of effective strategy to analyse iCPR performance, reinforce the skills and provide feedback (Chapter 2 – Section 2: Systematic Review of Literature)**

It became clear through the literature review, that the quality of CPR performance straight after training is similar, regardless of the way it is delivered (instructor-based; computer-based; mass training; self-instruction video; voice-advisory feedback) (Bhanji *et al.* 2015, Ko *et al.* 2018, Lin *et al.* 2018, Greif *et al.* 2021). Therefore, the traditional concept of instructor-based learning to deliver the initial iCPR training to participants was selected for this research. This is based on a theoretical session delivered by a qualified instructor, followed by practical training using an infant manikin.

Although the initial training approach was easily identifiable, it was not very clear what was the most effective way to reinforce the skills. Current evidence suggests that the use of automated real-time feedback (RTF) devices is a promising intervention to potentialize retention of CPR skills. Previous works already demonstrate that RTF enhances performance (Yeung *et al.* 2009, Botelho *et al.* 2016, Lin *et al.* 2018, Wang *et al.* 2020, Kong *et al.* 2020) and its use is included as a recommendation in the latest resuscitation guidelines (Lockey *et al.* 2021, Cheng *et al.* 2020). However, despite being proven effective, some researchers have conflicting conclusions with respect to its efficacy. For this reason, the author decided to perform a systematic literature review to investigate the usefulness of RTF devices

for CPR training and real-life CPR. The review had to include both paediatric and adult subjects due to limited studies in the paediatric population. The results of the systematic review were of vital importance to this thesis as based on them, RTF was chosen to be the system for reinforcement of skills and feedback strategy used in the experiments.

There are several models of RTF in the market, and all have their own benefits and flaws (Kurowski *et al.* 2015, Truszewski *et al.* 2016, Gugelmin-Almeida *et al.* 2021a). However, most of the devices do not provide feedback for infant CPR. Also, within the limited devices available for paediatric use, it was not possible to identify a device that provided measurement and/or feedback for the four outcome measures previously described (CCD, CCR, RL and DC). Moreover, as the focus of this research was not to investigate the best RTF device available, a kit developed in-house by Cardiff University, of which validity has been previously established (Martin 2013), was selected.

- **Step 3 – Reliability of human performance during iCPR (Chapter 3)**

During the literature review, it was noted that much is being investigated about teaching and retention of CPR skills, but nothing has been explored regarding the variability and/or consistency of individuals executing CPR skills. This can have a major impact on the analysis of retention of a skill because, if the individual's performance is not consistent within hours or days after training, any differences observed months later, could just be due to variation and inconsistency in iCPR performance, rather than improvement or skill decay.

For this reason, designing an experiment to measure repeated iCPR performance, following a short time lapse (not long enough to instigate skill decay) was of great importance. This experimental design (fully explained in Chapter 3) enabled the determination of whether an individual repeating the same skill under the same strict conditions was consistent. Such data enable the quantification of the natural variation of repeated iCPR performance.

- **Step 4 – Impact of hand dominance and fatigue during iCPR (Chapter 4)**

The reliability study cited above provided important data to inform the design, metrics of interest and analysis of results for the main retraining study (Chapter 5). Additionally, the experiment has also identified other elements that could potentially impact performance and influence interpretation of data in skill decay.

After data collection for the reliability study, some participants raised that they felt fatigued and asked if they could swap hands during iCPR performance. These topics were very relevant and had not been explored previously in the literature. This motivated the following study on the impact of hand fatigue and hand dominance in the delivery of iCPR.

It has been implied that the quality of chest compressions using the two-finger technique might be influenced by hand dominance and fatigue. However, while previous studies have explored hand dominance during CPR in adults, no research has specifically compared dominant and non-dominant hands during iCPR using the two-finger technique. Also, there are limited data on the impact of hand fatigue during resuscitation attempts, particularly in the infant population. Therefore, Chapter 4 describes the experiment to investigate differences in performance

between the dominant and non-dominant hand during simulated iCPR and, at the same time, to assess perception of fatigue and its relationship with iCPR performance.

The results of this study, besides informing real resuscitation attempts and potentially enhancing chest compression technique, were used in the design of the main retraining study (Chapter 6).

- **Step 5 – Retraining timeframe to maximise iCPR skills retention (Chapter 5)**

There are limited and inconclusive evidence regarding retraining schedule for paediatric resuscitation skills and this gap in knowledge limits the ability to suggest a timeframe for paediatric CPR retraining. The guidelines and literature pertaining to optimal timeframe for re-exposure of the skills has not been clearly determined and this could impact retention of iCPR skills.

Resuscitation guidelines recommend 'spaced training and retraining', and some researchers suggest that monthly exposure to the skills results in better retention (Oermann *et al.* 2011). However, with very high dropout rates of up to 50% (Singleton *et al.* 2018, Anderson *et al.* 2019), this timeframe would not be effective or viable in clinical practice. Other studies advocate a retraining schedule of six months, but it has been determined that CPR skills decay within weeks to months after training. Although regular updates are an important mechanism in an attempt to avoid skill decay, the optimal balance between retraining and sustainability has not yet been established.

For this reason, a scoping review of literature was performed (Chapter 5) to investigate the intervals of formal paediatric resuscitation training provided to healthcare professionals. The results of this review provided critical insight into the design of the iCPR retraining study.

- **Step 6 – Novel retraining model to achieve iCPR competence and maximise retention of skills (Chapter 6)**

The last study of this thesis sought to determine whether an individualised, competence-based strategy to simulated iCPR retraining could result in high skill retention at follow-up. The objectives were to determine the amount of re-exposure of skills was needed to achieve iCPR competence, and to establish if the acquired competence is retained over time.

The elements of variability in human performance (Chapter 3) and perception of fatigue (Chapter 4) were taken into consideration so that, interpretation of changes during the 12-month period of this study could be analysed without the potential confounding factors of those elements. Moreover, the results from the scoping review of the literature (Chapter 5) provided critical insight into the development and design of this study. The results provided robust evidence for the creation of the novel iCPR retraining strategy to maximise retention of high-quality iCPR skills, proposed by this thesis.

1.4 Thesis Chapters Outline

This is an integrated thesis, which differs from a traditional doctoral thesis. The original contribution to the field of research is the foundation of an integrated format

thesis, like the traditional model. Additionally, the Chapters provide a narrative that links the studies and published manuscripts.

This integrated thesis is divided into eight Chapters and contains five published manuscripts associated with the literature reviews and the experimental studies performed during the research.

The rationale behind the decision to develop the research following the integrated format approach, was to ensure the timely dissemination of the results to clinical practice and policy makers, avoiding the potential delays of the traditional format. That way, the recommendations derived from the research, could potentially enhance practice and influence decision-makers at the earliest possible opportunity.

Chapter 2 describes the current epidemiology, treatment and outcomes of cardiac arrest, with emphasis in the infant population. It also explores current guidelines, practices, performance and training of iCPR. Additionally, this Chapter presents a published systematic review of literature (Gugelmin-Almeida *et al.* 2021a) which assessed the effectiveness of using automated real-time feedback devices to improve CPR performance during simulation, training and real-life resuscitation attempts in the adult and paediatric populations.

Chapter 3 comprises two sections: the first section addresses in detail the methodology of the experimental study exploring variability in human performance during iCPR. Due to the word limitations of a published manuscript, important methodological aspects of the study are further explained in this section. It includes how the research approach addresses the aims, objectives and outcomes of the study; indicates the ethical considerations and participant recruitment; outlines the

research methods for collecting demographic and performance data; and provides context for the statistical choices to analyse the results. The second section of the Chapter contains the published article (Almeida *et al.* 2020). Additionally, an evaluation of the limitations of the study is presented at the end of the Chapter to contextualise the results.

Chapter 4 is also divided into two sections: Section 1 describes the methodology of the randomised experiment, investigating the differences between simulated iCPR performance with the dominant and non-dominant hand using the two-finger technique. This is followed by the published manuscript (Gugelmin-Almeida *et al.* 2021b), and evaluation of limitations of the study.

Chapter 5 investigates the intervals of formal paediatric resuscitation training provided to healthcare professionals. This was completed through a scoping review of literature performed in a systematic way (Gugelmin-Almeida *et al.* 2022a). The results from this review informed the methodological approach utilised in the retraining study which is explored in Chapter 6.

Section 1 of Chapter 6 details the methodology for this longitudinal, prospective, experimental study in exploring the quality, retention, and decay of iCPR delivered by university students. It demonstrates how the methodology addresses the aims, objectives and outcomes of the study; indicates the ethical considerations and participant recruitment; outlines the research methods for collecting demographic and performance data; and demonstrates the statistical approaches taken to analyse the results. Section 2 presents the published article (Gugelmin-Almeida *et al.* 2022b),

followed by an evaluation of the strengths and limitations of the study, to contextualise the results.

Chapter 7 offers a general discussion about the main findings of the thesis as a whole and compares them against relevant literature. It outlines the conclusions generated from the thesis and describes the impact of the research on clinical and educational facets of CPR. Finally, key recommendations and relevant directions for future research are explored in Chapter 8.

Chapter 2 Literature Review

This Chapter is divided into two sections: the first section presents key aspects of cardiac arrest and concepts related to cardiopulmonary resuscitation (CPR). Definitions, theories, techniques, guidelines, training, and retention of skills are presented to provide an overview of the topic and foundation for the development of this thesis. The second section is presented as a published systematic review of literature on the use of automated real-time feedback during CPR, (Gugelmin-Almeida *et al.* 2021a) which was performed to inform and shape the design of the experimental studies conducted to answer the questions of this thesis. These sections together, identify the gaps in literature and inform the rationale for this research.

Section 1

2.1 Cardiovascular System

The cardiovascular system is a highly organised collection of structures capable of adapting rapidly and effectively to changing requirements of millions of cells in the human body. It consists of the heart, blood and vessels that transport oxygen, nutrients, hormones and cellular waste products throughout the body (Rushmer 1989). Living cells can only survive and function in a chemically stable environment where nutrients and oxygen can be absorbed, while toxic waste products derived from their metabolic activities are eliminated. The cardiovascular system plays a vital role in maintaining this homeostasis via the continuous and controlled movement of

blood through the thousands of miles of capillaries that permeate every tissue and reach every cell in the body (Humphrey 2003).

From foetal to neonatal and infancy development, the cardiovascular system passes through extensive transformation until reaching its mature form in early childhood, making the cardiorespiratory physiology and anatomy highly different in neonates and infants, from that of older children and adults (Saikia 2019). During prenatal life, oxygen and nutrients are transferred from the mother's blood across the placenta into the foetus' right atrium via a single umbilical vein. Most of this oxygen-rich blood is directed into the left atrium through a structure called foramen ovale (a shunt between right and left atria). It then flows into the left ventricle, which distributes this oxygenated blood to the brain, the heart itself and the upper part of the body via the ascending aorta. The other part of the blood will flow into the right ventricle and to the descending aorta through the ductus arteriosus (a structure that connects the pulmonary artery to the aorta and bypasses the lungs), which is then distributed to the lower body. The now deoxygenated blood enters the umbilical arteries and flows back into the placenta, where carbon dioxide and waste products are released into the mother's circulatory system (Saikia 2019).

The transition from foetal to postnatal circulation begins at birth following the "first cry", causing the lungs to inflate and the "clamping of the umbilical cord", stopping placental circulation. These changes alter the pressure gradient between the left and right atrium, causing a functional closure of the foramen ovale over a few breaths (Sharma *et al.* 2010). Ductus arteriosus constricts and functionally closes within 24-48 hours, however a narrow ductus arteriosus may persist for a few days to several

weeks after birth, until it permanently closes during early infancy, by 4-8 weeks (Saikia 2019).

During early infancy, the cardiovascular system is controlled parasympathetically and a bradycardia response to autonomic stimuli, such as hypoxia, is a frequent occurrence which may result in severely reduced cardiac output and hypotension and consequent decrease of oxygen delivered to tissues. Over the first six months of life, sympathetic innervations gradually mature, taking control of the cardiovascular system of the infant (Saikia 2019).

2.2 Cardiac Arrest

Cardiac arrest is defined as a sudden stop of the mechanical activity of the heart due to electrical failure, followed by unresponsiveness, apnoea or agonal respirations and the cessation of blood circulation due to lack of cardiac output (Cummins *et al.* 1991, Jacobs *et al.* 2004, Ewy 2010). It is a potentially reversible medical emergency for both the adult and paediatric population yet, if untreated, can lead to death within minutes. This is particularly applicable to children due to their increased cerebral blood flow and higher metabolic needs, especially infants, due to the large differences seen in their cardiorespiratory physiology and anatomy as compared with adults (Tress *et al.* 2010, Kwok *et al.* 2015).

A healthy cardiac cycle consists of two phases: systole and diastole. To pump blood effectively during systole, the cardiac muscle contracts in a highly synchronised way, triggered by an electric impulse automatically generated in the right atrium by the sinoatrial (SA) node. This impulse is propagated through the internodal pathways, depolarising/contracting the atria, thus, pumping blood into the ventricles. The

atrioventricular (AV) node holds the impulse, allowing the ventricles to fill up with blood, before sending it through the bundle of His and further into the Purkinje fibres, depolarising the ventricles and consequently, pumping blood into the arteries to be distributed to the rest of the body and to the heart itself (Villars *et al.* 2004, Fukuta *et al.* 2008). In a cardiac arrest, this highly synchronised process (normal sinus rhythm) (Fig. 2-1) is interrupted by an electric malfunction which is associated with four distinct electrocardiographic rhythms: ventricular fibrillation (VF) (Fig. 2-2); pulseless ventricular tachycardia (VT) (Fig. 2-3); pulseless electrical activity (PEA) (Fig. 2-4); and asystole (Fig. 2-5). VF is the leading cause of cardiac arrest in adults, during which the electrical activity of the heart becomes chaotic, reducing the cardiac output. In the paediatric population however, the most common initial cardiac rhythm is non-shockable pulseless rhythms (majority asystole and some PEA) (Atkins *et al.* 2009, Nitta *et al.* 2011).

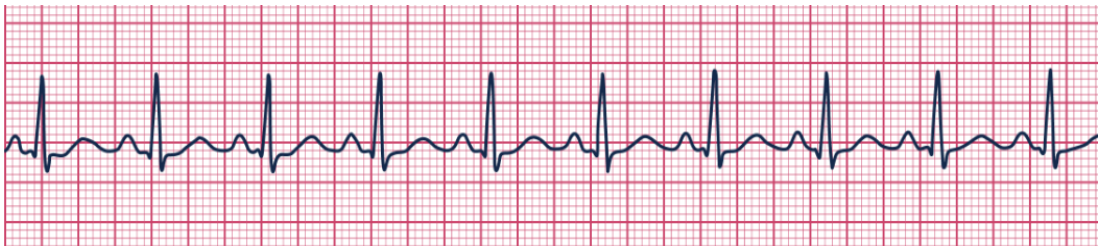

Figure 2-1 **Normal Sinus Ruthm (UNC 2022)**

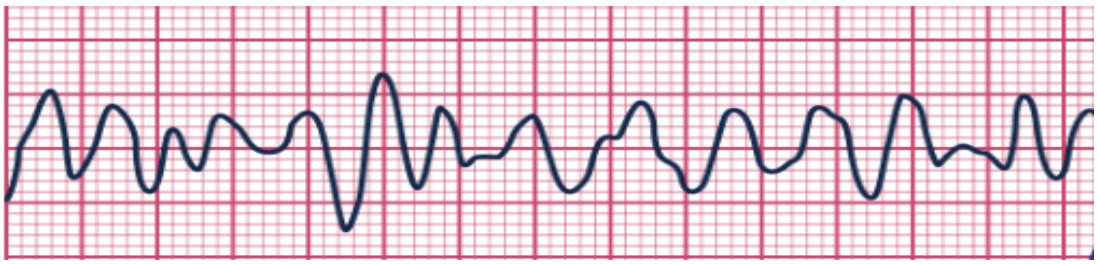

Figure 2-2 **Ventricular Fibrillation (UNC 2022)**

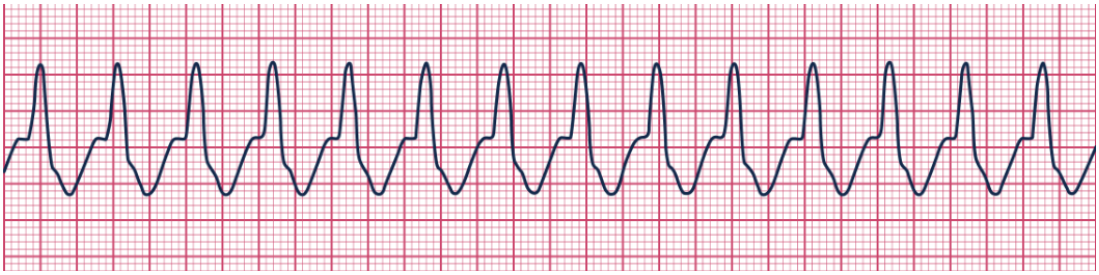

Figure 2-3 Ventricular Tachycardia (UNC 2022)

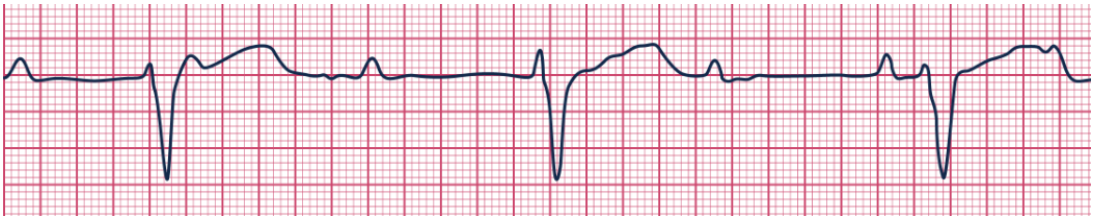

Figure 2-4 Pulseless Electrical Activity (UNC 2022)

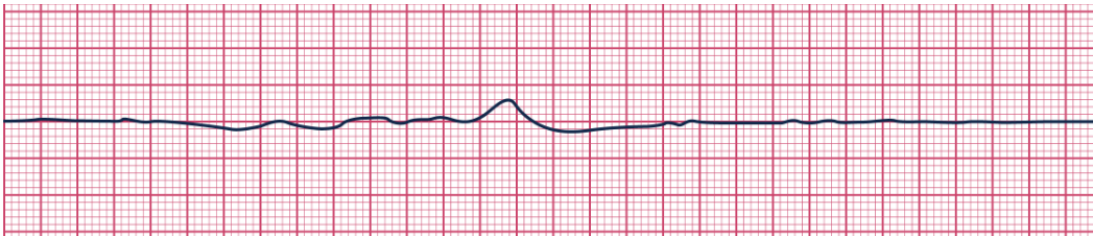

Figure 2-5 Asystole (UNC 2022)

The causes of cardiac arrests in the infant population vary considerably from those experienced in adults, principally due to the fundamental differences in the aetiology and pathophysiology, added to higher cerebral blood flow and increased metabolic needs, compared to older children and adults (Tress *et al.* 2010, Atkins *et al.* 2012a). Differently from adults, infant cardiac arrest is not usually caused by primary cardiac problems but is secondary to other origins. It normally develops from complications and progression of respiratory failure and circulatory shock or can represent the final common pathway for mortality, from infection, trauma and congenital anomalies (Maconochie *et al.* 2015, Kleinman 2018). Other sources of infant cardiac arrest include cardiac diseases, arrhythmias, infection, septicaemia, sudden infant death syndrome, pre-existing conditions (most commonly pulmonary, cardiac,

gastrointestinal, neurologic and oncologic), trauma, asphyxia, drowning, hyper/hypothermia and intoxication (Pell *et al.* 2003, Jacobs *et al.* 2004, Moler *et al.* 2009, Tress *et al.* 2010, De Maio *et al.* 2012, Maconochie *et al.* 2015, Rajan *et al.* 2015, Molyneux 2020).

2.2.1 Infant Cardiac Arrest: Epidemiology

"Epidemiology" is a term used to describe the occurrence and distribution of diseases and the factors and the associated outcomes (Gulis and Fujino 2015). The epidemiology of cardiac arrest has been reported for decades but still shows substantial variation between different regions of the world, in some instances, reaching more than 100% variability (Nichol *et al.* 2008). Currently, only estimates of the global incidence and outcome of cardiac arrest are available and are normally summaries of previously published literature with the described population, data collection methods, reporting processes, research design or data analysis not always sufficiently defined, which can influence the impact on reported incidence and outcomes (Nichol *et al.* 2008, Sasson *et al.* 2010, Perkins and Brace-McDonnell 2015, Mathiesen *et al.* 2018).

Similar to the adult population, the global incidence of paediatric cardiac arrest is unknown due to the absence of uniformity in relevant information, particularly with regard to aetiology (cause/origin), with numerous studies combining respiratory arrests with cardiac arrests or including aetiologies associated with increased risks of mortality, such as septic shock, asphyxia, trauma and sudden infant death syndrome (Donoghue *et al.* 2005, Berg *et al.* 2016, Bimerew *et al.* 2021).

Another important aspect that interferes with the aetiology, epidemiology and outcomes of cardiac arrest is the location of where it occurs. Out-of-hospital cardiac arrest (OHCA) significantly differs from in-hospital cardiac arrest (IHCA) in relation to origin, incidence and survival rates (Chung-Yu *et al.* 2018, Herlitz 2000, Høybye *et al.* 2021). Cardiac arrest happening outside of the healthcare setting is not frequently witnessed, leading to a more prolonged cessation of circulating blood. A positive outcome depends on the recognition of cardiac arrest by normally untrained people, bystander engagement to seek qualified help, and EMS decision-making to instruct initiation of CPR (Brandling *et al.* 2017). CPR is the initial emergency procedure in a cardiac arrest episode. Its quality, added to the early use of automated external defibrillators (AED), influence survival after cardiac arrest (Cheng *et al.* 2020). Additionally, the effectiveness of emergency medical services (EMS) plays an important role in increasing patient survival with positive neurological outcomes (Berger 2017, Holmén *et al.* 2020).

Conversely, it has been demonstrated that IHCA has a lower incidence, higher survival rate and positive outcomes when compared to OHCA. This may be by virtue of different factors such as the level of trained healthcare professionals, who are likely able to identify patient deterioration via physiological monitoring and regular assessments, allowing resuscitation treatment to be started sooner (Høybye *et al.* 2021). Moreover, trained professionals have the potential to deliver better-quality CPR compared to bystanders. In addition, they are more likely to have access to medications, protocols, equipment and devices in order to provide effective treatment. Furthermore, specialised rapid response teams, composed of health professionals with critical care expertise, are available for a fast response in a cardiac

arrest situation and yield additional support in the prevention and/or intervention after cardiac arrest (Reis 2002, Tibballs 2006, Meert 2009, Dukes *et al.* 2019).

Globally, OHCA represents approximately 60% of all documented cardiac arrests, with an incidence of 20 to 140 per 100,000 people (Herlitz 2000, Berdowski *et al.* 2010). The World Health Organization's (WHO) Global Health Observatory data estimated that 5.9 million children younger than five years of age died of cardiac arrest in 2015, making cardiac arrest one of the leading causes of death in the Western world, claiming more lives than prostate, breast and colorectal cancer, car accidents, HIV and firearms combined (Herlitz *et al.* 2000, Meaney *et al.* 2013, Kleinman 2018, WHO 2018).

In the UK, the British Heart Foundation, a charity organisation that funds research into the causes, diagnosis, treatment and prevention of heart and circulatory diseases, collaborates with the so called 'Out-of-Hospital Cardiac Arrest Outcomes Project', to quantify and establish the epidemiology and outcome of OHCA. According to the registry, about 30,000 people in the United Kingdom receive resuscitation for OHCA yearly, with reported survival to discharge rates ranging between two and 12% (Perkins and Brace-McDonnell 2015, Hawkes *et al.* 2017). It is assumed that about 6,000 cases happen in the paediatric population where infants comprise most of these occurrences (around 62%) (Chamberlain *et al.* 1991, Atkins *et al.* 2009, ONS 2011).

For episodes of IHCA, data from the UK National Cardiac Arrest Audit (NCAA), a national ongoing comparative outcome audit of IHCA in the UK, indicate that cardiac

arrests in the hospital setting occur in 1.6 per 1,000 hospital admissions, with rate of survival to hospital discharge of 18.4% (Nolan *et al.* 2014, Nolan *et al.* 2018).

In the United States, the 'Resuscitation Outcomes Consortium' created a registry of OHCA victims who were attended by EMS response systems in different geographic areas including US and Canadian communities with a population of around 23.7 million people. According to the database, over 350,000 people experience OHCA yearly, with an incidence of approximately 20,000 cases in the paediatric population, and infants comprising the majority of those cases, with a ten-fold increase (72.7) if compared to children (3.7) and adolescents (6.3) per 100,000 person-years (Bush *et al.* 1996, Atkins *et al.* 2009, Tress 2010, Meaney *et al.* 2013, Martinez and Totapally 2016, Virani *et al.* 2020). A statement from the American Heart Association (AHA) indicates that over 200,000 adults and 6,000 children are treated for IHCA every year. For infant patients, the incidence of IHCA is around 1.3% of all hospital admissions and 5.5% of all intensive care unit admissions (Reis *et al.* 2002, Tibballs and Kinney 2006, Morrison *et al.* 2013).

Other studies about epidemiology of cardiac arrest conducted in other countries, demonstrate similar conclusions when compared to the USA and the UK. In Helsinki, a study conducted two decades ago demonstrated that the incidence of OHCA was 9.8 per 100,000 person-years (Kuisma *et al.* 1995), with more recent research indicating that OHCA in patients younger than 16 years of age is 7.5 per 100,000 person-years (Atkins 2009). Another recent Japanese registry study reported that approximately 100,000 OHCA occur annually (Kitamura 2012), whilst in Melbourne and Denmark a reported incidence of only 5 and 3.3 per 100,000 person-years

respectively, has been demonstrated (Deasy *et al.* 2013), whereas the infant population has the highest incidence of 11.5 per 100,000 person-years (Rajan 2015).

To standardise cardiac arrest data definition and reporting used by cardiac arrest registries for both adult and paediatric population, the "Utstein recommendations" were introduced in 1990 and have been updated regularly, with the publication of a standardised reporting template for OHCA published in 2015 (Zaritsky 1995, Kuisma 1995, Perkins *et al.* 2015a). However, significant heterogeneity is still observed, making it difficult to compare cases and outcomes. Carefully outlining and standardising definitions related to cardiac arrest, may hopefully improve the quality of research. This promotes a better combination and comparison between published studies to gain a better understanding of epidemiology of cardiac arrest and development of strategies for a more positive outcome. This is particularly relevant to paediatric victims who have predominantly poor outcomes, with undesirable high rates of both mortality and morbidity (Donoghue 2005, Maconochie 2015, Lee *et al.* 2019b).

2.2.2 Survival Rates and Outcomes

Survival rate and outcome data vary extensively in the reported literature because of different data collection processes, variable outcome measurements, inclusion of varying patient populations, follow-up duration and other factors already discussed previously (Perkins and Brace-McDonnell 2015, Kigushi *et al.* 2020).

It has been reported that survival rates from paediatric IHCA have improved considerably in the past few decades, moving from 10% in the 1980s to above 25%

in 2005 (Reis *et al.* 2002, Nadkarni *et al.* 2006). More recent studies suggest an estimated survival rate of 40% to 55%, demonstrating a great disparity between countries and regions (Horisberger 2002, Berg 2016, Martinez *et al.* 2016, Virani *et al.* 2020, Scholefield *et al.* 2020). Nevertheless, despite more than six decades of research, the same results cannot be applied to paediatric OHCA where survival rates are believed to be, on average, around 11% worldwide (5% for infants and 13% for children and 17% adolescents), with only 4% of children surviving neurologically intact (Young and Seidel 1999, Donoghue *et al.* 2005, Atkins *et al.* 2009, Kleinman 2010, Nitta *et al.* 2011, de Caen *et al.* 2015a, de Caen *et al.* 2015b, Virani *et al.* 2020).

Although recent research indicates that paediatric cardiac arrest is an uncommon event with a significant variation between incidence, aetiology, outcome and survival, it is generally described as having remarkably poor survival with severe neurological sequalae in paediatric population, with infants having the highest incidences and the poorest survival outcomes (Atkins *et al.* 2012b, Rajan 2015, Kleinman *et al.* 2018). While research efforts on paediatric resuscitation have increased, it remains underrepresented at only 14% when compared to adult resuscitation (Scholz *et al.* 2020). With this in mind, this thesis will focus on the infant population, since research in this field is limited, and where a greatest potential lifetime can be gained or lost.

2.3 Cardiopulmonary Resuscitation (CPR)

CPR is a combination of emergency procedures to improve the chances of survival after a cardiac arrest. It includes a cyclic delivery of external chest compressions to pump blood to vital organs, combined with artificial ventilation (rescue breaths) to

supply oxygen to the brain, heart itself and other organs. Those resuscitation measures will improve cardiac arrest survival chances by contributing to the sustainability of the body's haemodynamic function, extending the preservation of brain activity, and reinstating the partial flow of oxygenated blood to the brain and vital organs (Perkins 2007, Sasson *et al.* 2010, Kwok *et al.* 2015, Lockey *et al.* 2021, Cheng *et al.* 2020).

The mechanism and physiological interactions involved in blood flow generated by chest compressions can be explained by two key theories. The first one, developed in 1960, is the "Heart or Cardiac Pump Theory". It declares that compressing the heart between the sternum and the vertebral column creates a pressure rise between the right ventricle vs pulmonary artery and between the left ventricle vs aorta, resulting in the opening of the respective valves, simultaneous closure of mitral and tricuspid valves and consequent blood flow from the ventricles. According to this theory, during the relaxation phase of chest compression, there is a rapid opening of the atrioventricular valves and closure of the aortic and pulmonary valves, allowing blood to return to the heart, re-filling the atria and ventricles ready for a new compression (Kuhn *et al.* 1991, Kim *et al.* 2015, Papadimitriou *et al.* 2013).

The other theory is the "Thoracic Pump theory", created in the 1980s, after experimental studies in humans (Chandra *et al.* 1980) and dogs (Halperin *et al.* 1986). It suggests that the displacement of the sternum against the vertebral spine causing direct cardiac compression is irrelevant. The mechanism supported by this theory is the increase in intrathoracic pressure caused by external chest compression, which forces blood to flow from the heart to the body, and the negative intrathoracic

pressure during the relaxation phase promoting the return of venous blood back to the heart. The thoracic pump theory therefore suggests that the heart acts as a passive conduit without having a pump function (Babbs 1980, Chalkias and Xanthos 2015, Georgiou *et al.* 2014).

Irrespective of which theory better explains the mechanism and physiological interactions involved in blood flow generated by chest compressions, the concept of CPR has existed for more than half a century, adapted from various other successful lifesaving methods.

2.3.1 History of CPR

'Anyone, anywhere can now initiate cardiac resuscitative procedures. All that is needed are two hands' (Kouwenhoven, 1960).

The origins of resuscitation extend back centuries, with some early mentions of ventilatory support occurring in the Bible and in ancient Egyptian texts, including the use of bellows to inflate the lungs of a dead animal and midwives breathing in infant's mouths, reviving them, when the child was thought to be dead. This technique became recognised and mouth-to-mouth resuscitation for drowning victims was officially recommended in 1741 by the Paris Academy of Sciences (Maier *et al.* 1984, Varon and Sternbach 1991, Cooper *et al.* 2006, LaHood and Moukabary, 2009).

The circulatory aspect of CPR (external chest compressions) was initially described in 1786 by a surgeon called John Sherwin, "*The surgeon should inflate the lungs and alternate compressing the breastbone*" (Maier *et al.* 1984) however, the method remained obscure with few reports until 1885, when Professor Franz Koenig ("the father of external cardiac compression") reported successful resuscitative efforts in

people. This was followed by his student Friedrich Maass who, in 1892, described the first successful survival using the technique for a child who went into cardiac arrest during surgical correction of harelip and achieved spontaneous circulation after about 50 minutes of external chest compressions (Maier *et al.* 1984, Figl *et al.* 2006). The technique remained idle until the late 1950s, when William Kouwenhoven popularised the method supported by reports that 14 out of 20 patients survived their cardiac arrest episodes with the use of external chest compressions and were discharged from hospital alive (Kouwenhoven *et al.* 1960).

Ventilatory and circulatory support were considered separate entities until 1960, when Peter Safar stated that the two techniques "cannot be considered any longer as separate units, but as parts of a whole and complete approach to resuscitation", promoting the birth of modern CPR, as we know it today (Safar *et al.* 1961, Eisenberg *et al.* 2007). With slight modifications, the concept of CPR has been recommended and used until now for both lay people and health care providers to improve survival after cardiac arrest.

2.3.2 Chain of Survival

Figure 2-6 Chain of Survival (RCUK 2022a)

Positive outcomes following OHCA require a cohesive set of coordinated measures defined by the links in the "Chain of Survival" which comprise of early recognition and call for help, early good quality CPR, early defibrillation and good standardised post-resuscitation care (Fig. 2-6). The individual links are interrelated, and the success of each link is dependent on the effectiveness of the preceding one (Cummins *et al.* 1991). This concept was first introduced in 1991 and, even though the design has since been modified several times, the message held in each link has remained consistent and it continues to be a symbol of resuscitation in many places worldwide (Nolan *et al.* 2006, Travers *et al.* 2010).

The first link of the chain prioritises early recognition of cardiac arrest (e.g. unresponsiveness, abnormal or agonal breathing) followed by calling for help (e.g. to call and notify the emergency medical services, to get an automated external defibrillator (AED) and to help with CPR). This link is normally performed by the general public, family members or bystanders, who will be the first people in a cardiac arrest scene (Perkins *et al.* 2015b).

The second link highlights the critical importance of early, effective, high-quality bystander CPR, to reinstate the partial flow of oxygenated blood to the brain and heart, delaying tissues' death and preserving brain function (Perkins 2007, Kwok *et al.* 2015, Greif *et al.* 2015). Research suggests that survival from OHCA can be increased up to fourfold with high-quality bystander CPR (Sasson *et al.* 2010, Hasselqvist-Ax *et al.* 2015).

Early defibrillation is the fundament of the third link to convert the heart back to its normal rhythm. According to research, for each minute without defibrillation, the

chance of survival decreases by 10% and if defibrillation is delivered within three to five minutes of the onset, survival rates may rise by up to 70% (Cummins *et al.* 1991, Valenzuela *et al.* 2000, Hasselqvist-Ax *et al.* 2015).

The fourth link, post resuscitation care to restore quality of life, relates to the response and interventions of pre-hospital EMS personnel prior to the arrival of the patient at an advanced care facility, followed by post resuscitation care delivered by hospital staff to preserve function of the brain and heart, with treatments such as extracorporeal membrane oxygenation, stents, thrombectomy/embolectomy, therapeutic hypothermia (which is represented by the blue brain in the last link of the chain) and other interventions (Nolan *et al.* 2006, Tijssen *et al.* 2015, Perkins *et al.* 2015a).

Survival from OHCA can increase by strengthening those four links in the Chain of Survival, particularly the first ones, with emphasis on high-quality chest compressions (Berdowski *et al.* 2010, Lund-Kordahl *et al.* 2010, Lindner *et al.* 2011, Rao and Kern 2018). The chain represents a window of opportunity to save the patient's life, thus this window may only be extended if the interventions are preformed quickly, concisely, with high-quality and standards, therefore increasing the likelihood of survival from OHCA.

Different strategies and research have been initiated in the UK and other countries to improve the various elements of the Chain of Survival including: improving the rate of bystander CPR and the use of automated external defibrillators (AEDs); providing CPR training in schools; creating public awareness of what to do when faced with an OHCA; improving audit and setting up a national defibrillator database;

mass training events; mandatory CPR testing as part of driving licence applications; development and testing of mobile phone apps for CPR performance (Merchant *et al.* 2010, Adelborg *et al.* 2011, Plant *et al.* 2013, Kalz *et al.* 2014, DfE 2014, Malta-Hansen *et al.* 2015, Perkins *et al.* 2016). Those are some examples of initiatives created to improve the elements of the Chain of Survival to increase survival rates from OHCA (Perkins *et al.* 2016). Data from these initiatives have led to a positive change in cardiac arrest related outcomes such as increase in the quality of bystander CPR; wider awareness of cardiac arrest and the importance of CPR; improvement in CPR knowledge and skills; increased bystander's willingness to provide CPR; and association with greater likelihood of patient survival (Merchant *et al.* 2010, Adelborg *et al.* 2011, DfE 2015, Malta-Hansen *et al.* 2015, Perkins *et al.* 2016, AHA 2018b).

2.3.3 Resuscitation Guidelines

Since 2000, resuscitation science has been evaluated every five years by representatives from the International Liaison Committee on Resuscitation (ILCOR), an organisation created in 1992 to facilitate a forum for collaboration between resuscitation councils around the world. ILCOR is responsible for the creation of recommendations related to different topics in cardiopulmonary resuscitation called CoSTR (Consensus on Science with Treatment Recommendations). This is based on a strategy to review current published evidence relevant to a particular topic, which is subsequently used by member organisations to develop evidence-based resuscitation guidelines. Examples of member resuscitation councils include but it is not limited to: European Resuscitation Council (ERC), American Heart Association (AHA), Resuscitation Council of Asia, and Australian and New Zealand Committee on

Resuscitation. In 2015, ILCOR described the transition between a 5-year cycle of review of evidence to a “near-continuous evidence evaluation process”, so that appraisal of resuscitation science is timely delivered and disseminated (ILCOR 2021).

In the United Kingdom, Resuscitation Council UK (RCUK) is the national organisation expert in resuscitation. It was founded in 1983 and has the mission to ensure that “every person in the country knows what they can do to help in a cardiac emergency and feels confident in their skills as a lifesaver” (RCUK 2021b). RCUK guidelines are currently filtered from the ERC guidelines and reviewed by experts with involvement from members of the public and cardiac arrest survivors, to ensure relevance to UK practice.

The first RCUK national recommendations for resuscitation of children were published in 1986 whilst ERC published the first European Paediatric Life Support (EPLS) guidelines in 1994. Since then, the guidelines have been updated every five years with the latest edition being published in 2021 (Skellett *et al.* 2021, Voorde *et al.* 2021).

This thesis is focused on infant cardiac arrest and infant cardiopulmonary resuscitation. Therefore, an emphasis will be given to the paediatric basic life support (BLS) guidelines, with focus on the infant population which, according to Skellet *et al.* (2021) is under the age of one year. Because there are significant differences between resuscitation sequence and technique for infants, compared to older children and adults, it is important to differentiate between them.

According to recent resuscitation guidelines (RCUK 2021a), the sequence of which iCPR is delivered and the technique used, depends upon the level of training of the

rescuer and how many rescuers are involved. The majority of bystanders should use the adult sequence (Fig. 2-7) on a child or infant, because this is the most commonly known technique that rescuers would be potentially more comfortable with, increasing the chance of delivering an effective CPR technique.

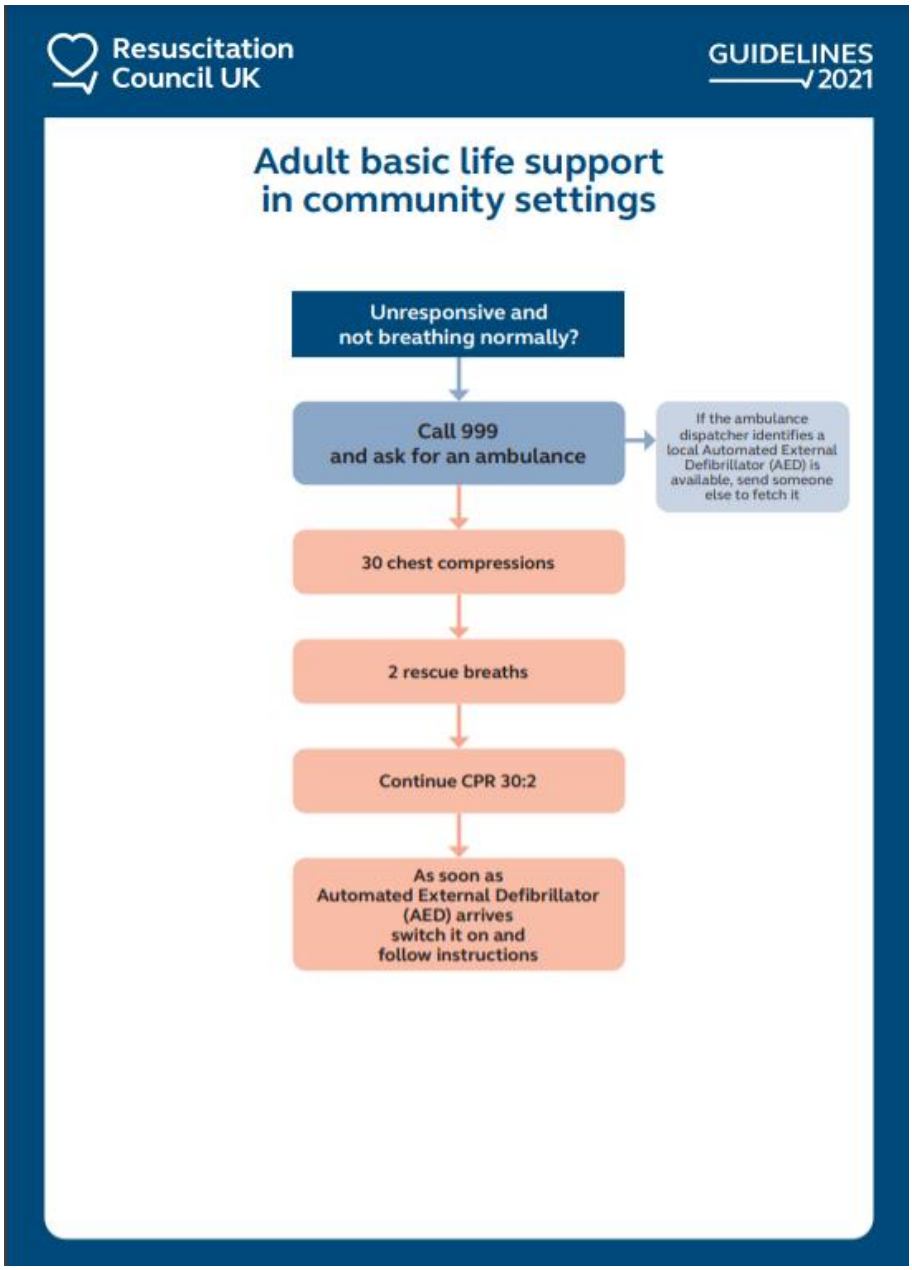

Figure 2-7 **Adult basic life support sequence in community setting (RCUK 2021a)**

Those rescuers who have been trained in paediatric resuscitation, could include the paediatric modifications, but still use the adult sequence (Fig. 2-8). The modifications are in place to account for the aetiology of most of the paediatric cardiac arrest, which stems from respiratory instability or hypoxia. The paediatric modifications to adult CPR include providing five rescue breaths before starting chest compressions and, if the rescuer is on their own, perform CPR for one minute before summoning help. Additionally, the chest should be compressed by at least one-third of its anterior-posterior diameter, which is approximately 4cm for an infant and approximately 5cm for an older child. Finally, the rescuer should use the two-thumb or two-finger technique for the infant to achieve an adequate depth of compression and reduce the risk of over compressing the chest with consequent poor quality iCPR and trauma to internal organs.

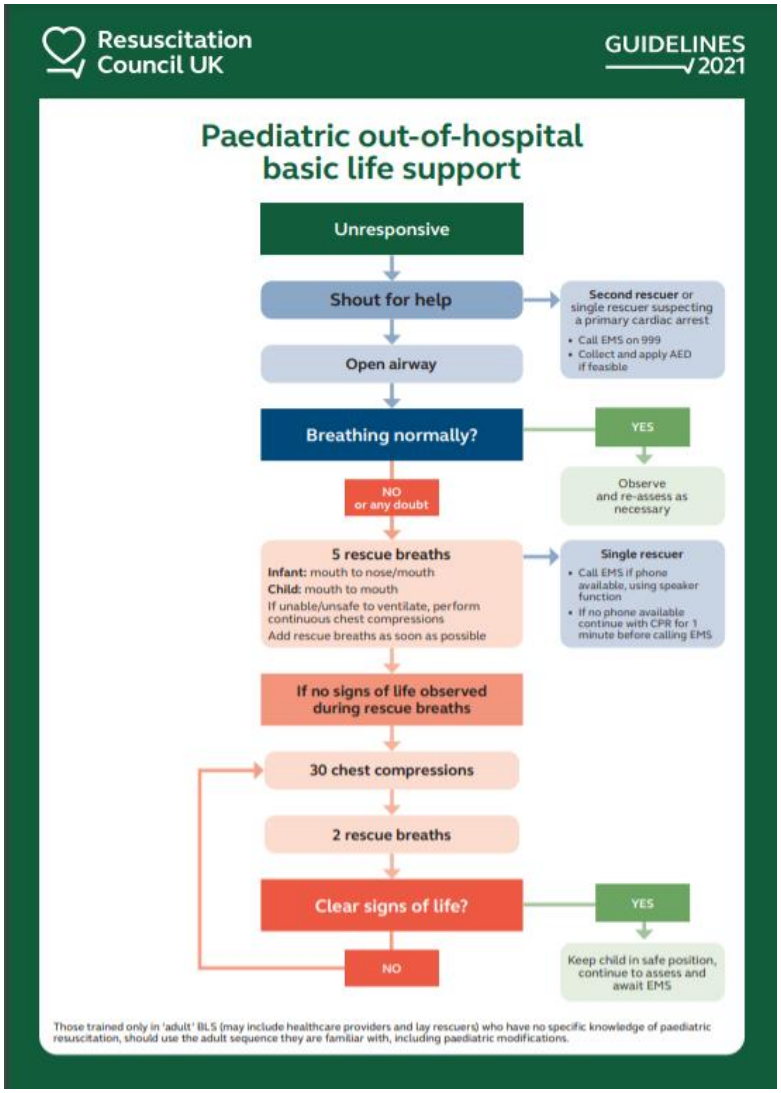

Figure 2-8 **Paediatric out-of-hospital basic life support (RCUK 2021c)**

Those who have duty to respond to paediatric emergencies are required to follow the paediatric algorithm in an attempt to deliver a more effective and comprehensive treatment (Fig. 2-9).

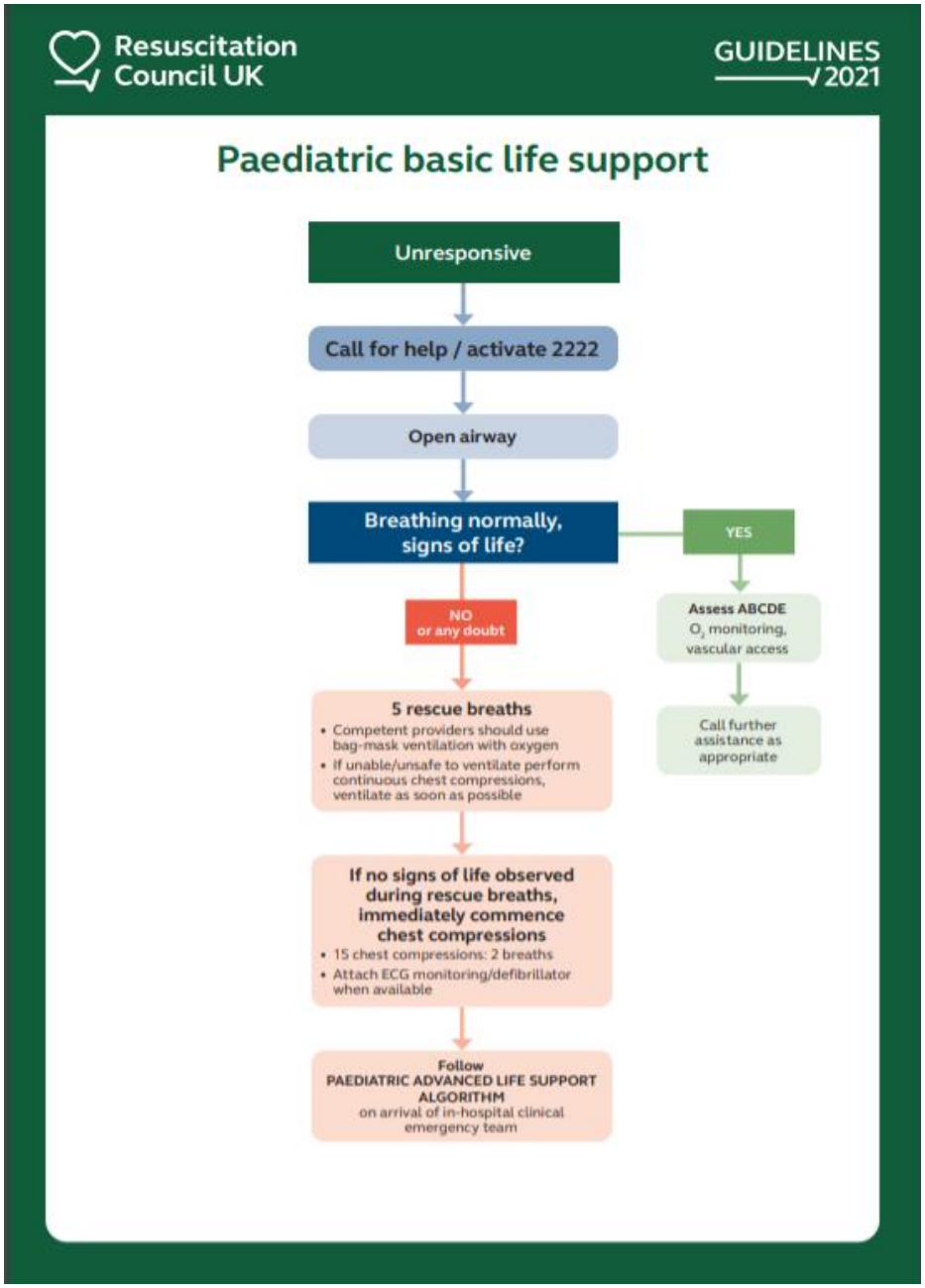

Figure 2-9 **Paediatric basic life support (RCUK 2021d)**

2.3.4 Infant CPR

Children, particularly infants, have limited compensatory mechanisms to overcome severe illness or injury, and the demands of cerebral blood flow and energy metabolism are higher than those in adults due to neuronal maturation and synaptogenesis (Tress *et al.* 2010). Therefore, in a cardiac arrest situation, prompt

commencement of high-quality CPR directly impacts survival and outcome (Aharon *et al.* 2001, Topjian *et al.* 2020, Skellett *et al.* 2021, Voorde *et al.* 2021).

Two standardised techniques have been described by resuscitation guidelines to rescue an infant in cardiac arrest, and their effectiveness have been investigated by several studies (Todres and Rogers 1975, Dorfsman *et al.* 2000, Udassi *et al.* 2009, Smereka *et al.* 2017, Millin *et al.* 2020). The latest resuscitation guidelines (Topjian *et al.* 2020, Skellett *et al.* 2021) recommend the two-thumb (TT) encircling technique (Fig. 1-2, Chapter 1) for more than one rescuer when performing CPR on an infant in cardiac arrest or the two-finger (TF) technique (Fig. 1-1, Chapter 1) for the lone rescuer delivering iCPR.

The TT technique consists of encircling the rescuer's hands around the infant's chest with the thumbs placed on the lower third of the sternum just above the xiphoid process and below the nipple line pointing towards the infant's head, while the hands and fingers support the back (Fig. 1-2 Chapter 1). Although this technique has been associated with better coronary perfusion and deeper and more consistent chest compressions (Todres and Rogers 1975, Menegazzi 1993, Dorfsman *et al.* 2000, Udassi *et al.* 2010), it is recommended to be used just when multiple rescuers are present. This is because there is a theoretical concern that it would result in poor quality ventilations (rescue breaths) when just one rescuer is present, due to potential difficulty in alternating between chest compressions and ventilations (Smereka *et al.* 2017, Millin *et al.* 2020). As ventilation is a fundamental part of iCPR due to the great majority of cardiac arrests in this age group having a respiratory

component to its pathophysiology, the resuscitation guidelines have strongly recommended the use of the TT technique for more than one rescuer for many years.

The TF technique involves placing the tips of the rescuer's fingers (usually middle and index fingers) on the lower third of the sternum, above the xiphoid process and below the nipple line, perpendicular to the chest (Fig. 1-1, Chapter 1). Recommended for the lone rescuer, this technique facilitates rapid transition between chest compressions and ventilation, minimising interruptions in chest compressions (Skellett *et al.* 2021).

The point of compression for both techniques, where the thumbs or fingers are placed, is an important factor to determine the quality of iCPR. Initially, the recommended compression point for chest compressions in infants was on the middle part of the sternum. However, after studies regarding infant cardiothoracic anatomy demonstrated that the infant heart lays a few centimetres below that landmark (Phillips and Zideman 1986, Finholt *et al.* 1986, Orlowski 1986), the point of compression for iCPR has been defined as the lower third of the sternum, just below the nipple line, avoiding the xiphoid process (Maconochie *et al.* 2015, Atkins *et al.* 2015, Maconochie *et al.* 2020, Skellett *et al.* 2021).

For an optimum outcome, iCPR must begin as soon as it is established that the victim is unconscious and not breathing. Based on the guidelines (Skellett *et al.* 2021), the sequence and technique to attempt resuscitation on an infant in cardiac arrest (out-of-hospital) is as follow:

- A member of the public or family should ensure the safety of themselves and infant.

- Recognise that the infant is unwell and check for responsiveness. This can be done by gently stimulating the infant by tapping the sole of their feet or saying their name.
- If no response, the rescuer should shout for help. When there is more than one rescuer, a second rescuer should call 999 to ask for EMS. If there is no other rescuer, the sequence of iCPR should be continued for one-minute before summoning help.
- The infant must be turned onto their back and the airway should be opened using the head tilt and chin lift technique (Fig 2-10).

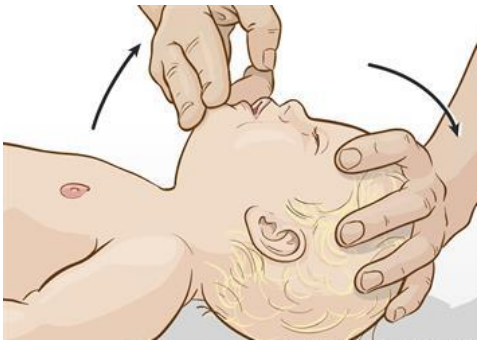

Figure 2-10 Head tilt and chin lift technique (AKH 2022)

- Keeping the airway open, the rescuer must look, listen, and feel for breathing (normal/abnormal/absent) by putting their face close to the infant's mouth and looking along the chest for any sign of life including chest movements, breath sounds, or coughing. This should take no more than ten seconds. In the initial few minutes after a cardiac arrest, the infant may be making some noisy, infrequent gasps. This is considered agonal breathing and should not be confused with normal breathing. If the rescuer isn't sure if breathing is normal, they must act as if it is not normal.

- If the infant is breathing normally, the rescuer should place the infant into the recovery position (Fig 2-11), maintaining the airway open and continuously assessing their condition. Help should be summoned at this point, if not done before.

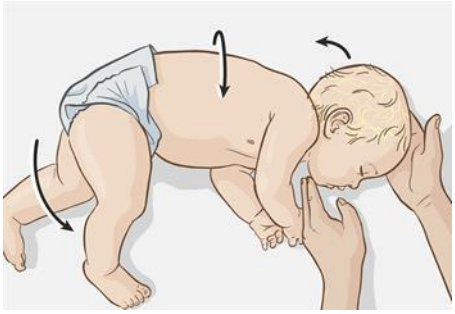

Figure 2-11 Recovery Position (AKH 2022)

- If the infant is not breathing normally, the rescuer should provide five initial rescue breaths:
    - Ensuring the head is in a neutral position and applying chin lift (Fig 2-10). As the infant's head is usually flexed when in supine position, a gentle lift is required.
    - The rescuer should take a normal breath in and, making sure there is a good seal, must cover the mouth and nose of the infant with their mouth, blowing steadily into the infant's mouth and nose over one second.
    - Maintaining the head position and chin lift, the rescuer should move away from the infant's face and watch for their chest to return to its original position as air comes out.
    - This sequence should be repeated four more times, totalling five rescue breaths.

- If the infant is still not breathing normally and there are no signs of life, the rescuer must start good quality chest compressions using the TT encircling technique or TF technique, according to the number of rescuers, as previously described in this Chapter. A more comprehensive explanation about chest compressions metrics will be provided later in Section 2.3.6 of this Chapter.
    - Chest compression depth should be at least one-third of the anterior–posterior dimension of the infant's chest, which is approximately 4cm, but never deeper than 5cm to avoid internal trauma.
    - Rate of compressions must be between 100-120 min^{-1}
    - A complete recoil or release of the chest should be aimed for during the relaxation phase (after each compression) to allow blood to return to the heart before the next compression.
    - Approximately 50% of the cycle should be the relaxation (or decompression) phase. This is also known as duty cycle, which is the percentage between compression and relaxation.
- After 30 high-quality chest compressions, the rescuer must provide two rescue breaths as described above.
- The combination of 30 chest compressions and two rescue breaths should be continued until the infant shows signs of life, qualified help (EMS) arrives, or the rescuer becomes exhausted and there is nobody to take over.

(Topjian *et al.* 2020, Skellett 2021, Van de Voorde *et al.* 2021)

2.3.5 Chest Compression Phases

Chest compressions during iCPR contribute to the maintenance of the haemodynamic function of the heart by mechanically generating blood flow to vital organs, including the heart itself. Chest compression can be divided in two segments: compression and decompression (or recoil).

During the compression phase, the increase in thoracic pressure and compression of the heart against the sternum and vertebrae, eject blood from the heart, lungs and vessels. If performed correctly, the compression phase increases cardiac output and provides a rise in blood pressure. Most vital organs get some blood supply during the compression phase of CPR, however, the heart is not perfused during compression. The vessels responsible for heart perfusion are the coronary arteries, which originate from the aorta and extend along the surface of the heart, perfusing the myocardium (Loukas *et al.* 2013). As the coronary arteries transverse the heart, chest compression squeezes these arteries, preventing perfusion to the heart. Therefore, coronary perfusion occurs during decompression.

In the decompression phase, the chest passively recoils, creating a negative intrathoracic pressure. It optimises haemodynamics by creating a vacuum inside the chest, refilling the heart and lungs in preparation for the next compression (Yannopoulos *et al.* 2004, Aufderheide *et al.* 2005). Thus, it is very important to allow the chest to fully recoil after each compression as incomplete recoil has a detrimental effect on coronary perfusion, which is associated with poor survival outcomes (Paradis *et al.* 1990).

Therefore, when iCPR is performed, both compression and decompression phases have equal importance in perfusing vital organs.

2.3.6 Infant Chest Compressions Metrics

Current resuscitation research and guidelines identified some components of chest compression that are closely related to high-quality iCPR performance: chest compression depth, chest compression rate, chest recoil or residual leaning and compression duty cycle (Maconochie *et al.* 2015, Topjian *et al.* 2020, Considine *et al.* 2020, Skellett *et al.* 2021). These CPR metrics have been recognised because of their influence on blood flow during a cardiac arrest and patient outcome. Comprehending the impact of these metrics and their relative relationships is important to the improvement of CPR quality and training, and the development of effective equipment to measure and optimise performance (Kramer-Johansen *et al.* 2007, Meaney *et al.* 2013, Topjian *et al.* 2020).

2.3.6.1 Chest Compression Depth

Chest compression depth (CCD) is described as the maximum posterior deflection of the chest during compressions and is recommended to be at least 1/3 the external anterior-posterior chest diameter in an infant (approximately 4cm) (Kramer-Johansen *et al.* 2007, Sutton *et al.* 2014b, Topjian *et al.* 2020, Maconochie *et al.* 2020, Skellett *et al.* 2021, Van de Voorde *et al.* 2021). This recommendation is based on animal studies (Babbs *et al.* 1983, Bellamy *et al.* 1984, Bruckner *et al.* 2022), paediatric chest computed tomography studies (Braga *et al.* 2009, Kao *et al.* 2009, Jin *et al.* 2016, Ong *et al.* 2021), retrospective observational studies (Sutton *et al.* 2010, Sutton *et al.* 2015, Lee *et al.* 2019a), post-mortem examinations (Bush *et al.*

1996, Weber *et al.* 2009, Collins *et al.* 2014) and manikin studies (Martin *et al.* 2013a, Kim *et al.* 2015).

According to Kramer-Johansen (2007), CCD is considered a challenging metric to be measured and adjusted during CPR as it cannot be easily visualised or inferred from simple metronomes. Since closed-chest compression was introduced back in 1960 (Kouwenhoven *et al.* 1960), the optimal chest compression depth has been frequently evaluated by several researchers. It has been demonstrated that shallow chest compressions are a common flaw during real CPR and simulated performance in both adult and paediatric populations (Martin *et al.* 2013b, Stiell *et al.* 2014, Kim *et al.* 2015), reducing cardiac output and coronary perfusion, which negatively impact survival to hospital discharge (Jin *et al.* 2016).

While deeper chest compressions, compliant to resuscitation guidelines, have shown correlation with increased cardiac output (Babbs *et al.* 1983, Bellamy *et al.* 1984), improved defibrillation success and survival to hospital discharge (Kramer-Johansen *et al.* 2006, Edelson *et al.* 2006), over compressing the chest may lead to iatrogenic injuries such as rib fractures, pneumothorax, epicardial haematoma, pulmonary haemorrhage, stomach perforation and retroperitoneal hematoma (Orlowski 1980, Reardon *et al.* 1987, Spevak *et al.* 1994, Weber *et al.* 2009, Collins *et al.* 2014, Lee *et al.* 2019a, Ong *et al.* 2021).

Prior findings of over-compression for paediatric CPR were limited by small datasets, as well as age and ethnic differences. For this reason, before the 2010 resuscitation guidelines, CCD for children was recommended to be up to 1/2 of the anterior-posterior chest diameter (Biarent *et al.* 2005, ILCOR 2005, RCUK 2005). However,

with further research concluding that this compression depth was too deep for children and could cause iatrogenic injuries, resuscitation guidelines introduced a CCD of at least 1/3 of the anterior-posterior diameter of the child's chest, and this recommendation has been maintained ever since (Biarent *et al.* 2010, Pederzini *et al.* 2010, Maconochie *et al.* 2015, Skellett *et al.* 2021).

2.3.6.2 Chest Compression Rate

Chest compression rate (CCR) is defined as the frequency of compressions performed during a determined interval (one minute as per guideline) and it is impacted by interruptions in chest compressions. The original reports of CPR suggested a varied chest compression rate starting with "about 60 times per minute" (Kouwenhoven *et al.* 1960, p.1066), reducing to 30-40 times per minute according to Franz Koenig's technique (Fig *et al.* 2006), jumping to 120 per minute after Friedrich Maass successfully resuscitated a child by increasing chest compression rate (Fig *et al.* 2006), until reaching the current recommendation of 100-120 compressions per minute (Topjian *et al.* 2020, Skellett *et al.* 2021, Voorde *et al.* 2021). The ideal CCR was originally unknown and, to this day, is still a subject of controversy. Data from animal studies suggest that 150 compressions per minute increases cardiac output (Maier *et al.* 1984), and 120 per minute increases 24-hour survival due to mean aortic and coronary perfusion pressures (Feneley *et al.* 1988). In 2010, ILCOR advised that CCR should be at least 100 per minute and due to scarce evidence, no recommendation of a precise upper limit should be advised (Koster *et al.* 2010). Current resuscitation guidelines recommend the chest compression rate to be between 100 and 120 min^{-1} (Topjian *et al.* 2020, Skellett *et al.* 2021, Voorde *et al.*

2021). Unlike compression depth, CCR is easy to quantify and adjust, as it can be directly observed or measured by feedback devices (Cheng *et al.* 2015, Calvete *et al.* 2017, Lin *et al.* 2018).

As a result of ethical constrains, most data relating to CPR performance originates from manikin studies (Abella *et al.* 2005, Martin *et al.* 2013b, Sutton *et al.* 2018, Duval *et al.* 2019) and animal models (Fitzgerald *et al.* 1981, Sunde *et al.* 1998a, Sunde *et al.* 1998b). The appropriate number of compressions delivered during CPR is substantially related to survival to hospital discharge (Sunde *et al.* 1998a, Kim *et al.* 2015, Dezfulian *et al.* 2018) and depends on the rate of compressions and interruptions since, even with appropriate delivery of CCR based on guidelines, pauses during CPR will significantly decrease the number of compressions actually delivered (Christenson *et al.* 2009). CCR below 80 min^{-1} or above 120 min^{-1} is associated with decreased return of spontaneous circulation and decreased survival to hospital discharge (Abella *et al.* 2005, Idris *et al.* 2105, Sutton *et al.* 2014a, Sutton *et al.* 2018).

According to Hwang *et al.* (2016), CCR is a key element of cardiac output during CPR, since chest compressions generate only 1/3 of the stroke volume when compared to spontaneous circulation. Therefore, maintaining compression rate as advocated by the resuscitation guidelines, can be an effective way to improve cardiac output during CPR.

2.3.6.3 Chest Recoil

Current resuscitation guidelines recommend full chest recoil after each compression (Topjian *et al.* 2020, Skellett *et al.* 2021, Voorde *et al.* 2021). This is defined as the return of the sternum to a neutral, anatomical position at the end of the decompression phase of CPR. The incomplete release of the chest (also known as residual leaning (RL)) results in increased intrathoracic pressure during the decompression phase, which in turn, reduces the return of venous blood to the heart, cardiac output, coronary perfusion and cerebral perfusion pressures (Yannopoulos *et al.* 2005, Zuercher *et al.* 2010, Sutton *et al.* 2010).

Data from paediatric animal studies and paediatric patients are vital to establish the minimal threshold at which RL causes detrimental consequences on haemodynamics in children. Results from adult patients may not be transferable to paediatric patients because of chest compliance and consequent greater intrathoracic effect of RL (Papastamelos *et al.* 1995, Maltese *et al.* 2008). Some studies have looked at real paediatric patients to determine the minimal RL that would impact haemodynamics. The results concluded that a RL >2.5kg was associated with clinically important changes in intrathoracic pressure (Sutton *et al.* 2010, Zuercher *et al.* 2010, Niles *et al.* 2011, Eilevstjønn *et al.* 2011, Glatz *et al.* 2013). Although a study conducted in piglets suggested that RL as little as 1.8kg decreases coronary perfusion and blood flow to the heart (Zuercher *et al.* 2007), the threshold was based on other laboratory investigations.

Despite resuscitation guidelines recommendation to completely release the chest to achieve a high-quality CPR and positive patient outcome, several studies have

established that incomplete chest release during decompression phase of CPR is commonly seen during adult and paediatric resuscitation in both out-of-hospital and in-hospital cardiac arrests (Aufderheide *et al.* 2005, Niles *et al.* 2009a, Glatz *et al.* 2013, Talikowska *et al.* 2020). This inefficiency highlights the necessity to train rescuers to achieve the recommended target ranges for each metric of CPR, including complete release of chest during the decompression phase.

2.3.6.4 Compression Duty Cycle

Compression duty cycle (DC) is another component of CPR and is defined as the proportion of time spent actively compressing the chest during the downstroke of compression (Babbs *et al.* 1995, Berg *et al.* 2010, Cutler *et al.* 2014).

Current recommendation from Resuscitation Council UK (RCUK) for compression DC is 50% in paediatric CPR (Skellett *et al.* 2021) and is based on evidence from animal and laboratory studies (Dean *et al.* 1991, Sunde *et al.* 1998a, Sunde *et al.* 1998b, Jung *et al.* 2006). However, it is important to recognise that, although DC remains a relatively understudied CPR quality metric, previous researchers have identified that compression DC of 30-50% can optimise cerebral and myocardial perfusion and haemodynamics of CPR (Fitzgerald *et al.* 1981, Dean *et al.* 1991, Sunde *et al.* 1998a, Babs 2006, Kim *et al.* 2020, Taegyun *et al.* 2020).

The few studies that have investigated DC as part of the outcome measures, concluded that rescuers do not meet current guidelines for this metric during resuscitation attempts (Martin *et al.* 2013a, Cutler *et al.* 2014, Johnson *et al.* 2015, Wolfe *et al.* 2016, Almeida *et al.* 2020). This is consistent with results based on other metrics concluding that poor adherence to resuscitation guidelines results in

ineffective CPR performance, leading to a reduced chance of return of spontaneous circulation and/or survival to hospital discharge.

Additionally, the relationship between compression DC and the other CPR metrics has been previously explored, due to their potential association with patient outcome (Wolfe *et al.* 2016). According to Johnson *et al.* (2015), DC was inversely associated with CCD and correlated with CCR, such that a lower DC corresponded to deeper compression and slower rate. This suggests that the proportion of time spent actively compressing the chest during the downstroke of compression, likely influences other important CPR metrics. Although evidence indicates that compression depth and rate are associated with better clinical outcomes (Stiell *et al.* 2012, Idris *et al.* 2012, Vadeboncoeur *et al.* 2014, Duval *et al.* 2019), these studies have not analysed DC, raising the question as to whether the influence in clinical prognosis was due to depth, rate, DC or a combination of them all.

The lack of sufficient studies incorporating DC in their outcome measures may be explained by the recommendations from Kramer-Johansen *et al.* (2007), an international working group to suggest standardised definitions and criteria of how best to report CPR quality based on its metrics. According to the above-mentioned authors, inclusion of DC in research should be optional due to the scarce data on patient outcome related to this metric and the limited ability to adapt and modify DC during CPR performance. Despite this recommendation, this thesis will incorporate DC into the measured metrics of the experimental studies, as the author believes this variable presents a significant value into the interpretation of results about quality of iCPR performance.

2.3.7 Rescue Breaths

As mentioned earlier in this thesis (Chapter 1 and Chapter 2, Section 2.3), rescue breaths are an essential part of infant cardiopulmonary resuscitation, due to the aetiology of cardiac arrests in children, often resulting from complications and progressions of respiratory failure (Kleinman 2018, Molyneux 2020). Therefore, as part of iCPR, rescue breaths should be provided either mouth-to-mouth (or mouth-to-mouth-and-nose), which could be supported by protective devices such as pocket mask or face shield; or via a self-inflating bag connected to endotracheal tube or face mask (Rodriguez 2013). Additionally, head position must be correctly adjusted with an adequate seal between the rescuer's mouth or mask and the patient's face.

Current resuscitation guidelines advocate a compression:ventilation ratio of 30:2 for bystander iCPR and 15:2 for rescuers with duty to respond to paediatric cardiac arrest (Skellett *et al.* 2021, Voorde *et al.* 2021). Although a 15:2 ratio provides more ventilation, recommending a different compression:ventilation ratio for children (15:2) and adults (30:2) when training lay people or basic life support, could impair learning, cause confusion or misunderstanding and omission (Manrique *et al.* 2020).

There are many aspects influencing an optimal compression:ventilation ratio during iCPR including compression and ventilation rates, pauses in chest compression, compression fraction, tidal volume, inspiratory time, and inspiratory pressure (Kramer-Johansen *et al.* 2007). This is an area of great research interest because both excessive ventilation (high rates and/or tidal volumes) and hypoventilation (low rates and/or tidal volume) can be potentially harmful when rescuing a patient in cardiac arrest (Halperin *et al.* 1986, Aufderheide and Lurie 2004, Wik *et al.* 2005, Santos-

Folgar *et al.* 2018). During iCPR, less ventilation is needed for adequate gas exchange, as a reduced blood flow is observed within the pulmonary circulation (Santos-Folgar 2018). Therefore, hyperventilating the patient can increase intrathoracic pressure, compromise venous return, and reduce cardiac output (Aufderheide and Lurie 2004, Rodriguez 2013). A correct balance between hypo and hyperventilation is thus critical to neurologically favourable survival to hospital discharge (Lurie *et al.* 2016).

Even though ventilation is undeniably important during iCPR, the author has omitted any further discussion on this topic, since the present thesis focuses on chest compressions and its variables during iCPR.

2.4 CPR Education and Training

Since the circulatory aspect of CPR (external chest compressions) was initially described in 1786, advances in paediatric resuscitation have evolved. Numerous groups and institutions have developed and established CPR training courses for healthcare providers and laypeople, which were based on the latest resuscitation guidelines. In 1983, the American Heart Association (AHA) recommended the development of a training course in paediatric advanced life support (PALS), with the first PALS courses beginning in 1988 (Quan and Seidel 1997). In the UK, there are a number of organisations that deliver CPR training (charities, voluntary ambulance services, private companies) which are all based on the latest RCUK guidelines. According to RCUK (2020), “healthcare organisations have an obligation to ensure that staff are trained and updated regularly and with appropriate frequency to a level of proficiency appropriate to each individual’s expected role.” However, it is not clear how frequently training or retraining should occur, and most organisations require

annual BLS training or even biannual (once every two years) for paediatric BLS, depending on the practitioner's role. However, with CPR skills and knowledge decaying just weeks to months after training (Kleinman *et al.* 2018, Saad *et al.* 2019, Lockey *et al.* 2021), it raises the question as to how optimal yearly updates are for maintaining the quality of paediatric CPR skills.

Current paediatric CPR training vary significantly worldwide, but commonly involves attendance at a two-hour instructor-led session every one or two years (RCUK 2015a, RCUK 2015b, Cheng *et al.* 2020, Lockey *et al.* 2021), often without measurement of competence. The minimum requirements to obtain certification are normally visually assessed by the instructor or via a self-assessment tool (Jones *et al.* 2015), suggesting that just taking part in the training does not mean the delegates' skills are of a high standard, which is confirmed by evidence demonstrating that performance immediately after training is consistently poor (Sutton *et al.* 2011, Martin *et al.* 2013a, Anderson *et al.* 2019, Matsuura *et al.* 2020, Lockey *et al.* 2021).

There are many ways in which adult or paediatric CPR training can be delivered. Traditionally, instructor-led training has been used to facilitate acquisition of knowledge and skills, but other methods can be an effective alternative. They include online-based distance learning with or without practice on manikins; mass training; virtual reality apps; peer-assisted learning; deliberate practice with shorter sessions spread over certain time; simulation; automated voice advisory manikin; booster training sessions; or in-situ training (de Vries *et al.* 2007, Perkins 2007, Harvey *et al.* 2012, Gugelmin-Almeida *et al.* 2021a, Lockey *et al.* 2021). The length of training, amount of hands-on practice, ratio of instructor:participants and equipment

availability, will depend on the method of delivery, however it is recommended that any CPR training should include practice on a manikin (RCUK 2020a, RCUK 2022b).

The UK CPR training model is bound by a set of criteria based on theoretical and practical training on a manikin, given by a qualified instructor according to the role of the learners. RCUK (2022b) defines four distinct groups for which training should be adapted accordingly:

1. The general public should have an awareness about cardiac arrest, CPR and automated external defibrillator (AED).
2. Secondary school children should be taught (embedded in the curriculum) basic CPR and AED training.
3. Those without a formal duty of care to rescue a person in cardiac arrest (e.g. teachers, lifeguards, first aiders, healthcare professionals without duty to respond to a cardiac arrest) should receive basic CPR and AED training.
4. Those with a duty of care to rescue a person in cardiac arrest (e.g. doctors, emergency department practitioners, high dependency unit practitioners) should receive an enhanced CPR and AED training.

Training specifications for these groups differ, but the principles underlying the training standards are that: (i) individuals should receive training based on their role and responsibilities; (ii) the method of training can be tailored to the individual groups; (iii) early recognition of cardiac arrest; (iv) summoning adequate help; (v) early high-quality CPR; and (vi) and early defibrillation (if advisable). Basic training should include theoretical background in CPR, chain of survival, safety and hazards, recognition of cardiac arrest, call for help, correct CPR performance with emphasis

on high-quality chest compressions, retrieving and using an AED, and when to stop CPR. Enhanced training should include elements of basic training plus methods of artificial ventilation, different compression:ventilation ratios, feedback of performance and debriefing (RCUK 2020b, Lockey *et al.* 2021, RCUK 2022b).

Training should be tailored to the needs of different types of learners and learning styles to ensure acquisition and maximise retention of resuscitation knowledge and skills (Greif *et al.* 2021). There is no specification about retraining, but RCUK recommends that skills should be refreshed at least once a year, but preferably more often. It is important to note that training and retraining are the same in the current UK model. There is no retraining strategy. Individuals receive the same training package on a yearly basis, and because CPR knowledge and skills decay within weeks to months after training (Kleinman *et al.* 2018, Saad *et al.* 2019, Lockey *et al.* 2021), this current system should be assessed for effectiveness.

2.4.1 Efficacy of Current CPR Education and Training

As previously mentioned, there is a substantial heterogeneity of education and training/retraining for both adult and paediatric CPR, and studies investigating the effectiveness of these strategies do not offer conclusive results. This is because of the varied methods applied including models of training, interventions, outcome measures and other variables (Finn *et al.* 2015). Identifying training and retraining models that enhance learning acquisition and retention of CPR skills is important to maximise performance and improve patient outcome after cardiac arrest (Donoghue *et al.* 2021).

In healthcare learning, aligning aspects of educational theories with healthcare training, provides a framework for designing and delivering effective learning strategies (Aliakbari *et al.* 2015). By understanding the importance of practical experiences, cognitive load, context of learning, and individual construction of knowledge, healthcare training can be tailored to maximise the potential to achieve learning outcomes (Aliakbari *et al.* 2015, Badyal and Singh 2017, Dong *et al.* 2021).

Many educational theories, concepts and principles have been suggested and applied in the context of healthcare learning including behavioural theories, cognitivism, experiential learning, constructivism, reflective models, critical theory, and others (Mukhalalati and Taylor 2019). Although there are individual characteristics that make each theory unique, they overlap in many aspects.

A common factor that is observed in almost every theory is the acknowledgement that the learner is actively involved in the educational process (Badyal and Singh 2017). This is applicable to cognitivism, a learning theory that focuses on the internal process of information suggesting that distinct types of skills will incur different cognitive processes. The facets involved such as memory, organisation and neurological connections are perceived as pivotal in cognitivism (Ertmer and Newby 1993, Patel *et al.* 2009). Similarly, constructivism emphasizes the role of the individual in constructing their own learning by connecting new knowledge to previous experiences. It involves encouraging critical thinking, problem-solving, and creativity as the learner builds their own understanding through active participation in a continuous constructed and reconstructed learning process (Torre *et al.* 2006, Aliakbari *et al.* 2015). Another educational theory that places the learner in the

centre of the learning process is behaviourism. This theory emphasizes the importance of reinforcement, feedback and repetition in shaping and sustaining changes in behaviours/skills (Ertmer and Newby 1993, Badyal and Singh 2017). Although each theory provides distinctive ways of viewing the educational process, it does not mean that they necessarily conflict with one another. Theories have the potential to complement each other, resulting in a more holistic educational process.

This research has used elements of different educational theories, concepts, and principles. For example, the use of feedback to reinforce outcome is based on behaviourism; self-guided practice to improve performance links to constructivism; and judging how to alter performance according to feedback follows constructivism. The most relevant approach used in this thesis that also focus on the learner as a pivotal element of the learning process, is the mastery learning concept. This model emphasizes the importance of achieving mastery over a particular subject or skill before moving on to more advanced levels of learning. It suggests that all learners can achieve mastery if they are given enough time and appropriate resources to learn at their own pace (Carroll 1989, Guskey 2007).

Mastery learning was developed in the 1960s by educational psychologist Benjamin Bloom, who argued that traditional teaching methods were ineffective, because they assumed that all individuals could learn at the same pace (Bloom 1968). The author proposed an alternative approach that would allow learners to master a skill in a series of small incremental steps aligned with key aspects such as defined learning outcomes; individualised training strategy; repeated instruction and feedback to

improve skills; and continuous evaluation of performance (Bloom 1968, Guskey 2007).

Current research in adult and paediatric CPR education has investigated the effectiveness of different educational theories and training models, with the majority pointing to the potential usefulness of alternate learning strategies (Niles *et al.* 2009b, Sutton *et al.* 2011, McGaghie *et al.* 2016, Panchal *et al.* 2020, Ingrassia *et al.* 2020). Many methods of training have been created based on the above-mentioned educational theories, with the most common discussed below.

Instructor-led, classroom-based has traditionally been the most common method of CPR training (Einspruch *et al.* 2007). This model offers good learning acquisition by substantially improving CPR metrics when compared to pre-training (Lynch *et al.* 2008, Hirose *et al.* 2014, Brown *et al.* 2016, Sand *et al.* 2021). However, associated costs, time and logistics are common barriers to this training model (Einspruch *et al.* 2007). Additionally, although performance improves from pre-training, CPR quality after training is frequently suboptimal and do not comply with resuscitation guidelines (Perkins *et al.* 2008, Martin *et al.* 2013a, Sutton *et al.* 2015, Manrique *et al.* 2020, Talikowska *et al.* 2020). This may be explained by the lack of measurement of competence or quantitative assessment of performance during training. Currently, the minimum requirements to obtain certification depends on subjective opinion that the instructor makes about an individual's performance against some pre-set criteria (Bullock *et al.* 2015) or via an assessment tool (Jones *et al.* 2015). It may be suggested that, despite attending the training and improving performance, participants do not achieve competence after training. Therefore, despite its

effectiveness, the current preferred method of CPR training/retraining should be reviewed.

In 2015, the concept of blended learning with online CPR teaching and hands-on practice on manikins was introduced by the AHA (Bhanji *et al.* 2015). Prior to that, studies have investigated its usefulness with some demonstrating improvement in CPR metrics compared to no training (Jones *et al.* 2007, Bobrow *et al.* 2013, Lehman *et al.* 215) and others resulting in improvement in some metrics but not others (e.g. depth and hand placement) (Godfred *et al.* 2013, Panchal *et al.* 2014). Furthermore, other studies concluded that online/video training was effective but not superior when compared to instructor-led training (Mancini *et al.* 2009, Saraç *et al.* 2010). Facing this inconclusiveness, it is clear that further evidence is needed in determining the effectiveness of online learning for high-quality CPR performance. Although, because online learning has similar results to instructor-led training, this strategy can be an effective alternative to face-to-face education, particularly in low-resource settings and/or geographically isolated locations (AHA 2018c, Lau *et al.* 2018).

Similarly to online/video-based learning, another potentially efficacious strategy to enhance CPR skills acquisition is the use of virtual reality (VR) or augmented reality (AR) during teaching. Many studies have investigated the use of these tools during CPR training with results indicating an increase in performance from pre-training (Bench *et al.* 2019, Nas *et al.* 2020, Kuyt *et al.* 2021, Ricci *et al.* 2022). Nevertheless, despite improvement in performance, other research suggests that VR/AR-based training are comparable but not more efficient than the traditional classroom-based, instructor-led courses (Khanal *et al.* 2014, Leary *et al.* 2019). This is also the case

when pocket reference cards are compared to AR glasses during simulated paediatric CPR. Siebert *et al.* (2017) concluded that, even though some of the outcome measures did not improve with the use of AR, adherence to the correct defibrillation doses was achieved. Although it is observed that the field of virtual and augmented reality in resuscitation is growing, it is still diverse and immature. Furthermore, despite its effectiveness, unless they are accepted by rescuers and trainers during healthcare training, their benefits become limited (Semeraro *et al.* 2009, Ingrassia *et al.* 2020).

Another important strategy for training and/or retraining of CPR skills is the incorporation of deliberate practice and/or mastery learning in resuscitation education. Deliberate practice is an approach where learners have enough time to improve performance through short repetition and immediate feedback (Ericsson *et al.* 1993). As previously mentioned in this section, mastery learning can be defined as the use of deliberate practice combined with individualised training strategy, repeated assessment, and feedback, based on a pre-defined achievement criterion. Passing this assessment implies that mastery of the task or skill has been achieved (McGaghie *et al.* 2016). These training models have been previously researched in the field of resuscitation and may be associated with improvement in performance and reduced skill decay (Wayne *et al.* 2006, Hunt *et al.* 2014, Diederich *et al.* 2019). Nevertheless, its impact is equivocal as other studies did not find a substantial difference in learner outcome (Boet *et al.* 2017, Lemke *et al.* 2020). This ambiguity may be attributed to the lack of consistency in study methodology, participants and outcome measures which are seen in current evidence on deliberate practice and mastery learning (Ericsson and Harwell 2019). Published literature in health and

other fields such as education, have used these terms in their methodology but, in reality, the intervention applied would not meet the requirements or definition of mastery learning and/or deliberate practice. A typical example would be when the learning and content are divided into short sessions spread over time (distributed practice). Although this strategy is likely to be beneficial, it lacks the repetitiveness coupled with immediate feedback to improve performance, as described in the deliberate practice approach (Macnamara *et al.* 2014).

To apply the concept of mastery learning in the resuscitation field, the elements of effective chest compressions may need to be segregated to establish a threshold measure of mastery. Quality chest compression is formed by different elements including four internationally recommended quality measures (CCR, CCD, RL, DC) which, in combination, culminate in high-quality resuscitation skill (Kramer-Johansen *et al.* 2007, Skellett *et al.* 2021). Therefore, segregating these measures in a way of establishing competence, may not result in mastery of CPR skills, as the above-mentioned variables must be achieved concomitantly for high-quality chest compression (Kramer-Johansen *et al.* 2007). This is particularly relevant to chest compression DC. Although current recommendation from RCUK for compression DC is 50% in paediatric CPR (Skellett *et al.* 2021), this metric remains relatively understudied and its application is still rare in current research. As previously mentioned in this Chapter, this may be explained by the recommendations from Kramer-Johansen *et al.* (2007) suggesting that inclusion of DC in research should be optional, due to the scarce data on patient outcome related to this metric and the limited ability to adapt and modify DC during CPR performance. Therefore, this particular metric is not part of “mastery” in many studies. This may impact the

interpretation of results as DC is closely related to other variables and consequently, may be associated with patient outcomes (Johnson *et al.* 2015, Wolfe *et al.* 2016).

Additionally, when determining the criteria for CPR mastery, apart from including high-quality metrics, appropriate clinical contexts must be acknowledged, as the learning objectives may not necessarily be identical. For laypeople for example, it may be more important to recognise a cardiac arrest and apply basic concepts of CPR and defibrillation (Kleinmann *et al.* 2015), whilst for healthcare professionals, optimising chest compression metrics and ventilations is expected (Link *et al.* 2015). Therefore, acknowledging that one-size fits all may not be an effective strategy in determining mastery level, is an important aspect during CPR training (Donogue *et al.* 2021).

Paired with the potential effectiveness of deliberate practice and/or mastery learning, simulation and real-time feedback are potentially strong components of the learning processes associated with resuscitation training and retraining (Wayne *et al.* 2006, Perkins *et al.* 2007, Cheng *et al.* 2015, Cortegiani *et al.* 2017). The use of the immersive clinical experience in a controlled environment without exposing the patients to risks, surpasses the old, mostly ineffective and unethical learning model of “see one, do one and teach one” (Mason *et al.* 2003, Morgan *et al.* 2005). Simulation-based training has been an important educational tool and research strategy in different areas, including cardiopulmonary resuscitation (Kunkler 2006). It allows targeting learner needs for the development of knowledge/skills, instead of patient’s medical circumstances, and permits for multiple attempts to achieve competence, without putting patients at risk (Kneebone *et al.* 2004). This is also the

case for “in-situ” or “just-in-time” training, where a short practice session is performed directly prior to and at/near the patient side where a potential cardiac arrest may occur (Niles *et al.* 2009a). These short “booster training” sessions have been shown to be effective in enhancing the quality and retention of CPR skills (Niles *et al.* 2009b, Sutton *et al.* 2011).

It is important to note that, despite the many benefits of simulation-based education, there are at least an equal number of challenges associated with its practice. Elements such as technical issues and logistics (including transport, set up, storage and maintenance of equipment); cultural obstacles (where healthcare practitioners may get concerned that “in-situ” training may be perceived as either disruptive or intimidating to patients and families); staff motivation; and availability of resources, are some of the examples associated with challenges or barriers to simulation-based training (Patterson *et al.* 2008). As with many other training/retraining strategies, research in simulation-based education presents heterogenous results, however evidence consistently supports the benefits of its practice (Perkins 2007, Weile *et al.* 2021).

Finally, many research methods and CPR education have implemented the use of RTF devices to potentialize the benefits of instructor-lead and/or simulation-based training. As further explained in Chapter 3, Section 3.11, the use of RTF allows for the measurement of performance, by quantifying quality measures such as CCR, CCD, RL, and DC. The technology provides visual and/or audio information on CPR quality to enhance performance according to resuscitation guidelines (Gruber *et al.* 2012). Its use has been profusely investigated in resuscitation research and it has been

demonstrated that the devices enhance CPR skill acquisition and performance during training and retraining for both adult and paediatric CPR (Gugelmin-Almeida *et al.* 2021a). Due to the complexity and importance of feedback in the acquisition and retention of CPR skills, Section 2.6 of this Chapter will further explore its use, benefits and challenges.

As explained so far in this Chapter, resuscitation training and/or retraining can be delivered using different strategies, depending on the learners' background and the context in which CPR will be expected to be performed. As such, identifying learners' needs is a pivotal aspect to be observed when developing an effective training model. Additionally, contemporary recommendations for complex psychomotor skills education such as CPR, recognise that psychomotor tasks involve knowledge and skill sub-parts (Nicholls *et al.* 2016). It is understood that any model of hands-on training improves psychomotor skills. Nevertheless, because knowledge and skills decay at different rates, with psychomotor skills deteriorating more rapidly than knowledge (Hamilton 2005, Allen *et al.* 2013), training/retraining should focus not on knowledge only, but on the skills sub-components of the overall CPR psychomotor task (Yeung *et al.* 2012). With this in mind, it can be suggested that integrating the concepts of instructor-led training with deliberate practice, mastery learning and RTF, can be a robust strategy to enhance paediatric and adult CPR training/retraining and potentially improve learning outcomes and retention of skills (Donogue *et al.* 2021).

2.5 Retention of CPR Skills

Poor CPR skill retention after initial training may be a contributing factor in the low survival rates after cardiac arrest (Saad *et al.* 2019). Evidence suggests significant skill

decay and decline of knowledge within months after training (Niles *et al.* 2017, Cheng *et al.* 2018, Lockey *et al.* 2021). Other studies indicate that skills decay as early as weeks after training (Young and King 2000, Spooner *et al.* 2007, Anderson *et al.* 2019), impacting CPR quality and lessening the chance of positive outcomes to cardiac arrest patients. The skill and knowledge decay are applicable to lay people (e.g. school age students, flight attendants, police officers) (Mahony *et al.* 2008, Anderson *et al.* 2012, Brown *et al.* 2016, Cho *et al.* 2021) or highly trained professionals (Niles *et al.* 2017, Anderson *et al.* 2019, Sand *et al.* 2021). The current paediatric and adult CPR retraining models are normally designed within the context of wider organisational demands and pressures; priorities; available resources and rescuer's needs. In the UK, there is no specification about retraining strategies, but RCUK recommends that skills should be refreshed at least once a year, but preferably more often (Lockey *et al.* 2021). This recommendation and current model should be assessed for effectiveness considering how soon after initial training, CPR knowledge and skills decay, as mentioned earlier in this section.

This decline may be explained by poor acquisition of knowledge and skills during initial training and inconsistent practice, thereafter, resulting in low-quality performance weeks or months later. Many studies have demonstrated that, despite participation in CPR training, rescuers do not perform good quality CPR immediately after training (Oermann *et al.* 2011, Manrique *et al.* 2020, Kuzma *et al.* 2020). This may be due to the use of visual assessment of skills or self-reported assessment, overestimating individual's performance. Considering that the quality of CPR skills cannot be effectively examined by visual assessment because of the different metrics and high motor-control demands, the feedback provided by instructors may

therefore be ineffective (Wang *et al.* 2015, Brenann *et al.* 2016). This may result in sub-optimal knowledge/skills acquisition and consequent low-quality performance. Additionally, deterioration of skills can be the result of muscle memory loss due to insufficient practice, partially due to the lengthy gap between mandatory training (every one or two years), and partially due to the low rates of cardiac arrests, reducing exposure to both simulated and real-life CPR performance (Cheng *et al.* 2020, Lockey *et al.* 2021). This issue, added to the possible ineffective acquisition of knowledge and skills, raises the question as to why the current training strategy of yearly or every two-yearly update is thought to be optimal for maintaining the quality of CPR skills.

Another explanation associated with decay of CPR skills may be the variability and inconsistent performance, which can impact results at follow-up. Many studies investigating retention of CPR skills have not accounted for natural variations in the delivery of this complex skill. Establishing variability in human performance is key to understanding changes and skill deterioration (Almeida *et al.* 2020). If performance is not consistent within days of training, then any differences seen months later could be due to variation and inconsistent performance rather than skill decay. This concept is broadly explained in Chapter 3.

In order to maintain adequate and effective CPR skills, previous research has tried to identify the frequency of training and retraining for both paediatric and adult CPR (Yang *et al.* 2012, Gugelmin-Almeida 2022b). Although the results are conflicting, there is a consensus that skill retention and patient outcomes may improve by increasing the frequency of retraining. Oermann and colleagues (2011) and Sullivan

and colleagues (2015) investigated skill retention with retraining at different intervals (3, 6, 9, 12 and 2, 3, 6 months respectively) and concluded that more refresher sessions were associated with better outcomes. This was also observed in studies by Niles *et al.* (2009b) and Sutton *et al.* (2011) performed in paediatric settings. Their results indicate that ≥2 refresher sessions after initial training significantly improved the likelihood of retaining paediatric CPR skills when compared to no refresher sessions.

Monthly exposure to CPR skills, added to incorporating repetitive practice for mastery learning, may be associated with enhanced educational outcomes and less skill decay (Niles *et al.* 2009b, Oermann *et al.* 2011, Anderson *et al.* 2019, Donogue *et al.* 2021). However, this may not be viable in clinical practice due to associated high costs, time away from clinical areas and staff motivation (Ward and Wood 2000). According to Greif *et al.* (2021), determining effective educational and retraining methods is key to linking scientific findings and implementation of results. Promoting high-quality paediatric CPR performance during resuscitation training/retraining may maximise retention of paediatric CPR skills that can then be transferred into clinical practice. Therefore, identifying the ideal strategy that facilitates effective learning and creates a sustainable retraining schedule to maximise skill retention is a key element that has yet to be established.

Considering the impact of the timeframe and length of retraining sessions to improve and maintain CPR skills, the author decided it would be pivotal to gather information on evidence of intervals and strategies of formal paediatric resuscitation training/retraining and the associated outcomes. Therefore, a scoping review of

literature was performed, in an attempt to best inform the design of an experimental study conducted as part of this research. It was essential to determine the appropriate amount of reinforcement needed and the rate of re-exposure for effective maintenance of paediatric CPR skills. This is further explored in Chapter 6.

2.6 The Use of Feedback for Training, Retraining and Retention of CPR Skills

Training and feedback are important elements for acquisition of motor skills (Bosse *et al.* 2015). Feedback can be presented in different formats, and it is unclear what type and frequency of feedback maximize the effect on cognitive or motor skills learning. Since training in the medical field is normally expensive (NHS 2019) due to temporary backfill of a multidisciplinary team, the equipment used and specialised trainer; finding effective training methods and efficient feedback strategies that can result in cost savings and adequate learning and retention of knowledge and skills are a significant objective for researchers worldwide.

In the context of motor learning research, feedback is normally directed at the outcome of a skill (e.g. quality of iCPR) or the movement/element associated with the skill (e.g. release force after chest compression) (Wulf *et al.* 2010). The latter is normally delivered by an instructor more efficiently when compared to the former, considering that the quality of iCPR cannot be effectively examined by visual assessment without the use of a mechanical feedback device. Since iCPR is a skill with different metrics and high motor-control demands, feedback and instructions for iCPR learning often involves reference to the learner's movements in relation to certain body parts, correlated with space and time (e.g. two fingers placed in the lower part of the infant's sternum, pressing 4cm down at a rate of 100-120

compressions per minute). However, there is evidence that feedback provided by instructors on chest compression skills during simulated CPR is of poor quality (Wang *et al.* 2015).

The role of feedback is to provide information about an individual's performance and/or understanding of a subject. In this context, studies have addressed elements such as types of feedback provided, the effect of feedback on outcome measures, accuracy of feedback and automated feedback devices (Yeung *et al.* 2009, Wang *et al.* 2020, Gugelmin-Almeida *et al.* 2021a). Although the benefits of feedback during CPR training have been evidenced (Perkins 2007, Lateef 2010, Pozner *et al.* 2011), there is no clarity with regards to what type of feedback is effective to improve learning and retention of the skills. In addition to instructor feedback, several automated devices have been developed and are used during adult and paediatric (including neonatal) CPR training and real resuscitation attempts, following recommendations from resuscitation guidelines (Chen *et al.* 2010, Dellimore *et al.* 2013, Bhanji *et al.* 2015, Cortegiani *et al.* 2017, Cheng *et al.* 2020, Greif *et al.* 2021, Lockey *et al.* 2021). However, while audio-visual feedback devices can be effective in offering real-time feedback on CPR performance, this may impair concentration and impact acquisition of CPR skills, because the devices involve audio-visual attention of the trainees during performance. 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 and patient outcome. (Greif *et al.* 2021, Gugelmin-Almeida *et al.* 2021a).

For this reason, it was decided that it would be crucial to perform a systematic literature review (Chapter 2, Section 2) to investigate the usefulness of feedback devices for CPR training and real-life performance. The review had to include both paediatric and adult subjects due to limited studies in the paediatric population. The results of the systematic review were of vital importance to this research as, based on them, the most effective feedback strategy was selected for reinforcement of skills during the experiments.

Section 2

This section addresses the methods of the systematic review – "Do automated real-time feedback devices improve CPR quality? A systematic review of literature" and presents it in form of a manuscript published in *Resuscitation Plus* as part of the integrated thesis format submission. The need to identify the usefulness of feedback devices for CPR training was a key aspect for the development of this thesis. The results would inform the most appropriate feedback strategy to be used for reinforcement of skills during the experiments, and further progress this research.

Systematic reviews are important tools to generate new knowledge based on the identification, evaluation, and summary of findings of all relevant studies of a particular topic. It makes the available evidence more accessible to researchers, clinicians, policy makers and the wider population (Gopalakrishnan and Ganeshkumar 2013).

The protocol for this systematic review was created and reported using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA), which aims to

offer a structured direction on the reporting of systematic reviews (Moher *et al.* 2009). The study design is outlined in the published manuscript, describing the electronic databases selected and PICOS (Population, Intervention, Control, Outcomes and Study design) selection. As previously explained in Section 2.4 of this Chapter, CPR training specifications differ for particular groups. The general public or school children have training adapted to what they need to know and do when providing bystander CPR. Similarly, healthcare practitioners with or without a formal duty of care to rescue a person in cardiac arrest will have different training formats (RCUK 2020a, Lockey *et al.* 2021, Skellett *et al.* 2021). Therefore, to maximise generalisability to the target population of this research, the selection of the studies included in this systematic review focused on healthcare providers.

The search strategy was designed by the author with the search terms revised by an experienced librarian. MeSH (Medical Subject Headings) was used to select suitable terms based on relevant concepts, with variations of search terms trialled using "Boolean" operators (OR, AND) to increase recall. Additionally, truncation (*) was also applied to maximise recall rate of relevant studies that could address the PICOS. The full search strategy and risk of bias assessment can be seen as appendices in the published manuscript.

See: Gugelmin-Almeida, D., Tobase, L., Polastri, T. F., Peres, H. H. C., and Timerman S., 2021. Do automated real-time feedback devices improve CPR quality? A systematic review of literature. *Resusc Plus*, 27 (6), 100-108.

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Training and education

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

Debora Gugelmin-Almeida[a,b,*], *Lucia Tobase*[c], *Thatiane Facholi Polastri*[d], *Heloisa Helena Ciqueto Peres*[e], *Sergio Timerman*[d]

[a] Faculty of Health and Social Sciences, Bournemouth University, Bournemouth Gateway Building, St. Pauls Lane, Bournemouth, BH8 8GP, England, United Kingdom

[b] Department of Anaesthesiology, Main Theatres, Royal Bournemouth and Christchurch Hospitals, Castle Lane East, Bournemouth, BH7 7DW, England, United Kingdom

[c] Centro Universitário São Camilo, Rua Raul Pompeia, 144, São Paulo, Brazil

[d] Instituto do Coração do Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, Av. Dr. Enéas de Carvalho Aguiar, 44, São Paulo, Brazil

[e] Escola de Enfermagem da Universidade de São Paulo, Av. Dr. Enéas de Carvalho Aguiar, 419, Brazil

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.[1,2] A current report by the American Heart Association (AHA) demonstrated that emergency medical services respond to more than 347,000 adults

* Corresponding author.
E-mail address: almeidad@bournemouth.ac.uk (D. Gugelmin-Almeida).

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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.[3] 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.[4,5]

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.[6–9] 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.[5,10,11]

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.[12,13] 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.[14,15]

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.[16–21] 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.[22] 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)[6,7] and AHA[8,9]

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."[23,24]

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).[25] 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[20] 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[16,18,20,21,26,27,29–31,33,34,36–39] and four randomised cross-over trials (RCOTs).[17,28,32,35] 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

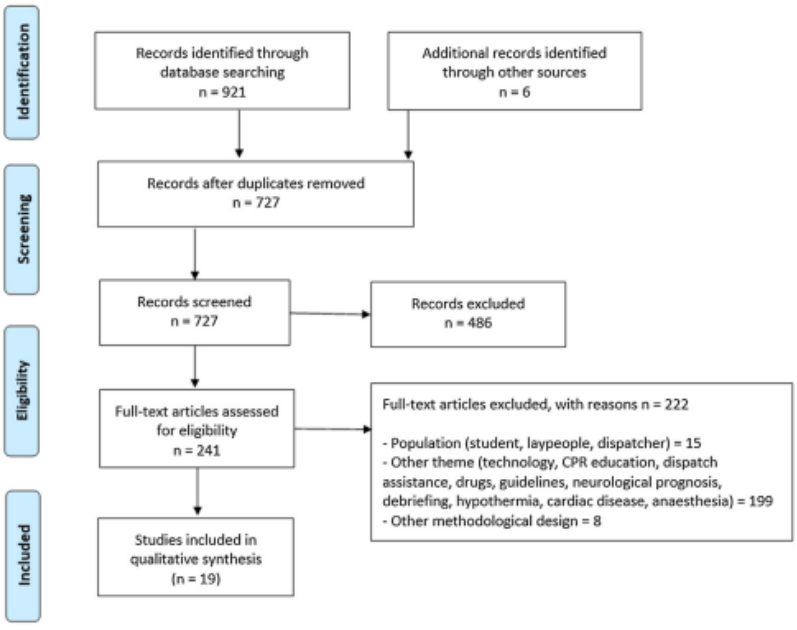

Fig. 1 – PRISMA—Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement.

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 (metronome) 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. Metronome 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% (±37.54) vs 67.09% (±31.95) P = 0.024 and depth percentage in target (48.86% (±42.67) vs 72.95% (±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 (±4.7 min^{-1}) vs 118.5 (±14.2 min^{-1}) P < 0.001; and depth (56.5 mm (±4.7 mm) vs 49.5 (±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
Truszewski 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 (±5.8) vs 129.4 (±22.4) P < 0.001; depth 54.5 (±9.5) vs 44.6 (±15.8) P < 0.001; and leaning (%) 21.5 (±9.7) vs 31.6 (±5.4) P = 0.018 Feedback device (CPR-Ezy) compared with standard CPR significantly improved rate only 101.5 (±4.8) vs 129.4 (±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 (±21.0) vs. 96.7 (±25.8) P = 0.026; and depth 5.54 (±1.89) vs 6.16 (±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% ± 27.8) vs (70.5% ± 37.7) P = 0.039; and depth (54.8 ± 33.5%) vs (35.9 ± 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 (±SD)) 8.64 (±0.7) vs 5.18 (±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.[3,5] International guidelines reinforce the critical importance of the quality of manual chest compression metrics such as rate, depth and complete release of chest.[3,6–9] 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.[40–42]

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.[43] 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).[13,18,31]

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.[44–46] 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.[47–51] 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[21,30,34,39] and the aspect of mattress deflection was acknowledged in most of them.[21,34,39]

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.[16–18,20,26,28,31] 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,[17,34] audio,[21,39] visual,[17,27–29,32,34] or audiovisual.[18,30,31,36–38] 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.[17,18,26,27,29,33,34] And one study demonstrated no change in performance when comparing standard CPR with the use of feedback device.[16] (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.[18,26,27a,27b,29a,29b–33,35,37,38] 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.[18,26,27a,27b,29b,30–33,35,37,38] 12 reported a significant improvement in the percentage of compression rate compliant with resuscitation guidelines when a feedback device was used.[18,26,27a,27b,29a,29b–33,37,38] And four studies demonstrated a significant improvement in the percentage of residual leaning compliant with resuscitation guidelines when a feedback device was used.[18,29a,29b,32] (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.[52] 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).[17,20,28,34,36] 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,[17] 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, Truszewski 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.[21,39] 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.[17,18,20,21,27b,28,29b–32,34,36–39] Conversely, other studies have demonstrated mixed effects, with results showing improvements in some of the outcome measures but not in others[26,27a,29a,33,35] or no improvement at all.[16] 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 Kirkibright et al.[53] and Yeung et al.[54] 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.[55]

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.[40–42] 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 ofinterest

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

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2.7 Chapter Summary and Next Steps

This Chapter discusses relevant topics related to cardiac arrest and cardiopulmonary resuscitation, particularly related to the infant population. It covers important aspects such as epidemiology, survival rates and outcomes of cardiac arrest worldwide; aspects of CPR including history, development of guidelines, chest compression metrics and ventilation. The Chapter also explores current evidence regarding CPR training/retraining and the efficacy of models of training. Finally, an overview of the use of feedback for training and the impact on retention of CPR skills. The Chapter provides current, evidence-based information about different aspects of iCPR and some of the gaps in knowledge that this research aims to address.

Next Steps

The following Chapters (3, 4 and 6) will describe and discuss the justification of the methodological approaches used for the experimental studies performed during the development of this thesis. Chapter 5 will outline the justification and methodology used for the scoping review of literature conducted to inform the design of Chapter 6. Each study generated a published manuscript which are included within the Chapters. However, because of the limited word count allowed in scientific articles, a broadened explanation of the methods is provided in this thesis to enhance the understanding of the reader.

Chapter 3 Justification of the Methods and Study Design: "Reliability Study"

3.1 Chapter Overview

This Chapter comprises two sections: the first one addresses in detail the methodology and design of STUDY 1 – "Consistency and variability in human performance during simulated infant CPR: a reliability study". This was an experimental study aimed at exploring variability in human performance during iCPR. The important justification of the methodological aspects of the study are further explained in this section, as it was not possible to include them in the published manuscript. This includes the detailed research approach; the aims, objectives, and outcomes of the study; ethical considerations; participant recruitment; research methods and context for the statistical choices to analyse the results. The second section of the Chapter is presented as the published manuscript (Almeida *et al.* 2020) as part of the integrated thesis format submission. An evaluation of the limitations of the study is presented at the end of the Chapter to contextualise the results. The next steps for the thesis are also discussed to support the reader to follow the development of the research.

Section 1

3.2 Aims and Objectives

The literature review presented in Chapter 2 of this thesis revealed that previous studies have recognised the importance of identifying the frequency of CPR retraining for the retention of adequate and effective skills (Niles *et al.* 2009b, Sutton *et al.* 2011, Oermann *et al.* 2011, Anderson *et al.* 2019, Panchal *et al.* 2020, Abelsson

et al. 2021). However, there is no evidence regarding the consistency of human performance during CPR. This is critical to broadly understand changes in CPR performance and determine its natural variability, to establish if any difference seen months after training could be due to variation and inconsistent performance rather than skill decay. Therefore, the aims of this reliability study progressed from the findings of the literature review. The author recognised that, prior to describing iCPR skill changes as deterioration or improvement, a critical step would be to establish variability in human performance to properly understand and interpret changes and natural variations in the delivery of a skill like iCPR.

To address the identified knowledge gap, the overall aims of the study were to explore and determine the repeated measure's reliability (degree of correlation between measurements) and variability of individuals performing simulated iCPR within the same day and between days.

To achieve the above aims, the following objectives were developed to inform the research design and processes:

1. To determine the degree of correlation between repeated measures for the following metrics: (i) chest compression rate (CCR), (ii) chest compression depth (CCD), (iii) residual leaning (RL), and (iv) compression duty cycle (DC), to establish consistency of iCPR performance.

2. To determine the degree of agreement between repeated measures for the following metrics: (i) CCR, (ii) CCD, (iii) RL, and (iv) compression DC, to establish consistency of iCPR performance.

3. To evaluate the effect of converting iCPR measures in quality indices (QI) - defined as the percentage of chest compressions meeting the following targets: (i) CCD (40mm - 45mm), (ii) CCR (100 – 120/min), (iii) RL (<2.5kg), (iv) compression DC (45% - 50%) and (v) overall performance (proportion of chest compressions achieving the 4 metrics simultaneously). Table 3-1, Section 3.11.4 provides justifications of the values above, selected to each target range.

3.3 Study Design

This study used an experimental, prospective, observational design that was conducted to test within-day and between-day reliability and variability of iCPR performance using repeated multiple measures. It was conducted in a simulated environment within a university setting with healthcare students from the following programmes: Operating Department Practice (ODP), Physiotherapy, Nursing, Paramedic Science, Occupational Therapy, Social Sciences and Midwifery. The justification as to why healthcare students were selected to be participants of this study is further explored in Section 3.7 of this Chapter.

There have been discussions about the issues and potential ethical barriers arising from when students are participants in research (Shannon 1979, Henry and Wright 2001). The major concerns involve: (i) the pressure felt by the students to participate in research, particularly when it is led by their Faculty. This is because of the relationship with their teacher/lecturer/professor that can be compromised (or compromise the research) by the student's participation (or not) in the research; (ii) the risk associated with participation in research, which are not obvious when the students grant consent.

Some authors suggested that when students are invited to take part in research, they may feel under pressure or coerced to sign up as participants, despite the explicit mention about the voluntariness and option to withdraw at any time without consequence. They may feel that not accepting to take part may generate a negative response from the Faculty and their colleagues, or negatively impact their studies and progress (Shannon 1979, Sullivan 2011).

However, Forester and McWhorter (2005) and Sarpel *et al.* (2013) investigated medical students' opinion on their participation as research volunteers and concluded that the students did not feel obliged to partake in the study. "In fact, respondents repeatedly affirmed that they had an active desire to participate in such studies, even if they themselves did not directly benefit" (Sarpel *et al.* 2013, p.5). The participants from both studies felt that taking part in research was crucial to improve their education, and they would not expect better grades or recommendation from taking part. Importantly, the qualitative response included those who completed the research, those who have not taken part and those who withdrew from the studies.

In recognition to this possible risk of students feeling coerced into taking part in this reliability study, the principal investigator ensured to explain the voluntariness and option to withdraw at any point without the need to explain. This was also clearly written in the participant's information sheet (Appendix 1) and participant's consent form (Appendix 2). Additionally, a gatekeeper was used as first point of contact for a particular group of students (further explained in Section 3.5 of this Chapter).

Another issue raised when students are volunteers in research is related to undetectable risk. Although scholars reflect on the risks involved in their research

and create a risk assessment with actions to counteract or minimise possible risks and hazards, some risks are not readily apparent or accounted for. Concerns about distractions and time away from their studies due to the tasks associated with the research may pose an unseen risk (DuBois 2002). However, it has also been shown that, if the demands of research become unmanageable, students feel comfortable to withdraw from the study without feeling that this will impact their studies and career progression (Sarpel *et al.* 2013). This has been observed in the abovementioned studies, where participants withdrew due to time constraints. Albeit there was a small demand associated with this reliability study (less than four hours in total), the participants were informed on three different occasions (during recruitment, consent stage and prior to commencement of the study) about the option to withdraw without prejudice. Despite this, there was no loss of participants at follow-up.

3.4 Ethics Protocol, Approval Process and Considerations

The research protocol and ethics application (Reference ID: 22558) were submitted on 25th October 2018 to Bournemouth University Research Ethics Committee (UREC), which is responsible for promoting best ethical practice in relation to research and research-related activities. Bournemouth University's Research Ethics Code of Practice (2021) informs local practices and procedures across the University and was used to guide the design and conduct of the study. The protocol included Participant Information Sheet, Participant Consent Form, Recruitment Poster, Participant Questionnaire and Risk Assessment (Appendices 1-5). The application was reviewed on 6th November 2018 and, after relevant amendments and justification based on

the reviewer comments, ethical approval was granted on 15th November 2018 (Appendix 6).

3.5 Gatekeeper

The author and principal investigator of this study is a lecturer for the ODP programme at Bournemouth University (BU), where the experiment was conducted and, although the study was open to all BU students, due to the potential recruitment of ODP students, a gatekeeper was used for the recruitment process only.

A gatekeeper is an individual or institution that represents the interests of and acts as a mediator between a researcher and potential participants (Singh and Wassenaar 2016). Gatekeepers may be healthcare professionals, community leaders, family members, director of an organisation, headteacher of an educational institution, who may also grant or deny permission for access to potential research participants.

In this study, the gatekeeper was the ODP programme lead who was not involved with the research being conducted and therefore, could offer the ODP students who were interested in taking part in the study, a separate and independent point of contact to the principal investigator.

3.6 Risk Assessment

It is well understood that considering the safety risks involved in a study and finding ways to minimise those risks of happening, are extremely important aspects of a research project (Department of Health 2005). Most types of research have some associated risks and appropriate arrangements must be in place to protect

participants and researchers should something go wrong during a study (Shaw and Barrett 2006).

During the planning of this study, a full risk assessment was undertaken to address any potential problems that could occur. The identified hazards associated with the study included trips and falls due to equipment and cables placed on the floor; latex allergy or skin irritation from manikin, accessories and disinfecting agent (wipes) used during the experiment; cross contamination of bodily fluids via manikin; and bruised or sore knees due to the position needed to deliver iCPR on the floor.

To minimise the risk of those hazards occurring, some control measures were put in place including:

- manikin to be stored away when not in use, and researchers and participants to be aware of trip hazards when entering the room and using the equipment;
- verbal confirmation from manufacturer that NO latex is used in manufacture of the manikin or accessories;
- follow manufacturer's recommendation to use cleaning wipes on the manikin after each use to eliminate the chance of cross-contamination;
- instruction given to participants on use of wipes in each session, and ensuring manikin is dry before re-use to reduce the chance of skin irritation;
- rubber matt to be used for every participant during delivery of iCPR.

The likelihood of the identified hazards causing harm to researchers and participants after control measures were in place was considered low and the risk was regarded as minimal. The full risk assessment is shown in Appendix 5.

3.7 Participant Recruitment

A convenience sample of healthcare students from BU was selected for this study. It can be suggested that they are the healthcare practitioners of the future, therefore their participation would increase the generalisability of the results. Additionally, their participation in this research could be considered as a valuable educational experience (Jager *et al.* 2017) as CPR training is mandatory to healthcare students and developing this skill could enhance their future practice.

Despite its unfavourable generalisability compared to probability samples, convenience samples account for over 92% of participants in research (Bornstein *et al.* 2013). To optimise the benefits of convenience sample and to enable a clear generalisability, the author limited its disadvantages in relation to population effects and subpopulation differences. In an attempt to reduce the chance of bias in the participants sample, one demographic aspect (healthcare students) was intentionally constrained, to reflect the target population (healthcare professionals), following the strategy of homogeneous convenience sample, for clearer generalisability. According to this strategy, "the more homogeneous a population, the easier (more probable) it is to generate a representative sample, even when using convenience sampling. Therefore, by intentionally constraining the sampling frame to reduce the amount of sociodemographic heterogeneity, the chance of bias in sampling, as it relates to sociodemographic characteristics of the target population, is reduced." (Jager *et al.* 2017, p.7).

The participants were recruited between January 2019 and February 2019 from BU healthcare student population via a poster (Appendix 3) displayed around the

University (primary recruitment tool), on Brightspace (BU's Virtual Learning Environment) and word of mouth. The multiple tools to recruit participants were selected in an attempt to reach a larger number of students and potentially reduce recruitment time. Lengthy recruitment periods or insufficient participants brings potential adverse scientific, economic, and ethical consequences, such as increased costs, cancelation or postponement of the research, and reduced statistical power with reduced sample (Kaur *et al.* 2012). The researcher's contact details were provided on the posters for interested students to get in touch for more information and subsequent enrolment. In addition, the gatekeeper contact details were also provided to enable ODP students to make the initial contact.

Thirty-three students contacted either the principal investigator or the gatekeeper via email and telephone. After the initial introduction and brief explanation of the study, potential participants were provided with an online copy of the Participant Information Sheet (Appendix 1). This included full details of the research project, such as study design, purpose, duration, methods, possible risks, the voluntary status of participation and that the participants could stop taking part in any activity or could withdraw at any point, up until their data had been anonymised and incorporated into the study, without having to give a reason. The potential participants were advised to read it and get back to the principal investigator if they wanted to enrol. Participant Information Sheet is an important aspect in research, as it enables potential volunteers to make an informed decision about their involvement or not in a study. To avoid misunderstanding or impaired comprehension, the content should be simple, succinct, and easy to read as

unnecessary complexity is likely to intimidate potential participants, impair comprehension and impact recruitment (Ennis and Wykes 2016).

After the initial contact, a sample of 30 participants was enrolled from different BU healthcare programmes (as described in Section 3.3). On the day of the study, two participants contacted the principal investigator to inform they would not be able to attend, and one participant did not turn up, making the final number of participants included in the study 27.

3.8 Informed Consent

Informed consent is an important aspect underpinning ethical principles in current research involving humans as participants. It confirms their agreement to participate in a study after understanding its specifications, risks and considering each aspect relevant to their decision whether to take part or not (Manti and Licari 2018).

One week prior to data collection, every participant was provided with a consent form (Appendix 2) and a written copy of the Participant Information Sheet (Appendix 1). Both documents were written in language easy to understand and minimised the possibility of coercion, helping to clarify the participant's right to voluntarily take part in the research or refuse it without any disadvantage or consequence.

Before the commencement of the study, there was an opportunity to discuss the research with the principal investigator and once more, the voluntary nature of the participation was emphasised. After answering the questions and confirming that the participants were satisfied, the consent forms were signed by the participant and principal investigator together and each participant was offered a copy of the signed consent form for their keeping.

3.9 Anonymity and Confidentiality

Protection of the students who were the participants in this research was the highest priority, therefore an identification code was generated for each participant to assure anonymisation and confidentiality. The consent form was the only document containing the identification code and participants' identification details (i.e., name and surname). Every other research document and data were anonymised. The principal investigator is the only person with access to the consent forms. Protecting participants' details can enhance the public's trust and credibility in research (Kaiser 2009).

3.10 Data Collection Process

Study packages containing an information sheet (which was also previously provided via email in advance of the study), a questionnaire and a consent form, all identified with the individual code and concealed in identical opaque envelopes were distributed to every participant. The researcher was available to discuss the study and to complete the consent form prior to engagement with the study. All participants were made aware that withdrawal from the study would be possible at any time and this decision would not impact their studies in the University.

Data relating to age, height, weight and self-declared physical issues that could compromise performance were gathered via the questionnaire (Appendix 4) in order to create a demographic profile of the sample. This information enables the determination of whether the participants are a representative sample of the target population for generalisation purposes. It can serve as independent variables in the research design and can also be explored for their moderating effect on dependent

variables (Connelly 2013). Only the demographic information that is necessary for the specific purposes of the research should be collected. There is evidence that age, height, weight and physical issues affect CPR performance (Ebbeling *et al.* 2010, Papalexopoulou *et al.* 2014, Jaafar *et al.* 2015) therefore, the above demographic metrics were selected for this study.

After informed consent and questionnaires were completed, participants received the standard four-stage approach Paediatric Basic Life support (BLS) education package (Bullock 2015) delivered by a qualified instructor. Although there are different methods and strategies for BLS or CPR training including blended learning, computer-based learning, peer learning and others (AHA 2018c, Arasteh *et al.* 2018, Riggs *et al.* 2019), RCUK recommends accredited life support courses for the delivery of CPR training (Lockey *et al.* 2021). Additionally, because the purpose of this study was not to assess the quality of training, the author selected the training method recommended by RCUK. Instructor-led, classroom-based has traditionally been the most common method of CPR training (Einspruch *et al.* 2007). This model offers good learning acquisition by substantially improving CPR metrics when compared to pre-training (Hirose *et al.* 2014). The four-stage approach was proposed by Peyton (1998) and adapted by Bullock (2000) for resuscitation training. It recommends the demonstration of CPR by the instructor without commentary, followed by demonstration of the skills, broken into simple steps and with commentary. The instructor then demonstrates the skill with the learner providing the commentary, and finally the learner demonstrates and comments on the skill (Bullock 2015). This approach has been demonstrated to significantly improve some segments of BLS

performance (Greif *et al.* 2010, Barelli and Scapigliati 2010, Krautter *et al.* 2015, Frangež *et al.* 2017).

Aligned with resuscitation guidelines for BLS rescuers with no duty to respond to a paediatric cardiac arrest, the training was delivered with a compression:ventilation ratio of 30:2. After the recommended 30-minute practice (Bullock 2015) on infant manikins (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway) using the two-finger (TF) technique, participants were individually invited to a separate room set up with the instrumented manikin (description below) for data collection. The TF technique was selected based on resuscitation guidelines that recommend this technique for the lone rescuer (as seen in Chapter 2, Section 2.3.4).

The principal investigator was in the data collection room to initiate and pause the software. Brief instructions on when to start and stop the iCPR were provided, however no further interaction between participants and the principal investigator was permitted during data collection. In addition, the participants did not receive any form of feedback. The reason for not providing feedback is that rescuers can make real time adjustments to their CPR attempt (Kornegay *et al.* 2018), which could impact their performance. Previous studies (Martin *et al.* 2013b, Buléon *et al.* 2016, Lin *et al.* 2018, Kandasami *et al.* 2019), suggest that metrics such as CCR, CCD, RL, handoff time, fatigue and general quality of CPR, significantly improve as a result of the use of real-time feedback during training, which could impact the interpretation of results of the current study.

iCPR performance data were collected on two occasions. The first was immediately following training and the second was collected after one week. This timeframe was

intentionally selected as the optimal balance between the likelihood of avoiding skill decay (Greif *et al.* 2015) and reducing the possibility of repeated learning effect (Bosse *et al.* 2015). Skill decay would interfere with the reliability results of this study therefore, a pragmatic one-week interval was selected. On each data collection, three trials of two-minute iCPR were captured, with a one-minute interval between trials. The statistical test selected (described in Section 3.13) requires three or more data inputs to look for a relationship (Koo and Li 2016). More than three trials had the potential to cause fatigue, impacting results by adding systematic error (Weir 2005). Therefore, three repeated measures were selected.

3.11 Instrumented Tool

The equipment used to quantify iCPR performance is thoroughly described below and comprised: (a) modified Laerdal® ALS CPR infant manikin; (b) two accelerometers; (c) data acquisition unit (DAQ); (d) personal computer with Laboratory Virtual Instrument Engineering Workbench (LabView) software and Matrix Laboratory (MatLab); (e) flow sensor; (f) power supply. The manikin used for data collection was permanently attached to a wood board and placed on the floor, to mimic the conditions of out-of-hospital iCPR. One accelerometer was fixed on the manikin's chest, on the lower third of the sternum just below the nipple line, avoiding the xiphoid process (according to a mark showing the attachment point). The other accelerometer was fixed on the board and used to act as a differential for the 'surface' on which the CPR was conducted, the floor, in this case. The flow sensor was fixed to the wooden board. Wires were placed towards the manikin's feet to avoid a potential trip hazard (Fig. 3-1). The power unit was placed away from the

manikin and the computer was on a table, with the screen away from the participant's view (Fig. 3-2).

Figure 3-1 **Modified manikin, accelerometers and flow sensor (personal collection)**

Figure 3-2 **Manikin, power supply, DAQ and PC (personal collection)**

There is an extensive range of devices to quantify adult CPR performance. They vary in specifications and include smartphone apps, portable devices that can be used with manikins, automated external defibrillator with CPR feedback and high-fidelity

manikins (Abella *et al.* 2007, Wutzler *et al.* 2014, Cortegiani *et al.* 2017). However, not many devices are commercially available for quantification of iCPR performance, limiting the options in this project.

Previous studies investigating the quality of paediatric CPR performance have done so by utilising a commercial infant manikin adapted or created by the researchers (Dellimore *et al.* 2013, Martin 2013b, Kandasami *et al.* 2019, Alkhafaji *et al.* 2021). These devices vary in their ability to analyse and quantify the metrics associated with high-quality iCPR (CCR, CCD, RL, DC). The vast majority provides feedback on CCR, CCD and RL without considering DC, as seen in Gugelmin-Almeida *et al.* (2021a). However, it has been explored in this thesis (Chapter 2, Section 2.3.6.4) that high-quality iCPR is dependent on effective DC to optimising venous return to the heart, myocardial perfusion, cardiac output and cerebral blood flow (Fitzgerald *et al.* 1981, Dean *et al.* 1991, Sunde *et al.* 1998a, Babs 2006, Kim *et al.* 2020). For this reason, a feedback device developed and validated for a previous study (Martin 2013), that is able to assess the quality of iCPR, quantify performance and provide guidance on all four iCPR metrics (CCR, CCD, RL and DC) was selected for the experimental studies in this thesis (Chapters 3, 4 and 6). Additionally, this project required the specific ability to manipulate values for the metrics related to iCPR performance therefore, having a set up where the algorithm (as explained in Section "d" below) could be manipulated, was necessary to analyse participants' data and convert into metrics of interest.

The equipment used to quantify iCPR performance is composed of:

3.11.1 Infant Manikin

The manikin used in this study was a Laerdal® ALS CPR infant training manikin (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway) representing a three-month-old, 5kg infant, which was modified during a previous study to allow a maximum chest compression depth of 56mm (Martin 2013).

According to Udassi *et al.* (2009) and Pederzini *et al.* (2010), infant manikins have a chest compression depth of a maximum of 1/3 of the external anterior/posterior thoracic diameter of the manikin, which is the recommendation of resuscitation guidelines for compression depth in infants (Skellett *et al.* 2021). However, this mechanical limitation of manikins may impair over-compression during CPR training (e.g. ½ of the external anterior-posterior thoracic diameter), making the rescuer unaware of a possible flawed performance which could potentially affect real chest compressions and cause intrathoracic trauma to the infant patient, impacting survival.

An experiment conducted by Braga *et al.* (2009), that used a computed tomography to calculate the ideal chest compression depths for young children and infants, concluded that the internal anterior-posterior chest depth of a three-month-old infant is 56mm. Therefore, the instrumented manikin used in this study was modified to allow the depth of compression to be increased from 40mm, which is the original manikin specification, to 56mm, which is the physiological internal anterior-posterior chest depth of a three-month-old infant. That way, learners using manikin for iCPR training would be able to explore their performance and adapt compression depth

accordingly, allowing them to deliver better quality chest compressions, potentially improving iCPR performance in real life cardiac arrest scenarios.

3.11.2 Accelerometers

To be able to measure chest displacement, accelerometers were used as part of the instrument tool. Accelerometers are electromechanical devices that measure acceleration of a moving object. They sense chest acceleration during compressions and from this, through double integration, calculate displacement, which in this case, was measured in millimetres. The accelerometers used provide an analog output, which is a continuous voltage that is proportional to acceleration (e.g. 2.5V for 0g, 2.7V for 0.5g, 3.3V for 2g; where g=G-force). The accelerometers were covered by rubber sheets to protect the devices and to provide a better grip to the rescuer.

For this study, two accelerometers were used. One was placed on the lower third of the manikin's sternum, upon a mark demonstrating the attachment point. The other was fixed between the back of the manikin and the board to act as a differential for the surface. This is to counteract overestimation due to deflection of surface. When CPR is performed on a mattress of soft surface for example, the use of a single accelerometer placed on the manikin or patient's chest produces a flawed measurement as it overestimates the depth of compression due to mattress deformation (i.e. the mattress under the manikin or patient compresses together) (Nishisaki *et al.* 2009, Sainio *et al.* 2014). Data related to accelerometer 2 have not influenced the results of the study as iCPR was performed on a hard floor, with no possible surface deflection.

3.11.3 Data Acquisition Unit

The analogue outputs generated by the accelerometers, were translated into digital representations that could be meaningfully manipulated by a computer. Therefore, to acquire the analog signal provided by the accelerometers, convert them into digital values for processing and transfer them to the computer, a data acquisition unit (DAQ) was used as part of the instrumented tool (National Instruments DAQ, Model no. NI USB 6008).

3.11.4 Labview and MatLab Softwares

Data acquisition applications are usually controlled by a programmable software and in this study, LabVIEW (National Instruments, TX, USA) was used to write the program that converted the acceleration output into displacement. Validity of this displacement data has previously been established (Kandasamy 2017). LabVIEW is designed to operate with Matlab software (The Math Works, US), which received the displacement data and, with a bespoke algorithm, analysed participants' data and converted it into four metrics: average CCD, average CCR, average RL and average compression DC. These metrics were further converted into quality performance measurements (quality indexes) by determining the percentage of compressions which met European Resuscitation Council (ERC) Guidelines for Resuscitation (Maconochie *et al.* 2015a) and Resuscitation Council UK (RCUK) Paediatric (Infant) BLS guidelines (Maconochie *et al.* 2015). Table 3-1 demonstrates the definitions of the metrics and the target ranges to calculate quality indexes for each iCPR metric.

Table 3-1 Definition of metrics with respective target range and relevant justification

Metric	Definition	Target range	Target range justification
Chest Compression Rate	The number of compressions per minute	100-120min^{-1}	Based on ERC and AHA guidelines (Maconochie *et al.* 2015a, Atkins *et al.* 2015)
Chest Compression Depth	The maximum relative displacement between the two accelerometers during each compression	40-45mm	ERC and AHA guidelines recommend a compression depth of at least one-third the external anterior-posterior chest diameter (approximately 40mm) for an infant (Maconochie *et al.* 2015a, Atkins *et al.* 2015). The upper threshold was selected based upon the hypothesis that a residual internal AP chest depth of <10mm may potentially cause intra-thoracic trauma (Braga *et al.* 2009, Meier *et al.* 2010)
Residual Leaning	The incomplete release of the chest wall after each compression measured in mm and converted to kg through the known stiffness of the manikin	<2.5kg	Inadequate recoil (> 2.5kg) causes high intrathoracic and right atrial pressure, reducing coronary perfusion, venous return to the heart, and blood flow generated by the next compression (Niles *et al.* 2011, Sutton *et al.* 2010, Zuercher *et al.* 2010)
Compression Duty Cycle	The ratio of time taken for compression relative to release.	45-50%	Based on RCUK guidelines (Maconochie *et al.* 2015). The lower threshold was selected based upon the hypothesis that a sharp 50% cut off for this metric could erroneously rank participants who performed near enough recommendation

3.12 Outcome Measures

The four variables selected for this study (CCR, CCD, RL, and DC) were based on resuscitation guidelines (Maconochie *et al.* 2015) and on guidance for the uniform reporting of the measured quality of CPR (Kramer-Johansen *et al.* 2007). Each variable was individually measured during each chest compression cycle (e.g. 30 compressions) and their correspondent averages calculated using a bespoke algorithm in MatLab. Additionally, to assess the quality of each variable, a quality index was calculated, which comprised of the proportion of chest compressions that complied with a target range for each variable based on resuscitation guidelines, as explained in Section 3.11.4.

The primary outcomes of the study were the degree of correlation and agreement between repeated measures for the above-mentioned metrics: (i) CCR, (ii) CCD, (iii) RL, and (iv) compression DC, to establish consistency of iCPR performance. The secondary outcomes were the degree of correlation between repeated measures for each respective quality indices (QI) and the overall iCPR performance, defined as the proportion of chest compressions achieving the 4 metrics within targets simultaneously.

3.13 Statistical Analysis

Descriptive statistics were used to analyse and summarise characteristics of demographic data. Mean and standard deviation (SD) were applied to report data with normal distribution via the Shapiro-Wilk test. Median with interquartile ranges [IQR], were used when assumption of normality was not met. All analyses were performed with a significance level of 0.05. Effect size calculations were used where

appropriate, to determine the magnitude of observed effect in the relationship or the difference between variables.

Both within-day and between-day repeated measures' reliability were determined using Intraclass Correlation Coefficient (ICC) estimates and their 95% confidence intervals. There are 10 forms of ICCs and each of them comprises different assumptions to be included in their calculations (Koo and Li 2016). For this reason, it is important that a correct ICC is selected according to the particularities of the research, as their results will lead to distinct interpretations when evaluating reliability. For this study, a two-way mixed effects model, with multiple measurements (type) and absolute agreement (definition) was selected to look for consistency in time points.

Traditionally, Bland-Altman plot and Pearson correlation coefficient have been commonly used to analyse reliability (Bland and Altman 1986, Hopkins 2000). However, these tests are not ideal measures of reliability as they do not provide both degree of agreement and correlation between measurements. Pearson correlation coefficient is a measure of correlation only, whilst Bland-Altman generates agreement between measures. Therefore, ICC was the most ideal measure of reliability for this study as it reflects both degree of correlation and agreement between measurements (Koo and Li 2016).

Reliability is calculated via a ratio of true variance over true variance plus error variance (Bartko 1966).

$$\text{Reliability} = \frac{\text{true variance}}{\text{true variance + error variance}}$$

Based on the 95% confidence interval of the ICC estimate, the values and interpretation of results are described in Table 3-2 (Portney and Watkins 2000, Koo and Li 2016, Portney and Watkins 2017). Reliability values range between 0 and 1, with values closer to 1 representing stronger reliability.

Table 3-2 ICC values and interpretation of results

ICC value range	Interpretation
< 0.5	Poor reliability
between 0.5 and 0.75	Moderate reliability
between 0.75 and 0.9	Good reliability
> 0.9	Excellent reliability

After determining ICC for each variable, the Standard Error of Measurement (SEM) was calculated to translate the results to the units of interest, and the Minimal Detectable Change ($MDC_{95\%}$) was also determined to quantify the natural variation in performance. In recent years, many researchers have suggested that no single reliability estimate should be used for reliability studies but that a combination of approaches is more likely to give a true picture of reliability (Bruton *et al.* 2000).

Determining only the ICC as a measure of reliability would be relatively limited because the ICC values are not related to the units of measurement of variables (e.g. mm for chest compression depth, or cpm for chest compression rate). Also, ICC offers a relative measure of reliability, which provides limited support in interpreting

individual changes between repeated tests. The degree to which repeated measurements vary for individuals is the absolute reliability, and it is represented either in the actual units of measurement, or as a proportion of the values measured, with less variability representing higher reliability (Lin *et al.* 2010). Therefore, to complement the ICC, both SEM and $MDC_{95\%}$ were calculated to determine the absolute reliability, or the variability in scores of an individual in repeated measurements.

The SEM quantifies the individual's variability and takes the number of errors related to measurements into consideration. These errors are associated with different factors such as the device used, biological factors, body position during measurements, time of day, and environmental changes such as temperature, noise, etc. (Bruton *et al.* 2000). The sources of variability that cannot be explained by the independent variable are accounted for. According to Bruton *et al.* (2000), if any measurement test were to be applied to a single person, an infinite number of times, it would be expected to generate results or scores that vary a little from trial to trial because of measurement errors, as mentioned above. The distribution of those measurements would follow a normal curve, with the mean representing the true value and the measurement errors occurring above and below the mean. For this reason, the standard deviation is used to calculate the SEM ($SEM = SD \times \sqrt{(1 - ICC)}$), so that the variation occurring above and below the mean is considered. The SEM will, therefore, estimate the standard error in a set of repeated measurements and is expressed in the actual units of measurement, with small values representing greater reliability. For example, if the unit of measurement is centimetre (cm), the

SEM will be in cm; if the unit is percentage, the SEM will be in percentage, making it easier for interpretation.

After calculating the ICC and SEM, the MDC was also determined as it is a clinically useful test for looking at absolute reliability. The MDC is defined as the minimal amount of change in the individual's score or result, that is not due to natural variation in measurement or error (as found with SEM). Therefore, changes in performance that are at or above the MDC values can be considered real change rather than the result of measurement error or natural variations (Haley and Fragala-Pinkham 2006). The formula used to calculate MDC is:

MDC = 1.96 x SEM x × √2 (where 1.96 represents 95%CI and √2 to account for two measurements - e.g. pre-test and post-test).

Additionally, significant differences were explored between time point 1 (straight after CPR training) and time point 2 (seven days later) measurements using Paired-sample T-test or Wilcoxon Test as appropriate. All analyses were performed with a significance level of 0.05 and effect size calculations were used where appropriate.

Microsoft Office Excel 2016 (Microsoft Corporation) was used to record the data, and IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA) was used for statistical calculations.

3.14 Data Management

The author minimised the scope of personal data to be collected by including only what was necessary as a mechanism to describe the demographics of the participants. Personal data including age, weight and height were collected as paper

copy in the form of a questionnaire with a codename associated with the consent form. Data could be identifiable at point of collection only, with limited access just to the principal investigator, and were anonymised by removing direct identifiers and aggregating variables (such as age) before being analysed and shared with other researchers in the study. From this point, data were not identifiable, and the identifiable format was managed according to the University's data management policy (Bournemouth University 2020).

The questionnaires and consent forms from this study will be held for five years from the date of publication of the research (Bournemouth University 2020). Hard copies of the consent forms are stored in a secure location and the questionnaires were scanned and saved as 'pdf' files on a BU password protected computer, with the original paper copies securely shredded and destroyed after digitalisation. The participants cannot be identified from the data in any reports or publications. Unless personal data have been anonymised, it will be limited only to those who have a legitimate reason to access it, for the purpose or purposes for which it is held by BU (Bournemouth University 2020).

The other data generated are linear acceleration describing the movement of the chest of the infant manikin which, through a computational algorithm, was converted into chest displacement and then into iCPR performance metrics represented by CCR, CCD, RL, and DC. These data are generated by sensors communicating to a data acquisition unit which is connected to and stored on a laptop. The data offer no clues to the identification of the participant as they contain only numbers, codes and graphs and are saved using a codename.

This data management strategy will be used for the other studies performed throughout this research (Chapters 4 and 6).

Section 2

This section presents the manuscript published in the *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine* as part of the integrated thesis format submission.

See: Almeida, D., Clark, C., Jones, M., McConnell, P., and Williams, J., 2020. Consistency and variability in human performance during simulated infant CPR: a reliability study. *Scand J Trauma Resusc Emerg Med,* 28 (91).

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Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine

ORIGINAL RESEARCH Open Access

Consistency and variability in human performance during simulate infant CPR: a reliability study

Debora Almeida[1,2*], Carol Clark[3], Michael Jones[4], Phillip McConnell[5] and Jonathan Williams[6]

Abstract

Background: Positive outcomes from infant cardiac arrest depend on the effective delivery of resuscitation techniques, including good quality infant cardiopulmonary resuscitation (iCPR) However, it has been established that iCPR skills decay within weeks or months after training. It is not known if the change in performance should be considered true change or inconsistent performance. The aim of this study was to investigate consistency and variability in human performance during iCPR.

Methods: An experimental, prospective, observational study conducted within a university setting with 27 healthcare students (mean (SD) age 32.6 (11.6) years, 74.1% female). On completion of paediatric basic life support (BLS) training, participants performed three trials of 2-min iCPR on a modified infant manikin on two occasions (immediately after training and after 1 week), where performance data were captured. Main outcome measures were within-day and between-day repeated measures reliability estimates, determined using Intraclass Correlation Coefficients (ICCs), Standard Error of Measurement (SEM) and Minimal Detectable Change ($MDC_{95\%}$) for chest compression rate, chest compression depth, residual leaning and duty cycle along with the conversion of these into quality indices according to international guidelines.

Results: A high degree of reliability was found for within-day and between-day for each variable with good to excellent ICCs and narrow confidence intervals. SEM values were low, demonstrating excellent consistency in repeated performance. Within-day MDC values were low for chest compression depth and chest compression rate (6 and 9%) and higher for duty cycle (15%) and residual leaning (22%). Between-day MDC values were low for chest compression depth and chest compression rate (3 and 7%) and higher for duty cycle (21%) and residual leaning (22%). Reliability reduced when metrics were transformed in quality indices.

Conclusion: iCPR skills are highly repeatable and consistent, demonstrating that changes in performance after training can be considered skill decay. However, when the metrics are transformed in quality indices, large changes are required to be confident of real change.

Keywords: Infant cardiopulmonary resuscitation, Repeatability, Reliability, Variation, Minimal detectable change

* Correspondence: almeidad@bournemouth.ac.uk
[1]Faculty of Health and Social Sciences, Bournemouth University, R604, Royal London House, Christchurch Road, Bournemouth BH1 3LT, England
[2]Department of Anesthesiology, Main Theatres, Royal Bournemouth and Christchurch Hospitals, Castle Lane East, Bournemouth BH7 7DW, England
Full list of author information is available at the end of the article

Background

Cardiac arrest is a worldwide health problem associated with considerable morbidity, mortality and extensive healthcare costs [1–3]. In the UK, over 30,000 out-of-hospital cardiac arrests (OHCA) occur yearly, with an estimate of around 6000 cases in the paediatric population, and infants comprising the majority of these occurrences [4–9]. Reported survival to discharge rates range between 2 and 18% for both OHCA and in-hospital cardiac arrest and paediatric cases are associated with undesirable high-rates of both mortality and morbidity, making cardiac arrest in the infant population, a substantial public health problem [5–10].

Positive outcomes from infant cardiac arrest depend on, in part, the effective delivery of resuscitation techniques, including quality infant cardiopulmonary resuscitation (iCPR), which is crucial for perfusion of vital organs [11, 12]. Quality iCPR is dependent on achieving four internationally recommended quality measures: chest compression depth; chest compression rate; complete chest recoil; and appropriate compression duty cycle, (the portion of time spent in compression) [13–15]. However, it has been demonstrated that the quality of chest compressions during paediatric CPR (including infant) delivered by lay persons, basic life support (BLS) and highly-trained-rescuers in both simulated and real paediatric cardiac arrest events is often performed inadequately, incorrectly, inconsistently or with excessive interruption [15–18].

The cause of CPR quality is likely multifactorial, however key elements include initial skill acquisition and subsequent retention and decay of skills. Several studies have established an urgent need to identify the frequency of iCPR re-training in order to maintain adequate and effective skills [19–23]. However, there are no studies that have examined the consistency of human performance during CPR and this study aims to address this knowledge gap.

Establishing variability in human performance is critical to understanding changes and determining natural variations in the delivery of a skill like iCPR. For example, if performance is not consistent within days of training, then any differences seen months later could be due to variation and inconsistent performance rather than skill decay. This is critical for the determination of skill decay which will facilitate the optimization of training intervals for CPR. Currently, no data has been reported on individuals' iCPR performance variability. Therefore, the aim of this study is to determine the repeated measures reliability and variability of individuals performing simulated iCPR.

Methods

Study design and setting

An experimental, prospective, observational design was used to test within-day and between-day reliability of iCPR performance and was conducted within a university setting. Bournemouth University Research Ethics Committee approval was obtained (reference ID: 22558) and following explanation of experimental procedures, written informed consent was gained. Age, sex, height, weight and self-declared physical issues that might compromise performance were gathered in order to create a demographic profile of the sample.

Participants

A convenience sample of 27 participants were recruited from university healthcare students (including Operating Department Practice, Physiotherapy, Nursing, Midwifery and Occupational Therapy). Inclusion criteria: students currently enrolled at the university with no previous training in paediatric life support. Exclusion criteria: students with any form of musculoskeletal pain requiring medical intervention in the last 12 months or self-declared inability to physically perform iCPR. Sample size was calculated based on Walter et al. (1988) [24] with alpha = 0.05; beta = 80%; three repetitions of the task; desirable and minimal correlation values set at 0.8 and 0.6 respectively, yielding a necessary sample size of 27.

Study procedures

On completion of informed consent, participants undertook the standard four stage approach 'Paediatric BLS' education package [25] with compression:ventilation ratio of 30:2 (aligned with resuscitation guidelines for BLS rescuers with no duty to respond to a paediatric cardiac arrest), delivered by a qualified instructor (PM). After 30-min practice on an infant manikin (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway) using the 2-finger technique, participants were invited to a separate room set up with the instrumented manikin (description below). Although the researcher was in the same room as the participants during data collection to initiate and pause the software, apart from brief instructions on when to start and stop the iCPR, there was no further interaction between participants and the researcher during data collection, and the participants didn't receive any form of feedback. Performance data pertaining to iCPR was captured on two occasions, firstly immediately following training and secondly after 1 week. This timeframe was deliberately selected to potentially avoid skill decay, which has been demonstrated to occur within weeks to months after training [21, 26]. Skill decay would interfere with the reliability results of this study therefore, a pragmatic 1-week interval has been selected. On each occasion, 3 trials of 2-min iCPR were captured, with 1-min interval between trials.

Equipment

The equipment used to quantify iCPR performance comprised of: (a) a CPR infant manikin (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway) representing a three-month-old, 5 kg infant. This manikin was modified during a previous study and its consistency has been established [27]. The modification was an improvement to allow the maximum compression depth to vary between 40 mm (original manikin specification) up to 56 mm (physiological internal chest depth of a three-month-old infant).; (b) 2 accelerometers; (c) data acquisition unit; (d) personal computer; (e) flow sensor and (f) power supply.

One accelerometer was fixed over the xiphoid process on the manikin's chest and the other used to act as a differential for the 'surface' on which the CPR was conducted, the floor in our case to mimic the conditions of OHCA.

The LabView software platform was used to power the accelerometers and compute double integrated acceleration data to provide chest displacement. Validity of this displacement data has previously been established [28]. Displacement data were transferred to MATLAB 2008b (The MathWorks Inc., Natick, MA) where a bespoke algorithm converted it into four metrics, average compression depth, average compression rate, average residual leaning and average duty cycle. Compression depth was defined as the maximum relative displacement between the two accelerometers and compression rate as the number of compressions per minute. Residual leaning was determined through incomplete release from the chest wall measured in mm and converted to kg through the known stiffness of the manikin. Duty cycle was defined as the ratio of time taken for compression relative to release and was calculated using a new algorithm, as published previously [29]. These metrics were further converted into quality indices (QI) by determining the percentage of compressions which met European Resuscitation Council Paediatric (Infant) Life Support Guidelines for Resuscitation (2015) [30] and Resuscitation Council UK Paediatric (Infant) BLS guidelines (2015) [14] outlined below.

Outcome measures

Primary outcomes - degree of correlation between repeated measures for: (i) chest compression rate, (ii) chest compression depth, (iii) residual leaning, and (iv) duty cycle, to establish reliability and consistency of iCPR performance.

Secondary outcomes - degree of correlation between repeated measures for each respective quality indices (QI) defined as: (i) compression rate (100–120/min), (ii) compression depth (40 mm - 45 mm),, (iii) residual leaning (<2.5 kg) and (iv) duty cycle (45–50%).

Statistical analysis

Demographic data were analyzed using descriptive statistics. Mean (SD) were used to report the data with a normal distribution, and median [IQR] were used when the assumption of normality was not met via Skewness, Kurtosis and Shapiro-Wilk test. Both within-day and between-day repeated measures reliability for each variable was determined using Intraclass Correlation Coefficient (ICC) estimates and their 95% confidence intervals (*Model:* 2-way mixed effects; *Type:* multiple measurements; *Definition:* absolute agreement), with values less than 0.5 indicating poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and greater than 0.90 excellent reliability [31]. Standard Error of Measurement (SEM) was also calculated to report variability of results in the units of interest and Minimal Detectable Change (MDC) was calculated to quantify the natural variation in performance, using the following equation: $MDC_{95\%} = 1.96 \times SEM \times \sqrt{2}$.

Microsoft Office Excel 2016 (Microsoft Corporation) and IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA) were used for statistical calculations.

Results

Participants demographics

A total of 27 healthcare students participated in this study including 20 females (74.1%). The mean (SD) age was 32.6 (11.6) years; height was 1.7 (0.1) meters and weight was 70.9 (12.4) kg. Each participant had previously received adult BLS training. No participants were lost at follow up.

Within-day reliability - chest compression variables

The mean values, ICC, SEM and MDC, are presented in Table 1.

A high degree of reliability was found for repeated iCPR for every variable with excellent ICCs and narrow confidence intervals. SEM values were low, demonstrating excellent consistency in repeated within-day performance.

MDC values were low for compression depth and compression rate (6 and 9%) and slightly higher for duty cycle (15%) and residual leaning (22%).

Between-day reliability – chest compression variables

The ICC, SEM and MDC for between-day reliability (immediately after training and 1 week later) and absolute difference between means for the two time points are presented in Table 2.

The ICC values ranged from good to excellent, with duty cycle demonstrating the lowest ICC and compression depth the greatest. The SEMs were low suggesting good consistency between days. The percentage MDC for between days followed the same pattern as within-

Table 1 Mean chest compression and within-day reliability - Time point 1

	Mean (SD)	ICC (95% CI)	SEM	MDC	MDC as % of mean
Rate (cpm)	104 (16)	.95 (.91–.97)	3.47	9.61	9%
Depth (mm)	42.9 (4.7)	.96 (.92–.98)	0.95	2.64	6%
Leaning (kg)	2.9 (0.9)	.94 (.88–.97)	0.23	0.64	22%
Duty cycle (%)	44 (11)	.95 (.91–.98)	2.41	6.68	15%

cpm Compressions per minute, *SD* Standard deviation, *ICC* Intraclass correlation coefficient, *SEM* Standard error of measurement, *MDC* Minimal detectable change

day, with low values for compression depth and compression rate (3 and 7%) and higher for duty cycle (21%) and residual leaning (22%).

Within-day reliability - chest compression quality indices (QI)

The mean values, ICC, SEM and MDC for each QI are presented in Table 3.

The ICC values were good to excellent for each QI with small confidence intervals suggesting a high level of reliability. The MDC values were higher than the equivalent primary variables, suggesting greater variability in performance when measured by QI.

Between-day reliability – chest compression quality indices (QI)

The ICC, SEM and MDC for between-day reliability using QI are presented in Table 4.

The ICC values ranged from moderate to good, with compression rate QI demonstrating the lowest value and compression depth QI the highest value.

The SEMs were low for compression depth QI, residual leaning QI and duty cycle QI suggesting good consistency between days for these variables. The percentage MDC was moderate for compression depth QI (21%), but considerably higher for the other QIs, demonstrating greater variability when measuring reliability of performance using QI.

Discussion

The aim of this study was to determine the repeated measures reliability and variability in performance of simulated iCPR. To the authors knowledge, this is the first time such an exploration has been conducted, providing novel insights into consistency of performance. Such insights enable the determination of change above natural variability in the performance of iCPR. This is an important area of inquiry related to the design of resuscitation training and interpretation of data on skill decay.

This study makes a number of additions to the existing literature. Firstly, the results suggest that the within-day reliability (straight after training) was good-to-excellent across each of the metrics considered. Little difference was determined between each of the variables suggesting no one metric was more reliable than the other. The MDC values, however, suggest that changes greater than 22% of the mean, are likely to be greater than that witnessed through natural variation for residual leaning and 15% for duty cycle. This indicates that these two determinants of performance are less consistent, thus requiring greater change to be considered true change.

Secondly, the results demonstrate similar findings were evident for between-day reliability where values were good to excellent. Chest compression rate and chest compression depth demonstrated higher ICC values with residual leaning and duty cycle achieving good ICC values. This remains evident when comparing MDC; with compression rate and compression depth presenting very small MDC values but residual leaning and duty cycle presenting 3 times the normalized MDC, suggesting much greater variability in these two variables. Previous studies haven't explored the ICC or MDC, making comparison to the literature difficult and this study's contribution to the existing knowledge novel.

There are a number of possibilities to explain why there may be greater variability in these two metrics. It is possible that these aspects of performance are less well known and understood by participants. The idea of rate and depth have been the subject of many media campaigns and even without training individuals are likely to understand the importance of these two metrics, with

Table 2 Mean absolute difference chest compression and between-day reliability – Time point 1 and Time point 2

	Mean (SD) absolute difference	ICC (95% CI)	SEM	MDC	MDC as % of mean (time point 1)
Rate (cpm)	9.0 (7.0)	.86 (.69–.94)	2.63	7.28	7%
Depth (mm)	1.9 (1.6)	.92 (.68–.97)	0.44	1.23	3%
Leaning (kg)	0.6 (0.5)	.78 (.42–.91)	0.23	0.65	22%
Duty cycle (%)	5.7 (6.7)	.75 (.44–.89)	3.38	9.36	21%

cpm Compressions per minute, *SD* Standard deviation, *ICC* Intraclass correlation coefficient, *SEM* Standard error of measurement, *MDC* Minimal detectable change

Table 3 Mean chest compression QI and within-day reliability for QI - Time point 1

	Mean (SD)	ICC (95% CI)	SEM	MDC	MDC as % of mean
Rate QI (%)	38 (29)	.90 (.81–.95)	9.26	25.67	67%
Depth QI (%)	45 (19)	.91 (.83–.96)	5.64	15.63	35%
Leaning QI (%)	42 (21)	.94 (.88–.97)	5.23	14.49	34%
Duty cycle QI (%)	18 (17)	.87 (.76–.94)	6.03	16.73	93%

SD Standard deviation, *ICC* Intraclass correlation coefficient, *SEM* Standard error of measurement, *MDC* Minimal detectable change

little or no attention being placed on leaning or duty cycle. Furthermore, during the standard training for basic life support, less attention is again drawn to these two variables. Therefore, participants are less likely to be concentrating on these particular aspects of performance. Moreover, it is possible that these concepts are more difficult to learn.

It is well understood that in the initial learning phase, there is a reduction in variability towards mastery [32]. Perhaps, the results are merely a reflection of immature learning or novice performance of the motor task, which is critical for effective reduction of variability associated with leaning and duty cycle.

Another point to be considered when analyzing the reasons of greater variability in residual leaning and duty cycle is that, as previously suggested, there may be interactions between different metrics of CPR [33]. It was determined that a faster compression phase and slower relaxation phase, which produces a shorter duty cycle, correlated with a deeper compression depth. Therefore, small variations in compression depth will also be born out as variance in other metrics due to the relationship between them.

It is common place to convert actual numbers denoting CPR performance into quality indices or composite variables [16, 20, 22, 23, 34, 35]. This provides the reader with an understanding of the context pertaining to what is to be considered 'good quality' CPR. Despite this, the present study is the first to explore the notion of reliability of such a method of quantifying iCPR performance, therefore, filling this gap in the literature. Therefore, the third contribution made by this study is the demonstration that reliability was lower, and variability higher once iCPR variables are converted into such quality indices. The within-day reliability values remain good to excellent with small confidence intervals, however, due to much larger standard deviations, the SEM values and MDC values are much greater. This suggests that converting the values on individual metrics into the dichotomy of 'good quality CPR' or 'bad quality CPR' seems to result in greater variance in measured performance. Perhaps, this is due to individuals being close to the boundary of good/bad performance (i.e. around 50% for duty cycle). If some individuals near the 50% boundary, occasionally produce a 'good quality' compression/relaxation percentage and sometimes a 'bad quality' one, then the overall mean of them might be somewhere near the 50%. However, the duty cycle QI could be quite varied across those individuals. This may drive the variance witnessed for the quality indices, raising questions whether there should be a 'hard cut off' at the quality boundaries (i.e. would 51% really be 'bad' but 50% 'good' duty cycle?).

The results presented by this study demonstrate that chest compression performance during iCPR is consistent and reliable. It is also indicated that changes in performance between days which are greater than 3% of the initial value for compression depth, 7% for compression rate, 21% for residual leaning and 22% for duty cycle, represent true change in performance, indicating a decay or improvement of the iCPR skill. Higher changes are required when those metrics are converted into quality indices. Such values can serve as a reference for the learning, maintenance, improvement and decay of the metrics associated with the skills of iCPR.

Limitations

Our study has some limitations. First, we used an infant manikin to evaluate chest compressions quality and although various studies investigating CPR performance use both paediatric and adult manikins, it is recognized

Table 4 Mean absolute difference chest compression QI and between-day reliability for QI - Time point 1 and Time point 2

	Mean (SD) absolute difference	ICC (95% CI)	SEM	MDC	MDC as % of mean (time point 1)
Rate QI (%)	21 (20)	.52(−.07–.78)	13.83	38.33	101%
Depth QI (%)	12 (9)	.81(.54–.91)	3.38	9.33	21%
Leaning QI (%)	15 (13)	.77(.36–.90)	6.30	17.47	42%
Duty cycle QI (%)	10 (11)	.68(.29–.85)	6.25	17.33	96%

cpm Compressions per minute, *SD* Standard deviation, ICC Intraclass correlation coefficient, *SEM* Standard error of measurement, *MDC* Minimal detectable change

that they may not exactly replicate the characteristics and chest compliance of human beings.

Second, the data collection sessions were based on individual iCPR performance in the simulated context, and as such, the participants were not exposed to background noise, other rescuers, distractions, interruptions or the stress and complications that may occur during a real cardiac arrest, limiting the transferability of our results to real life performance.

Third, we recruited a group of students from a single institution. Therefore, the caution is advised before generalization to the wider population.

Finally, we did not include rescue breaths in the analysis of our study even though ventilation is an extremely important aspect of paediatric CPR. Our focus was on chest compressions quality and consistency and we suggest that further studies should assess rescue breath skills to fully understand the reliability and consistency of those skills during iCPR performance.

Conclusions

In summary, our study provides important additions to the growing evidence about iCPR skill acquisition and decay. For the first time, the consistency of performance of iCPR has been explored with results demonstrating that iCPR performance was highly repeatable and consistent, and this was maintained over a week. These results provide an opportunity to further explore iCPR skill acquisition and decay. Another important addition is that, when the chest compression metrics are converted into quality indices, which is a methodology commonly used in many resuscitation studies, the results are not as consistent or repeatable and the natural variation should therefore be taken into account. This means, future studies should consider investigating both metrics and quality indices when reporting individual iCPR skills performance, in order to differentiate between natural variation and skill development or decay. Previous studies, however, have explored skill acquisition and decay based on the conversion of metrics into quality indices without an acknowledgment of natural variation, potentially resulting in erroneous conclusion.

The clinical relevance of this study is attributed to the understanding of iCPR skill acquisition, maintenance, variability and decay, which will enhance iCPR training and performance, improving the chances of survival after infant cardiac arrest.

Abbreviations

BLS: Basic life support; CPR: Cardiopulmonary resuscitation; iCPR: Infant cardiopulmonary resuscitation; ICC: Intraclass correlation coefficient; IQR: Interquartile range; MDC: Minimal detectable change; OHCA: Out-of-hospital cardiac arrests; QI: Quality index; SD: Standard deviation; SEM: Standard error of measurement

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Authors' contributions

Each of the authors have participated in the study conception and design. DA, JW and PM participated in data acquisition. DA, JW and CC completed analysis and data interpretation. All authors were involved in the drafting, editing, critical revision and approval of the final manuscript and agree to be accountable for all aspects of the work.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by Bournemouth University Research Ethics Committee (reference ID: 22558). All participants provided written informed consent to participate.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Faculty of Health and Social Sciences, Bournemouth University, R604, Royal London House, Christchurch Road, Bournemouth BH1 3LT, England. [2]Department of Anesthesiology, Main Theatres, Royal Bournemouth and Christchurch Hospitals, Castle Lane East, Bournemouth BH7 7DW, England. [3]Faculty of Health and Social Sciences, Bournemouth University, R612, Royal London House, Christchurch Road, Bournemouth BH1 3LT, England. [4]Cardiff School of Engineering, Cardiff University, Cardiff CF23 3AA, Wales. [5]Resuscitation Services, Heart Club, Royal Bournemouth Hospital, Castle Lane East, Bournemouth BH7 7DW, England. [6]Faculty of Health and Social Sciences, Bournemouth University, R611, Royal London House, Christchurch Road, Bournemouth BH1 3LT, England.

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3.15 Limitations

As mentioned in the manuscript, there are some limitations associated with this study. The first point to discuss is the use of manikin to evaluate chest compression quality. CPR training has incorporated manikins to enhance quality since the early 1960s, enabling the learner to practice relevant skills and reflect on performance, without the risk of causing harm to real-life patients (Rosen 2013, Laerdal Medical 2016, Damewood 2016). However, it is recognised that manikins may not replicate the anatomical characteristic of human beings including tissue rigidity, cervical spine mobility and chest compliance (Hesselfeldt 2005, Cook *et al.* 2007). Additionally, different types and variations have been identified between manikins from the same or different manufactures (Laerdal 2016, Health Simulation 2019, WHO 2021). These inaccuracies may impact the results using manikins, limiting the transferability to real life performance.

Another important aspect that needs some consideration is the simulated context in which this study was conducted. Simulation-based training has been an important educational tool and research strategy in different areas including cardiopulmonary resuscitation (Kunkler 2006). Although it allows the learner to practice and demonstrate the skills in a controlled and safe environment, the participants are not exposed to relevant features encountered in real resuscitation attempts, including background noise, other rescuers, distractions, interruptions or the stress and complications that may occur during a real cardiac arrest (Perkins *et al.* 2007).

A group of healthcare students from a single institution was selected for this study. Despite its unfavourable generalisability compared to probability samples,

convenience samples account for over 92% of participants in research (Bornstein *et al.* 2013). Therefore, to optimise its benefits and to enable a clearer generalisability, the author limited its disadvantages in relation to population effects and subpopulation differences. In an attempt to reduce the chance of bias in the participants sample, one demographic aspect (healthcare students) was intentionally constrained, to reflect the target population (healthcare professionals), following the strategy of homogeneous convenience sample, for clearer generalisability. According to this strategy, "the more homogeneous a population, the easier (more probable) it is to generate a representative sample, even when using convenience sampling. Therefore, by intentionally constraining the sampling frame to reduce the amount of sociodemographic heterogeneity, the chance of bias in sampling, as it relates to sociodemographic characteristics of the target population, is reduced." (Jager *et al.* 2017, parag.15). However, caution is advised before generalisation of the results of this study to the wider population.

The final aspect that brings some limitations to the study is that rescue breaths were not included in the analysis, despite ventilation being an extremely important aspect of paediatric CPR. The focus was the quality and consistency chest compressions, and it is suggested that further studies should assess rescue breath skills to fully understand the reliability and consistency of those skills during iCPR performance.

3.16 Chapter Summary and Next Steps

This Chapter describes an experimental, prospective, observational design that was conducted to test within-day and between-day reliability and variability of iCPR performance, using repeated multiple measures. It was designed due to the lack of

evidence regarding variability and/or consistency of individuals' executing CPR skills. Performance variability can have a major impact on the analysis of retention of a skill because, if the individual's iCPR performance is not consistent within hours or days after training, then any differences observed months later, could just be due to variation and inconsistent iCPR performance, rather than improvement or skill decay. The experiment enabled the determination of whether or not an individual repeating the same skill under the same strict conditions was consistent. Such data support the quantification of the natural variation of repeated iCPR performance.

The study was novel and essential to inform the next step of this thesis and adds important information to the growing evidence about iCPR skill acquisition and decay. This was the first time that an exploration of consistency and variability of chest compressions during iCPR has been performed, providing an understanding around changes (decay or improvement) in performance after training. The results demonstrated that iCPR was a highly repeatable and consistent skill, with the performance metrics maintained over a week. It can therefore be suggested that changes seen in performance after training can be considered true change, rather than inconsistent performance.

Another important addition that may impact interpretation of results from previous or future research is that, when the chest compression metrics are converted into quality indices, the results are not as consistent or repeatable. Transforming CPR metric into quality index is commonly used in many resuscitation studies to offer the reader an understanding of the framework relating to effectiveness of performance (i.e. 'good quality' or 'bad quality' CPR). However, this study concluded that when

this is applied, the results are not as consistent or repeatable and the natural variation in performance should, therefore, be taken into account. This is because quite large changes in performance are required to be confident of real change rather than just inconsistent performance. Previous resuscitation studies have explored skill acquisition and decay based on the conversion of metrics into quality indices without an acknowledgment of natural variation of performance, potentially resulting in erroneous conclusion. For example, some of the changes alluded to as decline in previous studies may just represent natural variation in performance rather than skill decay. This means, future studies should consider investigating both chest compression metrics and quality indices when reporting results of iCPR skills, in order to differentiate between natural variation in performance vs skill improvement or decay.

The clinical relevance of this study is attributed to the understanding of iCPR skill acquisition, maintenance, variability, and decay. This will inform future study designs and provide a broader context when interpreting results from studies using quality indices as performance measures. Additionally, the new knowledge acquired from this study will enhance iCPR training and performance, potentially improving the chances of survival after infant cardiac arrest.

Next steps

The results of this reliability study provided essential information about consistency of human performance during iCPR. The experiment has also identified further elements that could potentially impact rescuer's performance and influence interpretation of data in skill decay. After data collection, some participants asked if

it would be acceptable to change hands during delivery of iCPR and if this would impact performance. This was attributed to fatigue felt during the repeated two-minute trials with one-minute interval between them. These topics were very relevant and had not been explored previously in the literature for iCPR. Understanding the impact of hand fatigue and hand dominance in the delivery of iCPR was essential to the continuity of this thesis, therefore motivating the conception of the next study (Chapter 4).

Chapter 4 Justification of the Methods and Study Design: "Dominant Hand Study "

4.1 Chapter Overview

This Chapter is divided into two sections: the first part addresses the methodology of STUDY 2 – "Dominant versus non-dominant hand during simulated infant CPR using the two-finger technique: a randomised study". This was a randomised study, investigating the differences between simulated iCPR performance with the dominant and non-dominant hands using the two-finger (TF) technique. Similar to the previous Chapter, a broad explanation of the research strategy will be explored in detail in the first section, followed by the published manuscript (Gugelmin-Almeida *et al.* 2021b). Aspects such as the aims, objectives and outcomes of the study will be explored, alongside ethical considerations, participant recruitment and statistical choices. Since some features of this study are identical throughout the experiments of this thesis (i.e. data management, anonymity and confidentiality, instrumented tool), a brief explanation with signposting will be provided to avoid duplication of information. The final part of this Chapter will evaluate the limitations of this study, and provide information about the next steps for the development of this thesis

Section 1

4.2 Aims and Objectives

This study was designed based on the gaps identified during the previous experiment (Chapter 3) which, without further exploration, could potentially impact rescuer's performance and influence interpretation of data in iCPR skill performance and decay.

As previously mentioned, some participants of the previous study (Chapter 3) questioned if it would be acceptable to swap hands during delivery of iCPR when using the TF technique and if this would impact performance quality. This was attributed to fatigue felt during the three two-minute trials with one-minute interval. These topics (fatigue and hand dominance) are very relevant and, to the authors knowledge, had not been fully explored in the literature for iCPR, where the TF technique is used by the lone rescuer.

Previous research has explored the effect of fatigue and hand dominance during CPR in adults and older children (Wang *et al.* 2015, Kim *et al.* 2015, Jo *et al.* 2017, Duff *et al.* 2021). Others have investigated the use of different fingers during iCPR using the TF technique (Kim *et al.* 2016) or compared the quality of TF and two-thumb (TT) techniques for infant chest compressions (Smereka *et al.* 2017, Pellegrino *et al.* 2019). However, until the present day, there has been no investigation to compare dominant hand (DH) and non-dominant hand (NH) during iCPR performance using the TF technique, or the impact of fatigue in iCPR performance. Both aspects are important factors that need further exploration, considering that current resuscitation guidelines advocate the use of TF technique for a single rescuer performing iCPR (Maconochie *et al.* 2015). Therefore, this randomised study aimed to investigate the impact of hand fatigue and hand dominance in the delivery of simulated iCPR using the TF technique.

To achieve the above aim, the following objectives were developed to inform the research design and processes:

1. To evaluate the quality of simulated iCPR performance for chest compression depth, chest compression rate, residual leaning, and compression duty cycle delivered with the DH.

2. To evaluate the quality of simulated iCPR performance for chest compression depth, chest compression rate, residual leaning, and compression duty cycle delivered with the NH.

3. To establish the difference between DH and NH for chest compression depth, chest compression rate, residual leaning, and compression duty cycle.

4. To analyse the difference between the first and last 30 seconds of simulated iCPR performance with the DH and NH for chest compression depth, chest compression rate, residual leaning, and compression duty cycle.

5. To assess perception of fatigue as measured via visual analogue scale (VAS) after three-minute simulated iCPR for the DH and NH.

6. To determine the relationship between perception of fatigue and simulated iCPR performance for the DH and NH.

4.3 Study Design

This was an experimental, prospective, randomised study. It was conducted to investigate chest compression performance with the DH and NH whilst delivering iCPR using the TF technique. It was conducted in a simulated environment within a university setting, where an event open to the students, staff, and the general public, was being held (further explained in Section 4.5 of this Chapter). Inclusion criteria for this study involved: (a) adults (over 18-year-old) taking part in the event held at the

university; (b) have received training in paediatric life support either previously or during the event. Participants were excluded if they had shoulder, wrist, knee, or spinal injury requiring medical intervention in the last 12 months or if they were unable to perform chest compressions for physical or medical reasons.

With different ways to sample a population for research, considering whether the selected sampling frame fits the study's aims and objectives is a key aspect for the research to be valid (Martinez-Mesa *et al.* 2016). The sample frame for this study was people attending an event about cardiac arrest and CPR (further explained in Section 4.6). This is a type of non-probability sampling strategy, where participants are selected based on their accessibility to the research (Bornstein *et al.* 2013). Convenience sample, as applied to this study, is one of the most common types of non-probability sampling and, despite its unfavourable generalisability compared to probability samples, it accounts for over 92% of participants in research (Bornstein *et al.* 2013). The key advantages of convenience sampling are that it is efficient, simple to implement and inexpensive (Jager *et al.* 2017).

Since the aim of this study was to investigate the impact of hand fatigue and hand dominance during simulated iCPR, the target population of this study was "people willing and trained to provide iCPR in an emergency". Therefore, by recruiting people attending a public event about CPR for the sample, there may have been better representation of the relevant population. These individuals may differ from the wider population in a number of ways. They may be more aware of the importance of CPR, be well-motivated and confident to take part, or have higher socioeconomic status as they are part of the wider university community (Hubble *et al.* 2021). This

may bring risk of sampling bias, however, these biases are unlikely to influence the main question being investigated by this study.

4.4 Ethics Protocol, Approval Process and Considerations

The research protocol and ethics application (Reference ID: 27970) were submitted on 17th September 2019 to UREC. Similarly, to the previous study, the Ethics Code of Practice (Bournemouth University 2021) was used to guide the design, development and conduct of the study. The protocol included Participant Information Sheet, Participant Consent Form, Participant Questionnaire and Risk Assessment (Appendices 7-10).

The application was reviewed on 2nd October 2019 and approved on 3rd October, without major amendments (Appendix 11).

4.5 Risk Assessment

A full risk assessment was undertaken during the planning of this study to address any potential problem that could occur. Consideration of the safety and risks involved and finding ways to minimise those risks of happening were based on principles of safe research, employed in the previous experiment (Chapter 3, Section 3.6). The identified hazards associated with the study included trips and falls due to equipment and cables; skin irritation from disinfecting agent (wipes) used to clean the manikin and equipment during the experiment; and bruised or sore knees due to the position needed to deliver iCPR on the floor.

Control measures were put in place in order to minimise the risk of these hazards occurring, including: researchers and participants to be aware of trip hazards when

approaching and using the equipment; manikin to be stored away or placed on the table when not in use, with cables tucked under the manikin and/or the table; instruction given to participants on the safe use of wipes after their session; ensuring manikin is dry before re-use to reduce the chance of skin irritation; and rubber mats to be used for every participant during delivery of iCPR.

The likelihood of the identified hazards causing harm to researchers and participants after control measures were in place was considered low, and the risk was regarded as minimal. Full risk assessment is shown in Appendix 10.

4.6 Participant Recruitment and Informed Consent

Potential participants were engaging in the "Restart a Heart Day", an event organised by BU to raise awareness of cardiac arrest and to teach people how to perform CPR. As previously mentioned, this event was open to students, members of staff and the general public. Attendants of the event had the opportunity to engage in activities related to cardiac arrest and received CPR training (adult and paediatric) delivered by qualified instructors. On completion of the paediatric CPR session, individuals were asked by the CPR instructor if they would like to take part in the research. The CPR instructor, who was not involved with the research, acted as the gatekeeper for the participants. As previously mentioned, a gatekeeper is an individual or institution that represents the interests of and acts as a mediator between a researcher and potential participants (Singh and Wassenaar 2016). Due to the detachment and impartiality, the CPR instructor could offer potential participants an initial independent and unbiased point of contact to the study, prior to the principal investigator.

Those who demonstrated an interest were directed to the principal investigator who explained the aims of the study, what their participation would entail, the risks involved, the potential benefits to the resuscitation field and the participant's right to voluntarily take part in the research or refuse it without any disadvantage or consequence. There was an opportunity to discuss the research with the principal investigator on an individual basis, as the participants engaged in the event at different times during the day.

Once the questions were answered, the principal investigator confirmed if the individual was still interested in taking part. After that, a written copy of the Participant Information Sheet (Appendix 7) was provided and a written consent (Appendix 8) with an individualised identification code was signed by both the participant and the principal investigator together, and each participant was offered a copy of the signed consent form for their keeping. The participant was made aware that withdrawal from the study would be possible at any time before the data were anonymised, at which point, they could not be identified anymore.

An identification code was generated for each participant to assure anonymisation and confidentiality. The consent form was the only document containing the identification code and participants' identification details (i.e., name and surname). The principal investigator is the only person with access to the consent forms.

4.7 Data Collection Process

After signing the consent form, participants received a questionnaire identified with the individual code. Data relating to age, sex, height, weight, hand dominance and self-declared physical issues that could compromise performance were gathered via

the questionnaire (Appendix 9) to create a demographic profile of the sample. Chapter 3, Section 3.10 explains the importance of collecting essential demographic data relevant to the study.

After completing the questionnaire, participants were invited to perform three-minute iCPR on the modified infant manikin (described in Section 3.11 of Chapter 3) using the TF technique with a compression:ventilation ratio of 30:2. This ratio was selected based on the latest resuscitation guidelines for BLS rescuers who have no duty to respond to a paediatric cardiac arrest (Maconochie *et al.* 2015). A three-minute timeframe was purposively selected in an attempt to instigate fatigue based on evidence suggesting that fatigue is induced within this timeframe (Ashton *et al.* 2002, AHA 2015, Cobo-Vázquez *et al.* 2018), particularly when TF technique is used. CPR research in the adult population suggests that chest compression quality declines progressively over three minutes and that rescuers are not aware of deterioration in performance (Ochoa *et al.* 1998, Ashton *et al.* 2002, Duff *et al.* 2021). Additionally, Jiang *et al.* (2015) concluded that the TF technique is more fatiguing than the TT technique during iCPR. Furthermore, studies on motor learning and motor variability have shown that muscle fatigue implies a drop in voluntary muscle force and a decline in accuracy of performance, particularly in fine motor skills (Edward 1983, Allen and Proske 2006, Missenard *et al.* 2008, Singh *et al.* 2010), impacting iCPR quality. Based on this evidence, a three-minute timeframe was purposively selected in an attempt to instigate fatigue.

The first trial (three-minute iCPR) was performed using either DH or NH, based on the randomised order generated by a web-based computer programme

(Random.org). Since the effects of the first trial may carry over into the second trial, participants were randomly assigned as to which hand they performed with first.

After completing trial one, participants rested for one-minute and then completed three-minute iCPR with their other hand (trial two). A pragmatic one-minute break was selected to enable the participants to recover from the initial test and to minimise the likelihood of fatigue at the start of the second trial. The participants did not receive any form of feedback on performance during or after any of the two trials. The reason for not providing feedback is that rescuers can make real time adjustments to their CPR attempt (Kornegay *et al.* 2018), which could impact their performance. Previous studies (Martin *et al.* 2013b, Buléon *et al.* 2016, Lin *et al.* 2018, Kandasami *et al.* 2019), suggest that metrics such as CCR, CCD, RL, handoff time, fatigue, and general quality of CPR, significantly improve as a result of the use of real-time feedback during training, which could impact the results of the current study.

On completion of each trial, participants were asked to rate their level of perceived fatigue. Considering that the quality of CPR may be dependent on the physical status of the rescuer (Lucia *et al.* 1999), tiredness and fatigue are factors that can influence performance (Ashton *et al.* 2002, Rad and Rad 2017). Many methods of measuring fatigue exist in the wider literature (Vøllestad 1997, Chen *et al.* 2002, Srikantan 2005, Taylor 2012, Rad and Rad 2017). This is likely due to the multiple constructs covered by fatigue, which is a complex and multifaceted event with a diverse root of possible causes (Halson 2014). There are a number of different definitions of fatigue, and the one selected for this study is 'perception of fatigue', a subsection of fatigue that can

be defined as “changes in sensations that regulate the integrity of the performer” (Enoka and Duchateau 2016).

Perception of fatigue has been measured using Likert scales, Borg scale, or other categorical data approaches (Impellizzeri and Maffiuletti 2007, Cabral *et al.* 2017, Sato *et al.* 2018, Egger *et al.* 2020, Reynolds *et al.* 2020, Tobase *et al.* 2023). However, such methods preclude the use of parametric statistics, preventing correlational approaches. To overcome these limitations, previous studies have used a visual analogue scale (VAS), which is universally recognised and one of the most common scales used for assessing perception of fatigue and recovery (Tseng *et al.* 2010, Le Meur *et al.* 2013, Halson 2014). Such an approach generates continuous data, enabling parametric statistical application. In addition, VAS has been used directly to measure perception of fatigue relating to CPR (Srikantan 2005, Riera *et al.* 2007, McDonald *et al.* 2013, Zhang *et al.* 2013, Rad and Rad 2017). Therefore, VAS was adopted to measure perception of fatigue for the current study. To avoid potential bias from previous fatigue measurement (trial one), a new VAS was provided to measure fatigue at trial two.

4.8 Instrumented Tool

The equipment used to quantify iCPR performance and analyse the objectives of the study has been previously described in Chapter 3 (Section 3.11). However, some modifications to the MatLab algorithm were performed based on results from that study. The algorithm initially used for the reliability study included chest compression metrics with a set of range values to establish performance quality (Chapter 3, Section 3.11.4, Table 3-1). However, the results of that study concluded that, due to

human variability in iCPR performance in relation to RL and DC, there needs to be a buffer in the range value for those metrics so that real change in performance can be detected. Therefore, an adaptation to MatLab code was needed to incorporate this new finding and the values used are demonstrated in Table 4-1.

In addition to that, after individual performance, participants' data were only converted into four metrics:

1. average chest compression depth, calculated using the maximum relative displacement between the two accelerometers.

2. average chest compression rate (the number of compressions per minute).

3. average residual leaning, determined through incomplete release from the chest wall measured in mm and converted to kg through the known stiffness of the manikin.

4. average compression duty cycle (the ratio of time taken for compression relative to release).

This is different from previous study (Chapter 3), where data were also converted into quality indices. However, because results from that study indicated that performance was not as consistent and repeatable when data were converted into quality indices, it was the decided that this method should not be used going forward to avoid erroneous interpretation of future studies' results.

Table 4-1 Definitions of the metrics and the new target ranges to establish iCPR quality based on average of compressions for each variable.

Metric	Definition	Target range	Target range justification
Chest Compression Rate	The number of compressions per minute	100-120min^{-1}	Based on ERC and AHA guidelines (Maconochie *et al.* 2015, Atkins *et al.* 2015).
Chest Compression Depth	The maximum relative displacement between the two accelerometers during each compression	40-45mm	ERC and AHA guidelines recommend a compression depth of at least one-third the external anterior-posterior chest diameter (approximately 40mm) for an infant (Maconochie *et al.* 2015, Atkins *et al.* 2015). The upper threshold was selected based upon the hypothesis that a residual internal AP chest depth of <10mm may potentially cause intra-thoracic trauma (Braga *et al.* 2009, Meier *et al.* 2010).
Residual Leaning	The incomplete release from the chest wall after each compression measured in mm and converted to kg through the known stiffness of the manikin	<3.1kg	Inadequate recoil (> 2.5kg) causes high intrathoracic and right atrial pressure, reducing coronary perfusion, venous return to the heart, and blood flow generated by the next compression (Niles *et al.* 2011, Sutton *et al.* 2010, Zuercher *et al.* 2010). However, based on the previous study of his thesis (Chapter 3), due to a greater variability of

			RL, there needs to be a buffer of 22% so that incorrect performance of this metric can be detected.
Compression Duty Cycle	The ratio of time taken for compression relative to release.	30-55%	Based on RCUK guidelines (Maconochie *et al.* 2015). The lower threshold was selected based upon the hypothesis that a shorter duty cycle provides significant superior myocardial and cerebral perfusion in infant swine model (Dean *et al.* 1991, Kim *et al.* 2020). The higher threshold was based on the previous study of his thesis (Chapter 3), which demonstrated that DC has a greater variability, therefore, there needs to be a buffer of 21% so that incorrect performance of this metric can be detected. However, because a DC of 60% declines cerebral perfusion pressure in consequence of a decline in mean aortic pressure (Dean *et al.* 1991), a 55% DC was selected as the higher threshold.

4.9 Outcome Measures

The four variables selected for this study (CCR, CCD, RL, and DC) are the same metrics analysed previously (in the repeatability study, Chapter 3) and will be used in the following experiment (Chapter 6). These metrics were identified as components of

chest compression that are closely related to high-quality iCPR performance and were based on resuscitation guidelines (Maconochie *et al.* 2015, Atkins *et al.* 2015) and on guidance for the uniform reporting of the measured quality of CPR (Kramer-Johansen *et al.* 2007).

As this study aimed to investigate the impact of hand fatigue and hand dominance in the delivery of simulated iCPR using the TF technique, the outcomes were:

1. The difference between DH and NH for each chest compression variable (CCD, CCR, RL, and DC) during the three-minute iCPR performance.

2. The difference between the first and last 30 seconds of iCPR performance with the DH and NH for each metric (CCD, CCR, RL, and DC). The initial 30 seconds were selected as there may be a settling period of performance so, if only the initial 10 seconds were captured, it may not have been a true reflection of iCPR performance. Similarly, the researcher wanted to capture the very end of the cycle (last 30 seconds) where the potential for fatigue is the greatest, as explained in Section 4.7 of this Chapter.

3. Perception of fatigue between DH and NH as measured via VAS. As previously explained in Section 4.7 of this Chapter, there are a number of ways to measure perception of fatigue. However, a quick and simple method would be to get it quantified using a scale from 0 to 100, where continuous data would be provided so that correlational statistics could be performed. Therefore, the VAS was selected to measure and quantify perception of fatigue.

4. The relationship between perception of fatigue and iCPR performance.

4.10 Statistical Analysis

To determine what statistical tests should be applied to this study, a comprehensive analysis of options and discussion between the research team has taken place. Although one of the aims of this study was a simple comparison between dominant and non-dominant hands, if there was only one variable, CCR for example, a paired T-test or Wilcoxon could be applied because it was the same participant performing with the DH and the NH. For any missing data, that specific participant would be removed. This could then be repeated for each of the other variables. However, that would be equal to four different T-tests (or non-parametric equivalent), which raises the question as to the increased likelihood of finding something by chance (type-1 error).

One alternative would be to reduce the Alpha value using Bonferroni correction, therefore reducing the chance of finding something by chance. So, an Alpha value of 0.05 would be divided by four (the number of metrics in the study), resulting in a value of 0.01 (1% probability to find something by chance rather than 5%). However, the challenge with this approach is that a significant finding may be missed due to the substantial reduction of the Alpha value (type-2 error).

The other option would be to do an analysis of variance (ANOVA) to find out if there was a difference in the four variables at some point (providing all the data points were normally distributed). If ANOVA determined that there was a difference in any pairings, then a post-hoc analysis could be performed to identify where the difference was, and in this case, the T-tests could be individually applied because a significant difference had been found via the ANOVA.

The statistical choice for comparison between DH and NH for CCR, CCD, RL, DC, and perception of fatigue (using VAS), was to use the ANOVA first and then a two-sided paired T-test for normally distributed data and Wilcoxon signed-rank test for non-parametric data for each respective metric. This option was also performed to analyse the change in chest compression performance over time (first 30 seconds and last 30 seconds).

In relation to fatigue and its effect on iCPR metrics, correlation tests were used to determine the relationship between perceived fatigue and performance. The question to be answered was how much fatigue affects iCPR performance, and a method to determine this is to explore the correlation between the VAS and performance with the DH and the NH independently. After finding the correlation coefficient value, there was the need to investigate if the relationship was significant. Therefore, Pearson's correlation coefficient was used for normally distributed metrics and the non-parametric alternative Spearman's Rho test was used as appropriate. After finding if there was a significant correlation between each individual iCPR metric and perception of fatigue, the percentage of the amount that each variable (CCR, CCD, RL, and DC) could be explained by the other variable (perception of fatigue) was also calculated. Finally, mean/median values for each relevant metric were calculated for the DH and the NH to check for similarity in performance with each hand. For example, after finding a significant correlation between RL and VAS for the NH but not for the DH, the median value of RL (non-parametrically distributed) was calculated for the DH (=2.6kg) and for the NH (also =2.6kg). This result enabled the research team to conclude that, although the

participants were able to perform similarly for this metric (RL in this case) with the DH and the NH, the effort was much greater for the NH.

4.11 Data Management

The strategy for data management has been previously explained in Chapter 3, Section 3.14.

Section 2

This section presents the manuscript published in *Resuscitation Plus* as part of the integrated thesis format submission.

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Simulation and education

Dominant versus non-dominant hand during simulated infant CPR using the two-finger technique: a randomised study

Debora Gugelmin-Almeida[a,b,*], *Carol Clark*[a], *Ursula Rolfe*[a], *Michael Jones*[c], *Jonathan Williams*[a]

[a] Faculty of Health and Social Sciences, Bournemouth University, Bournemouth Gateway Building, St. Pauls Lane, Bournemouth, BH8 8GP, England

[b] Department of Anaesthesiology, Main Theatres, Royal Bournemouth and Christchurch Hospitals, Castle Lane East, Bournemouth, BH7 7DW, England

[c] Cardiff School of Engineering, Cardiff University, Cardiff, CF23 3AA, Wales

Abstract

Aims: The aim of this randomised study was to compare the two-finger technique (TFT) performance using dominant hand (DH) and non-dominant hand (NH) during simulated infant CPR (iCPR).

Methods: 24 participants performed 3-min iCPR using TFT with DH or NH followed by 3-min iCPR with their other hand. Perceived fatigue was rated using visual analogue scale. Primary outcomes - (i) difference between DH and NH for compression depth (CCD), compression rate (CCR), residual leaning (RL) and duty cycle (DC); (ii) difference between first and last 30 s of iCPR performance with DH and NH. Secondary outcomes - (i) perception of fatigue between DH and NH; (ii) relationship between perception of fatigue and iCPR performance.

Results: No significant difference between DH and NH for any iCPR metric. CCR (DH: $P = 0.02$; NH: $P = 0.004$) and DC (DH: $P = 0.04$; NH: $P < 0.001$) were significantly different for the last 30 s for DH and NH. Perception of fatigue for NH (76.8 ± 13.4 mm) was significantly higher ($t = -3.7$, $P < 0.001$) compared to DH (62.8 ± 12.5 mm). No significant correlation between iCPR metrics and perception of fatigue for DH. However, a significant correlation was found for CCR ($r = 0.43$; $P = 0.04$) and RL ($r = -0.48$; $P = 0.02$) for NH.

Conclusion: No difference in performance of iCPR with DH versus NH was determined. However, perception of fatigue is higher in NH and was related to CCR and RL, with no effect on quality of performance. Based on our results, individuals performing iCPR can offer similar quality of infant chest compressions regardless of the hand used or the perception of fatigue, under the conditions explored in this study.

Keywords: Infant cardiopulmonary resuscitation, Two-finger technique, Dominant hand, Non-dominant hand, Manikin

Introduction

Despite advances and growing evidence that survival to hospital discharge for out-of-hospital cardiac arrest (OHCA) in the paediatric population has increased over the years, it continues to be a major public health problem, with high rates of morbidity and mortality.[1,2]

Most paediatric cardiac arrest events occur in infants (44–64%),[1,3,4] which represent the lowest survival rates (1.4–3.7%) compared to children (3.6–9.8%) or adolescents (8.9–16.3%).[1,2,4,5]

Key elements of infant OHCA survival are multifactorial and include high quality infant cardiopulmonary resuscitation (iCPR) with effective ventilation and chest compression techniques. The components of iCPR include chest compression rate (CCR), chest

* Corresponding author.
E-mail address: almeidad@bournemouth.ac.uk (D. Gugelmin-Almeida).

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compression depth (CCD), residual leaning (RL) and duty cycle (DC). Two standardised techniques have been described for infant chest compressions: the two-thumb encircling technique (TTT) for more than one rescuer or the two-finger technique (TFT) for the lone rescuer. TTT has been suggested to be of superior quality when compared to TFT even for a lone rescuer because of a reduced hand fatigue and deeper chest compression depth,[6–8] however, the current evidence has not resulted in changes to guidelines, which still advocate the TFT for lone rescuers when performing CPR on an infant in cardiac arrest.[9–11] Current resuscitation guidelines do not specify which hand to use (dominant, non-dominant or either), but performance aspects related to hand dominance must be considered.

It has been suggested that the quality of chest compressions using theTFT might be influenced by factors such as finger or hand strength and fatigue,[12] indicating that hand dominance may impact on the quality of iCPR using this technique as the mechanisms of force generation and maintenance may differ between dominant hand (DH) and non-dominant hand (NH), thereby affecting CCR, CCD, RL and DC.

Previous studies have investigated the quality of chest compressions based on hand dominance during CPR in the adult[13–18] or older child populations.[19] Others have explored the difference between the TTT and TFT for infant chest compressions,[20–25] or the use of different fingers with the TFT.[12] However, to date, no research has specifically compared DH and NH for iCPR performance using TFT. Therefore, in an attempt to fill a gap in the knowledge and to reproduce a single rescuer performing iCPR in an OHCA episode, evaluation of hand dominance using TFT is warranted.

The aim of this randomised study was to investigate chest compression performance of the DH and NH whilst delivering simulated iCPR using the TFT.

Methods

Study design and setting

This study utilised a prospective, experimental, randomised design and was conducted in a simulated setting at a university. Ethical approval was granted by the university board (reference ID: 27970) and written informed consent was obtained following a description of the study and its procedures. Data relating to age, weight, height, hand dominance, sex and self-declared physical issues, that could compromise performance, were collected via a questionnaire with the purpose of creating a demographic profile of the sample.

Participants

A convenience sample of 24 participants was recruited from an event organised by Bournemouth University, open to students, staff and the general public. The sample size was based on a theoretical difference of 15% for compression depth between DH and NH and a standard deviation of 20%, with alpha of 0.05 and power set to 80%.

Exclusion criteria were a self-declared inability to perform iCPR for reasons such as physical limitation to complete the CPR task (e.g. unable to kneel).

Study procedures

Potential participants were engaging in the "Restart a Heart Day", an event to raise awareness to cardiac arrest and teach people how to perform adult and paediatric CPR. On completion of the paediatric CPR session, interested people were invited to take part in the study. Experimental procedures were explained by the principal investigator and, after signing the consent form, volunteers were invited to perform 3-min iCPR on a modified manikin (description below) using the TFT with a compression:ventilation ratio of 30:2 (aligned with resuscitation guidelines for Basic Life Support rescuers, with no duty to respond to a paediatric cardiac arrest), using either DH or NH (trial 1). A 3-min timeframe was purposively selected in an attempt to instigate fatigue based on evidence suggesting that fatigue is induced within this timeframe,[26–28] particularly when TFT is used.[7]

After a 1-min rest, participants then completed 3-min iCPR with their other hand (trial 2). Each individual, therefore, acted as their own control. The order of the trials was randomised using a web-based computer programme.[29] No feedback on performance was provided. On completion of each trial, participants were asked to rate their level of perceived fatigue, using a visual analogue scale (VAS).

Instrumented equipment

The equipment used to analyse iCPR performance included: (i) a baby manikin representing a 5 kg, three-month-old infant (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway). This manikin was modified during a previous study to allow a maximum compression depth of 56 mm[30] and was instrumented with (ii) two accelerometers (one fixed on the manikin's chest and the other on the board where the manikin was placed, acting as a differential, for the surface on which the CPR was conducted). Data were acquired by (iii) a data acquisition unit (LabView), connected to a (iv) personal computer (PC) and (v) a power supply.

Accelerometer data were generated through the LabView software platform. LabView computed acceleration and converted this into displacement, representing the displacement of the chest. Displacement data were then transferred to MATLAB 2014b (The MathWorks Inc, Natick, MA) and converted into the following metrics: average chest compression depth (maximum relative displacement between the two accelerometers), average chest compression rate (the number of compressions per minute), average residual leaning (determined through incomplete release from the chest wall measured in mm and converted to kg through the known stiffness of the manikin), and average duty cycle (the ratio of time taken for compression relative to release) via a bespoke algorithm. Validity of this acceleration data has been established previously[31] and details of the instrumented manikin have been published elsewhere.[30]

Outcome measures

Primary outcomes were (i) the difference between DH and NH for chest compression depth, chest compression rate, residual leaning and duty cycle, and (ii) the difference between the first and last 30 s of iCPR performance with the DH and NH for chest compression depth, chest compression rate, residual leaning and duty cycle. Secondary outcomes were (i) perception of fatigue as measured via VAS between DH and NH and (ii) the relationship between perception of fatigue and performance.

Statistical analysis

Descriptive statistics were used to explore the demographic data. Normality was determined via Skewness, Kurtosis and Shapiro-Wilk

Table 1 – Mean (SD), *Median [IQR]* and P values for iCPR metrics – DH and NH.

	DH	NH	P value
CCR (cpm)	118.9 (14.3)	117.3 (16.7)	0.57
CCD (mm)	42.6 (4.5)	43.5 (4.4)	0.19
RL (kg)	2.9 (1.2)	*2.6 [0.7]*[a]	0.42
DC (%)	39.3 (9.2)	39.3 (9.5)	0.99

CCR; chest compression rate, CCD; chest compression depth, RL; Residual Leaning, DC; Duty Cycle, cpm; compressions per minute, DH; dominant hand, NH; non-dominant hand.
[a] Wilcoxon test for non-parametric.

tests. Mean and standard deviation (SD) were used to report the data with a normal distribution; *median and interquartile range [IQR]*, when the assumption of normality was not met.

A two-sided paired *t*-test was used for normally distributed data and Wilcoxon signed-rank test for non-parametric data for each metric (CCD, CCR, RL, DC and perception of fatigue) and for the change in chest compression performance over time (first 30 s and last 30 s). Correlation between iCPR metrics and perceived fatigue was analysed using Pearson Correlation and the non-parametric alternative Spearman's Rho test was used as appropriate.

Statistical calculations were performed using SPSS software (SPSS 25, IBM Corp., Armonk, NY, USA) and Microsoft Office Excel 2016 (Microsoft Corporation). All P values were two-tailed, and significance was established at $P < 0.05$.

Results

Participant demographics

A total of 24 people participated in this study, 14 females (58%) and 10 males (42%). Data from one participant was incomplete due to equipment malfunction at the point of collection and was not included in the final analysis. The mean (SD) age was 31.6 (11.6) years, weight 80.2 (16) kg and height 171.2 (9.8) cm. Four participants were left-hand dominant.

Difference between DH and NH for iCPR performance

Each iCPR metric for both DH and NH was normally distributed apart from RL with the NH. This metric failed the test for normality ($P = 0.008$), due to a series of outliers and, after being manually screened to determine whether the numbers were likely to be true results, the Wilcoxon signed-rank test was performed for this particular variable.

The mean (SD), *median [IQR]* and *P* values for DH and NH are shown in Table 1, which explores the difference between DH and NH for each metric. CCR, CCD, RL and DC were not significantly different when performed with the DH compared to the NH.

Difference between the first and last 30 s of chest compressions during iCPR performance

Each chest compression metric for both DH and NH were normally distributed for the first and last 30 s of iCPR performance apart from RL performed with the NH. This metric failed the test for normality for both the first and the last 30 s ($P = 0.02$).

The mean (SD), *median [IQR]* and P values for the first and last 30 s of iCPR performance are displayed in Table 2, which explores the difference between DH and NH for each metric in the first and last 30 s of iCPR performance. CCR and DC were significantly different for the last 30 s compared to the first 30 s for both DH and NH. CCD and RL were not significantly different for DH and NH.

Perception of fatigue between DH and NH

The results for perception of fatigue between DH and NH are demonstrated in Fig. 1. This metric was normally distributed for both DH and NH. The mean difference in the scores for perception of fatigue between the DH (62.8 ± 12.5 mm) was significantly lower ($t = -3.7$, $P < 0.001$) than the NH (76.8 ± 13.4 mm).

Relationship between perception of fatigue and iCPR performance with DH and NH

There was no correlation between DH and perception of fatigue for any of the metrics. However, there was a significant correlation between perception of fatigue and CCR ($r = 0.43$, $P = 0.04$) and RL ($r = -0.48$, $P = 0.02$) for the NH (Table 3). The coefficient of determination demonstrated that for the NH, 19% of CCR and 23% of RL can be explained by perception of fatigue.

Discussion

The results of this randomised study suggest that there is no significant difference between DH and NH in terms of the overall chest compression performance for the four measured variables for iCPR. Although differences have been demonstrated in older children and adults, our result is consistent with some of the existing data on hand

Table 2 – Mean (SD), *Median [IQR]* and P values for first and last 30 s – DH and NH.

	DH first 30 s	DH last 30 s	P value	NH first 30 s	NH last 30 s	P value
CCR (cpm)	112.1 (11.5)	107.1 (9.8)	0.02	110.8 (11.5)	106 (13.5)	0.004
CCD (mm)	43.1 (4.4)	42.6 (4.7)	0.25	44.3 (4.7)	43.8 (5.2)	0.59
RL (kg)	2.9 (1.1)	3 (1.3)	0.75	*2.4 [1]*[a]	*2.7 [1]*[a]	0.18
DC (%)	38.3 (9.7)	41.7 (10.6)	0.04	38.7 (9.6)	44.4 (9.4)	<0.001

CCR; chest compression rate, CCD; chest compression depth, RL; Residual Leaning, DC; Duty Cycle, cpm; compressions per minute, DH; dominant hand, NH; non-dominant hand.
[a] Wilcoxon test for non-parametric.

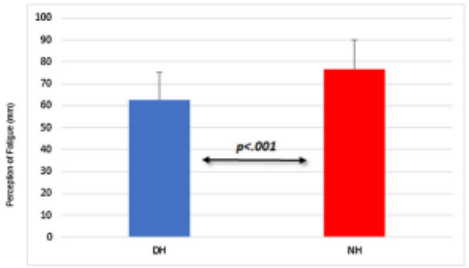

Fig. 1 – Perception of fatigue between dominant and non-dominant hand.
Data representing the mean results and standard deviation for perception of fatigue after 3-min simulated infant CPR performance with the dominant hand and after 3-min simulated infant CPR performance with the non-dominant hand.

dominance. Oh et al. (2014)[32] investigated if hand dominance correlates to the quality of one-handed chest compressions during paediatric CPR and concluded that the average values for the metrics measured (CCR and CCD) were not significantly different using the DH or NH. Similarly, Kim et al. (2015)[19] compared one-hand technique in paediatric CPR for CCR, CCD and peak compression pressure and found no significant differences. In the adult population, Nikandish et al. (2008)[17] investigated the quality of adult chest compressions in relation to the hand in contact with the sternum delivered by first year healthcare students and concluded that it was not significantly different. However, the results from our experiment and the studies cited above contrast with the findings from Kim et al. (2016),[12] who compared infant chest compressions using index-middle vs. middle-ring fingers for the right vs. the left hand and concluded that the most effective performance for the TFT was obtained using the index-middle fingers of the right hand. Despite hand dominance not being specified in their study, it demonstrated a significant difference between performance with the right and left hand. The explanation for this difference may lie in the metrics measured by Kim et al.[12] Their results are based on the comparison between right vs. left hand for mean compression depth and the percentage of "deep enough" compressions. It has been raised recently by Almeida et al.[33] that converting numbers related to CPR performance into percentage or quality indices produces greater variance in measured performance. This could have impacted the results of the afore-mentioned study, which used percentage as a metric of performance. Another occurrence that deserves a remark is the intermanual transfer of learned skill. This phenomenon of skill transfer suggests that a motor task learned with one hand generates practice effects for the opposite, untrained hand.[34] This theory may have influenced the results of our study by potentially narrowing down the observed difference in performance between hands, particularly because of the short interval (1-min) between the DH and NH trials. However, such a short duration is likely to mirror that of the lone rescuer where the time delay between switching hands is minimal. It is not clear as to the effect of intermanual transfer with longer durations of pauses between hands during iCPR.

Another finding demonstrated by our present study was a significant difference in performance during the final 30 s of iCPR, compared with the first 30 s for CCR and DC. This suggests that there was inconsistent performance during the 3 min of CPR, which is comparable with the results from Nikandish et al. (2008)[17] and Jiang et al. (2015),[7] whose studies show a significant reduction in the percentage of correct compressions during ongoing resuscitation. One reason to explain this difference may lie in fatigue, as previous research has shown that CPR performance is affected by greater variability over time.[7,21,27,28,35,36] However, the correlation between perception of fatigue and performance in our study was modest at best for CCR and non-existent for DC. Therefore, the mechanism behind this difference in performance between the first and last 30 s of iCPR performance remains unclear. Despite the finding being significant, the mean values of those metrics remain within current iCPR guidelines, raising the question as to the clinical significance of this finding.

Whilst the iCPR performance in the present study was not different for the DH vs. the NH, the perception of fatigue, represented by VAS, was significantly higher for the NH when compared to the DH after 3 min of iCPR. This indicates that, although participants can perform similarly, regardless of hand used, the effort to maintain quality is greater for the NH. This finding may be explained by the relationship between iCPR and finger strength. It has been determined that performance of TFT may be influenced by the amount of finger strength, finger slave (unintentional force produced by fingers that are not used or required during performance—i.e. thumb, ring and little finger) and hand grip power.[12] Some studies have identified that the hand grip power and finger strength are greater in the right hand even if finger slaving is not significantly different,[37–40] indicating that hand dominance may impact on the perceived fatigue of iCPR using the TFT as the mechanisms of force generation and maintenance may differ between DH and NH.

Limitations

Our study has some limitations. First, the participants were lay people, selected from a convenience sample, with little or no previous CPR

Table 3 – Correlation Coefficients and P values for iCPR metrics and perception of fatigue.

iCPR variables X perception of fatigue	DH Correlation	P value	NH Correlation	P value	R squared
CCR (cpm)	−0.16	0.47	0.43	0.04	0.185
CCD (mm)	0.05	0.82	0.36	0.09	
RL (kg)	−0.01	0.98	−0.48[a]	0.02	0.229
DC (%)	−0.04	0.87	0.29	0.18	

iCPR; infant cardiopulmonary resuscitation, CCR; chest compression rate, CCD; chest compression depth, RL; Residual Leaning, DC; Duty Cycle, cpm; compressions per minute, DH; dominant hand, NH; non-dominant hand.
[a] Spearman's rho test for non-parametric.

training, which does not necessarily represent a sample of general population, limiting the generalisability of the findings. Second, this was a manikin-based study conducted in a simulated environment, so direct transferability to real resuscitation may be limited. Third, our study examined a 3-min interval of infant chest compression, therefore the results cannot be applied to the situation where a single rescuer performs iCPR for a longer period where increased levels of fatigue could be expected. Fourth, the large number of bivariate comparisons were conducted, potentially raising the chance of type 1 error, as no correction for multiple comparisons were made. However, the reporting of actual P-values enables the reader to make their own interpretation. Moreover, the majority of findings were non-significant. Finally, important parameters such as ventilation, hands-off time and hand preference were not part of the outcome measures, which could have impacted the results. Further studies are required to investigate the aspects of these parameters in relation to fatigue and performance.

Conclusions

In this randomised, simulated trial, no significant difference was found in the quality of chest compressions during iCPR performance for DH and NH using the TFT. Despite a small association between perception of fatigue and performance, no effect on quality was determined and participants were able to maintain similar quality iCPR, regardless of reporting higher levels of perception of fatigue in the NH. Nevertheless, future studies should investigate the effect of prolonged iCPR to further the understanding of these factors on performance. Based on the findings of the present study, individuals performing iCPR can be confident in their ability to offer similar quality of infant resuscitation regardless of the hand used or the perception of fatigue, under the conditions explored in this study.

Credit author statement

DA, CC, UR, MJ, and JW 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 and JW have considerably contributed to the acquisition, analysis and interpretation of data.

DA, CC, UR, MJ and JW have drafted the article and revised it critically for important intellectual content.

Declaration of interest

None.

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4.12 *Limitations*

This study presents some limitations that need to be considered. As described in the manuscript, the participants of this study were lay people, selected from a convenience sample of an event about cardiac arrest and CPR. They had little or no previous CPR knowledge but could have been more aware of the importance of CPR, which does not necessarily represent a sample of general population, limiting the generalisability of the findings.

Other important aspects that can limit direct transferability to real resuscitation practice are the use of manikin to evaluate chest compression quality and the simulated context in which this study was conducted. These two limitations were also described and further explored in the previous study (Chapter 3, Section 3.15, paragraphs one and two).

The time interval of infant chest compressions examined in the experiment was three minutes, therefore the results cannot be transferred to the situation where iCPR is performed for longer, where increased levels of fatigue could be expected.

The study compared CCR, CCD, RL, DC, and perception of fatigue with the dominant and non-dominant hands. It is understood that a large number of bivariate comparisons can potentially increase the chance of type-1 error, where results are reported as significant when in fact, they have occurred by chance. However, by reducing alpha level using a correction for multiple comparisons, could increase the chance of type-2 error as explained in Section 4.10 in this Chapter, along with a description of statistical tests performed in order to reduce type-1 and type-2 errors.

Nevertheless, the author has reported the actual p-values, enabling the reader to make their own interpretation.

The final aspect that brings some limitations to the study is that important parameters such as ventilation, hands-off time and hand preference were not included in the analysis. Despite ventilation being an extremely important aspect of paediatric CPR, the focus was on infant chest compressions. It is suggested that further studies should assess ventilation and hands-off time to fully understand the differences between DH and NH during iCPR performance.

4.13 Chapter Summary and Next Steps

This Chapter describes an experimental, prospective, randomised study aimed to explore the differences in performance between the DH and NH during simulated iCPR using the two-finger technique, and to assess perception of fatigue and its relationship with iCPR performance. It was designed based on the gaps identified during the previous experiment (Chapter 3) which, without further exploration, could potentially impact rescuer's performance and influence interpretation of data in iCPR skill performance and decay.

Twenty-four participants performed three-minute iCPR on an infant manikin using either DH or NH. After one-minute rest, they completed three-minute iCPR with their other hand. Feedback on performance was not provided. On completion of each trial, participants were asked to rate their level of perceived fatigue using VAS. CCR, CCD, RL and DC were individually measured to analyse performance using a bespoke algorithm. Four outcome measures were selected: the difference between DH and NH for each variable; the difference between the first and last 30 seconds of iCPR

performance with the DH and NH; perception of fatigue for DH and NH; the relationship between perception of fatigue and iCPR performance.

The results of this study indicate that CCR, CCD, RL, and DC were not significantly different when performed with the DH compared to the NH. However, perception of fatigue, represented by VAS, for the NH was significantly higher than the DH after three minutes of iCPR. This indicates that, although participants can perform similarly, regardless of hand used, the effort to maintain quality is greater for the NH.

Additionally, a significant correlation between perception of fatigue and CCR and RL for the NH was encountered. The increased perception of fatigue with the NH may be explained by the relationship between iCPR with the TF technique and the amount of finger strength, finger slave and hand grip power, as the mechanisms of force generation and maintenance may differ between DH and NH. Despite this association, participants were able to maintain comparable chest compressions, with no effect on quality, suggesting that rescuers can be confident that similar iCPR can be provided regardless of the hand used.

Next steps

With a new understanding about consistency of iCPR performance generated by the reliability experiment (Chapter 3), and a better comprehension about hand dominance and hand fatigue when the TF technique is used in the delivery of iCPR (explored in this Chapter), the next step for the thesis was to investigate whether a competence-based strategy to iCPR skills retraining could result in skill retention. This was essential to inform the development of a new model of iCPR retraining strategy, which is the ultimate aim of this thesis. However, due to the limited and inconclusive

evidence regarding an optimal retraining schedule for paediatric resuscitation skills identified in the literature review (Chapter 2), the author concluded that a scoping review of literature (explored in Chapter 5) investigating the intervals, strategies and associated outcomes of formal paediatric resuscitation training provided to healthcare professionals, was an essential step to progress this thesis and further develop the design of the competence-based iCPR retraining study. The methodological approach of the scoping review and the published manuscript are presented in Chapter 5.

Chapter 5 Justification of the Methods and Study Design: "Scoping Review of Literature"

5.1 Chapter Overview

This Chapter is divided into two sections: the first section addresses the methodology of STUDY 3 – "What can be learned from the literature about intervals and strategies for paediatric CPR retraining of healthcare professionals? A scoping review of literature". This scoping review investigates the approaches and timeframes of paediatric CPR skills retraining delivered to healthcare professionals, and summarises the relevant outcomes associated with the retraining including patient outcomes, quality of performance, retention of knowledge and skills, and rescuer's confidence. The second section provides the published manuscript (Gugelmin-Almeida *et al.* 2022a) as part of the integrated thesis format submission. An evaluation of the limitations of the study is presented at the end of the Chapter, to contextualise the results and signpost the reader to the next steps of the thesis.

When conducting the literature review (Chapter 2), the author identified limited and inconclusive evidence regarding an optimal retraining schedule for paediatric resuscitation skills. At that point however, other studies were needed to be performed in order to inform the design of the competence-based strategy to iCPR retraining study. The author had to identify the benefits of using real-time feedback (RTF) during iCPR retraining (Chapter 2, Section 2) to establish if this type of feedback strategy was appropriate for this research. Additionally, an understanding about consistency of iCPR performance was key to interpreting skill changes after training

(Chapter 3). Hand dominance and perception of fatigue during iCPR were also important aspects that needed further exploration (Chapter 4).

With the new knowledge generated as a result of the above-mentioned experiments, the author decided to revisit an important aspect related to intervals of paediatric resuscitation retraining. The optimal timeframe to iCPR retraining has not been established, as previously recognised in Chapter 2. Therefore, the author concluded that a scoping review of literature investigating the intervals, strategies and associated outcomes of formal paediatric CPR training/retraining delivered to healthcare professionals, was an essential step to complement the design of the competence-based iCPR retraining study. For this reason, this scoping review of literature was conducted at this stage and is being presented halfway through the thesis.

Section 1

5.2 Aims and Objectives

This scoping review of literature was conducted to explore the evidence regarding retraining schedules for paediatric resuscitation skills, so that an effective and sustainable timeframe for paediatric CPR retraining could be defined. This missing piece of information was essential to further develop the design of the competence-based iCPR retraining study and the progress of this thesis.

Prior to starting this review, the author and the research team discussed the best framework to reach the aim of this current study (as described in the last paragraph of this section) and concluded that a scoping review would be the most suitable

method as it allows for a more nuanced presentation and discussion of the heterogeneous study designs and findings. The objective was to identify the scope of evidence available regarding paediatric CPR retraining intervals and strategies, and outline key aspects about the topic, to inform the design of the next experimental study.

Scoping reviews are important tools within the field of evidence synthesis. They are a suitable strategy to establish the coverage of evidence on a specific topic and provide an overview of available studies with an overview of their focus (Arksey and O'Malley 2005, Grant and Booth 2009, Colquhoun *et al.* 2014, Peters *et al.* 2015). Although scoping reviews are similar to systematic reviews in that they follow a structured process, there are some key differences in methodologies and purposes. The general reasons for conducting scoping reviews are to identify the types of evidence in a particular field, instead of aiming to answer a defined research question, as seen in systematic reviews (Arksey and O'Malley 2005). With a more comprehensive scope regarding the inclusion criteria, scoping reviews are still designed based on a pre-defined protocol to be transparent and reproductible and include a systematic and exhaustive search of information, with extracted data presented in a structured way.

Earlier in Chapter 2, it was discussed that monthly CPR training can enhance retention of skills (Oermann *et al.* 2011, Anderson *et al.* 2019). However, this timeframe may not be achievable in clinical settings due to associated high costs, staff motivation and consequent dropouts (Ward and Wood 2000). Other studies advocate a retraining schedule of six months (Ciurzynski *et al.* 2017), with resuscitation

guidelines recommending exposure to the skills yearly or every two years (RCUK 2020a, Cheng *et al.* 2020, Lockey *et al.* 2021). However, it has been determined that CPR skills decay within weeks or months after training (Niles *et al.* 2017, Anderson *et al.* 2019, Lockey *et al.* 2021). Therefore, identifying evidence about paediatric CPR retraining intervals was an essential step to inform the design of the competence-based iCPR retraining study.

This scoping review of literature aimed to investigate what has been previously explored regarding the intervals and strategies of formal paediatric resuscitation retraining provided to healthcare professionals and provide a summary of the associated outcomes including quality of performance, retention of knowledge and skills, confidence, and patient outcomes.

5.3 Study Protocol

The protocol for this scoping review was created and reported using the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR), which is an adapted reporting guideline that aims to offer a structured direction on the reporting of scoping reviews (Tricco *et al.* 2018). It outlines a minimum set of items to include in research reports and, together with other reporting guidelines, have demonstrated to enhance transparency of the methodological approach and confidence in research findings (Altman and Simera 2014).

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) is the commonly used guideline for systematic reviews but some of its items may not be relevant to scoping reviews, whereas other significant aspects may be missing for

scoping reviews (Tricco *et al.* 2018). Thus, based on the original PRISMA statement (Liberati *et al.* 2009), PRISMA-ScR was developed with 20 essential reporting items and two optional items.

5.4 Study Design

The study design is outlined in the published manuscript (Chapter 5, Section 2) and describes the PICOST (Population, Intervention, Control, Outcomes, Study design and Timeframe) selection and eligibility criteria. The choice was based on the need to identify what has been previously investigated in relation to paediatric CPR retraining timeframes and strategies, which would inform the design of the next experimental study (Chapter 6) and further develop this thesis. An effective selection for PICOST was important to maximise the extraction of relevant studies to answer the research question of this scoping review: "What can be learned from the literature regarding strategies and intervals of paediatric CPR retraining provided to healthcare professionals in relation to good quality performance; better retention of knowledge and/or skills; improved confidence; and/or better patient outcomes?"

A couple of challenges were encountered when selecting the PICOST strategy for this scoping review. The first was related to the variation of terms to describe formal paediatric CPR training. There is a wide range of training courses provided to healthcare practitioners (AHA 2022, ERC 2022, RCUK 2022b), with different intended learning outcomes and designed for professionals working in diverse areas of care. It was fundamental that any type of paediatric resuscitation training was included in the analysis, therefore the "intervention" selected for PICOST was determined as "any form of formal pCPR training". To ensure the scoping review included every

relevant training or course, a speculative search was performed prior to the main search for the scoping review to establish what types of paediatric resuscitation training are offered worldwide.

The following paediatric resuscitation courses were identified:

Paediatric Basic Life Support: designed for healthcare professionals, lay people and other professionals who are required to recognise life-threatening emergencies and provide basic cardiovascular life support skills including high-quality chest compressions, effective ventilations and deliver early use of an automated external defibrillator (AED).

Paediatric Advanced Life Support (PALS): designed for healthcare professionals who have a duty to respond to children and infants during emergencies and for those who work in emergency response teams, emergency medicine, intensive care, and critical care units.

European Paediatric Advanced Life Support (EPALS): intended for healthcare professionals who care for deteriorating paediatric patients and paediatric cardiac arrests as part of their clinical duties, as well as those who teach on a regular basis.

Paediatric Immediate Life Support (PILS): intended for healthcare professionals who may need to care for paediatric patients during an emergency.

Advanced Paediatric Life Support (APLS): designed for healthcare professionals who have a duty of care to manage children with life threatening emergencies as part of their clinical duties.

Pre-hospital Paediatric Life Support (PHPLS): designed to provide the knowledge and practical procedures required for effective treatment of a seriously ill and or injured child prior to hospital admission.

Advanced Trauma Life Support (ATLS): for immediate management of trauma patients and inter-hospital transfer.

The resuscitation training programmes listed above were part of the inclusion criteria, as they all involve training healthcare practitioners on how to provide paediatric CPR, although there were differences in content of the training programs.

The other challenge encountered when selecting the PICOST strategy for this scoping review was related to the population. It is recognised that there is a disparity between training content and strategies for healthcare professionals, healthcare students, members of the public (bystanders), or members of the public with duty of care to children (e.g. teachers, lifeguards) (RCUK 2020a, Lockey *et al.* 2021, Skellett *et al.* 2021). The disparity includes learning the full paediatric CPR sequence with compression:ventilation rate of 15:2; learning the adult CPR sequence with compression:ventilation rate of 30:2 to apply to children in cardiac arrest; or even learning the adult CPR sequence with paediatric modifications, which makes it more appropriate for use on children (as explained in Chapter 2, Section 2.3.3). Therefore, to standardise the approach of paediatric training and retraining strategies, the population for this scoping review was healthcare professionals receiving formal paediatric CPR retraining.

5.5 Search Strategy

The search strategy is described in the published manuscript (Chapter 5, Section 2) but, in consequence of word limitations, an important aspect related to the key words used in the review will be addressed in this section for completeness.

Prior to finalising the study protocol, the author and the research team spent some time with an experienced librarian to develop an effective search strategy that would lead to the retrieval of a high recall rate of relevant studies that could address the PICOST (McGowan and Sampson 2005). Search terms were selected based on an analysis of the main concepts of the research question using MeSH, which is considered a valuable tool for identifying concepts and selecting relevant terms (Salvador-Oliván, 2019). Truncation (*) was used to avoid having to individually include every probable variation of the terms in the search and to increase recall. Additionally, an analysis of key words and the relevant combinations generated by MySearch was performed. MySearch is a federated search engine (i.e., EBSCO Discovery Service) that searches over 80 databases simultaneously. Furthermore, variations of search terms were trialled using “Boolean” operators (OR, AND) to maximise recall rate of relevant studies that could address the PICOST.

This pre-search effort to develop an effective search strategy was of ultimate importance as, according to Salvador-Oliván and colleagues (2019), there is normally a high percentage of errors in search strategies with most errors impacting recall. This can potentially influence the conclusions of the reviews, as studies with relevant and important results may not be identified.

The initial literature search and analysis were carried out in August 2019 to inform the design of the competence-based iCPR retraining study (Chapter 6) and updated in March 2022. The detailed search strategy is presented in the appendix of the manuscript.

5.6 Data Extraction and Synthesis

The initial search was carried in EBSCO (MySearch), which covers numerous databases, including the ones selected for this review, as shown in the manuscript. Some databases were irrelevant, but it was beneficial to take a multi-disciplinary approach so that relevant studies could be identified. Separate search on Embase was undertaken as this database was not covered by EBSCO. Additionally, the reference lists from included articles were manually searched to identify and select any additional studies not yet captured.

An Excel spreadsheet was used to organise the extracted data from included full text sources using a "descriptive-analytical" method within a pre-set framework (Arksey and O'Malley 2005). This was to certify that disparities among studies were consistently captured and summarised for further analysis. The pre-set categories included:

- Study identification: first author; title; DOI (Digital Object Identifier); year of publication; geographic location
- Study design: context; intervention; duration of study
- Participants: sample size; profession; setting
- Training/retraining details: BLS, PALS, EPALS, PILS, etc; duration of training and/or retraining; type of training

- Outcome measures: knowledge; confidence; ability to deliver effective CPR; skill retention; etc.
- Methods of assessment
- Results
- Conclusion

Data extraction revealed a disparity in the methods used in the studies, dissimilar retraining schedules and interventions, and a varied range of outcome measures. In consequence, data synthesis presented some challenges with sources that did not fit precisely into the categories. Categorising the timeframe and length of interventions during retraining was challenging, due to the heterogeneity of the studies designs. This can be observed in the manuscript, shown in Section 2 below.

Section 2

This section presents the manuscript published in *Resuscitation Plus* as part of the integrated thesis format submission.

See: Gugelmin-Almeida, D., Tobase, L., Maconochie, I., Polastri T., Gesteira, E., C., and Williams, J., 2022. What can be learned from the literature about intervals and strategies for paediatric CPR retraining of healthcare professionals? A scoping review of literature. *Resuscitation Plus,* 12.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9630773/

Available online at www.sciencedirect.com

Resuscitation Plus

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

Review

What can be learned from the literature about intervals and strategies for paediatric CPR retraining of healthcare professionals? A scoping review of literature

Debora Gugelmin-Almeida[a,*], *Lucia Tobase*[b], *Ian Maconochie*[c], *Thatiane Polastri*[d], *Elaine Cristina Rodrigues Gesteira*[e], *Jonathan Williams*[a]

Abstract

Background: Effective training and retraining may be key to good quality paediatric cardiopulmonary resuscitation (pCPR). PCPR skills decay within months after training, making the current retraining intervals ineffective. Establishing an effective retraining strategy is fundamental to improve quality of performance and potentially enhance patient outcomes.

Objective: To investigate the intervals and strategies of formal paediatric resuscitation retraining provided to healthcare professionals, and the associated outcomes including patient outcomes, quality of performance, retention of knowledge and skills and rescuer's confidence.

Methods: This review was drafted and reported using the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR). PubMed, Medline, Cochrane, Embase, CINAHL Complete, ERIC and Web of Science were searched and studies addressing the PICOST question were selected.

Results: The results indicate complex data due to significant heterogeneity among study findings in relation to study design, retraining strategies, outcome measures and length of intervention. Out of 4706 studies identified, 21 were included with most of them opting for monthly or more frequent retraining sessions. The length of intervention ranged from 2-minutes up to 3.5 hours, with most studies selecting shorter durations (<1h). All studies pointed to the importance of regular retraining sessions for acquisition and retention of pCPR skills.

Conclusions: Brief and frequent pCPR retraining may result in more successful skill retention and consequent higher-quality performance. There is no strong evidence regarding the ideal retraining schedule however, with as little as two minutes of refresher training every month, there is the potential to increase pCPR performance and retain the skills for longer.

Keywords: Paediatric cardiopulmonary resuscitation, Training strategies, Retraining intervals, Scoping review, Healthcare professionals

Introduction

Survival from paediatric cardiac arrest is dependent on medical interventions including high quality paediatric cardiopulmonary resuscitation (pCPR).[1–3] However, pCPR quality frequently does not meet current standards. Long interruptions and incorrect chest compression depth and rate are some of the challenges, potentially impacting positive outcomes.[4–6]

Effective training and retraining may be key to pCPR quality. Previous studies demonstrated that learners acquire CPR knowledge and skills irrespective of the method it is delivered[7–13] however, evidence shows that CPR skills decay within weeks to months after training, demonstrating that the current retraining intervals of one

Abbreviations: APLS, Advanced paediatric life support, ATLS, Advanced trauma life support, BLS, Basic life support, CPR, Cardiopulmonary resuscitation, EM, Emergency medical, EMS, Emergency medical services, EPALS, European paediatric advanced life support, ILCOR, International liaison committee on resuscitation, pCPR, Paediatric cardiopulmonary resuscitation, PALS, Paediatric advanced life support, PHPLS, Pre-hospital paediatric life support, PILS, Paediatric intermediate life support, RCT, Randomised controlled trial

* Corresponding author.
E-mail address: almeidad@bournemouth.ac.uk (D. Gugelmin-Almeida).

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or two years is ineffective.[9,14–16] This, coupled with paediatric cardiac arrest being an uncommon event, with an incidence of 8.04/100,000 for out-of-hospital cardiac arrests and around 1/1000 admissions for in-hospital cardiac arrests, further perpetuates the challenge in retaining pCPR skill.[17–19] Current resuscitation guidelines recommend a distributed practice model for teaching and learning CPR skills, however, there is no clarity over the optimal gap between training or retraining sessions.[19–21] It has been suggested that monthly retraining can enhance retention[16,22–23] yet, this may not be feasible in clinical areas due to associated high costs, staff motivation and drop outs.[16,24] Previous reviews have explored retraining intervals for laypersons and spaced learning for resuscitation training, however these reviews did not focus on paediatric CPR. High-quality CPR has been associated with improved survival outcomes after cardiac arrest in the adult population.[25–27] Establishing an effective retraining strategy that facilitates learning and maximizes retention of pCPR skills is fundamental to improve quality of performance and potentially enhance patient outcomes after cardiac arrest.

This scoping review aimed to provide a contemporary synthesis of the literature exploring intervals and strategies of formal paediatric resuscitation training/retraining provided to healthcare professionals, and the associated outcomes including patient-level outcomes, quality of pCPR performance, retention of knowledge and skills, and rescuer's confidence. Since interventions such as "low dose, high frequency"[28–29] is not considered full retraining but short exposures to the skills, the term "refresher" will be used alongside retraining when appropriate.

Methods

Study design and protocol

In order to achieve the above stated aim, a scoping review was the preferred method. It enables to determine the scope of evidence available, provide an overview on key aspects underpinning the research area and gaps in literature to be identified.[30]

This scoping review protocol was drafted and reported using the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR).[31] To the best of the authors' knowledge, there are no existing scoping or systematic reviews exploring the same or similar research question based in the paediatric population. Ethical approval was not applicable to this study.

Research question

The research question was based on PICOST (Population, Intervention, Control, Outcomes, Study design and Timeframe) and defined as: "What can be learned from the literature regarding strategies and intervals of paediatric CPR retraining provided to healthcare professionals in relation to patient outcomes; good quality performance; better retention of knowledge and/or skills; and/or improved rescuer's confidence?"

P - healthcare professionals including doctors, nurses, EMS providers, Allied Health Professionals or any other healthcare professional working in any geographic location and any setting (pre-hospital, community and hospitals) undergoing formal pCPR retraining.

I - any form of formal pCPR retraining.

C - different retraining or refresher intervals.

O – patient outcome; ability to deliver effective pCPR – simulated or real; knowledge and skill improvement; retention of knowledge and skills; and rescuer's confidence.

S - Primary studies (quantitative, qualitative and mixed-methods) including randomised controlled trials (RCTs), non-randomised controlled trials, interrupted time series, controlled before-and-after studies, observational and cohort studies were included in order to consider different aspects of measuring outcomes.

T - studies published between January 2005 and March 2022 (since the first publication of the 2005 guidelines on resuscitation by the ILCOR process, feeding scientific literature to the different Resuscitation Councils).

Eligibility criteria

All studies addressing the PICOST question were eligible, including paediatric manikin and/or simulation; paediatric basic life support (BLS) retraining; paediatric advanced life support (PALS); European paediatric advanced life support (EPALS); advanced paediatric life support (APLS); paediatric immediate life support (PILS); pre-hospital paediatric life support (PHPLS); and advanced trauma life support (ATLS). Studies based on neonatal CPR training/ retraining; adult CPR training/retraining; healthcare students; unpublished studies and studies in a language other than English were excluded from this review.

Search strategy

The following databases were searched by three researchers (DA, LT, TP): PubMed/Medline; Cochrane; Excerpta Medica Database (Embase); Cumulative Index to Nursing and Allied Health Literature (CINAHL) Complete and Web of Science. A pre-defined search strategy was used combining Boolean operators 'AND' and 'OR' with medical search headings and subheadings (e.g. MESH) when applicable. The search terms (Appendix 1) were drafted by the research team and revised by an experienced librarian. The reference lists from included sources were manually searched to identify any further studies not yet captured.

Study identification and selection criteria

All articles initially identified were sent to the web-based bibliographic manager (EndNote Desktop X9) where duplicate references were removed. To increase consistency, two reviewers (DA and LT) screened the identified sources for relevance by evaluating the titles and abstracts according to the proposed eligibility criteria. Disagreement was resolved by consensus, moderated by a third reviewer (TP). If during abstract screening suitability could not be determined, further evaluation of the full text was performed, at which point, those studies that did not fit the eligibility criteria were excluded.

Data extraction and analysis

Data from included full text sources were extracted and organised in an Excel spreadsheet using a "descriptive-analytical" method within a pre-set framework[32] to ensure that variations between studies were uniformly captured and described. Study identification (first author, title, DOI, year of publication, geographic location); study design (context, sample size, intervention, duration); participants (profession, setting); training/retraining details (BLS, PALS, EPALS, PILS, etc.); outcomes (knowledge, confidence, ability to deliver effective CPR, skill retention, etc.); methods of assessment; results; and conclusion were summarised for further analysis.

Results

The initial search resulted in 6272 studies. Of those, 1566 were duplicates, resulting in 4706 titles post-deduplication. After reading titles and abstracts, 134 were selected for full text review. Of those, one could not be retrieved and 112 were discarded for not fully fulfilling the inclusion criteria, leaving 21 studies included in the analysis, as seen in Fig. 1.

Study characteristics

Study characteristics and interventions are summarised in Table 1. Over 3000 healthcare professionals were involved including nurses, paediatric residents, emergency medicine residents, EMS providers, physicians, respiratory therapists and pharmacists.

The geographical areas consisted of Thailand,[33] USA,[22,28,34–38,40–41,43–44,47,51] Japan/USA,[45] UK,[39] Canada,[42,46,49] Australia[48] and Norway.[50] The methodology varied significantly and included pre/post-test,[33,36,40,47,51] mixed-methods,[34] interventional studies,[35,37] RCTs[28,38–39,44–46,49–50] and observational studies.[22,41–43,48]

Different training strategies were observed, with the majority of studies using PALS or BLS as initial training models. Most of the interventions (14) were team-based training[33–36,40,43–51] but of those, 12 studies included cognitive and/or psychomotor skill practice on individual level.[33–36,40,43–47,49–50] Interventions included the traditional instructor-based training;[28,33,45,49] simulation-based mock code program;[34,47,51] simulation only;[38] simulation with debriefing;[35,44,48] high-fidelity simulation;[47] feedback of performance;[33,43] refresher sessions;[22,41] training with real-time feedback;[28,37,39–42,50] and distributed practice.[44–46,49] As some studies used distributed practice as part of their learning strategies prior to retraining interventions,[44–46,49] the authors highlighted these studies in the results table (Table 1), as the concept of distributed practice may have a positive effect on performance and retention of skills.[9] Based on training strategies, there was an improvement in outcome measures for most of the study designs.[22,28,33–37,42–49,51] Three studies did not see significant or lasting improvement when using real-time feedback[39–40,50] and one study using simulation only as a training strategy resulted in improvement but with decline over time.[38]

Outcome measures have also differed between studies and comprised of patient outcomes;[34] pCPR skill metrics (depth, rate, recoil, chest compression fraction, pauses);[28,33–37,39–47,50] retention of pCPR skills;[28,38,42,44,46,49] knowledge;[34–36,40,44,47–49,51] behavioural performance;[45] confidence;[34–36,40,47–49,51] time to achieve good quality pCPR;[22] and frequency of practice.[39]

Methods to assess outcome measures included hospital record for cardiac arrest survival rates;[34] video recording;[34–35,41,49] Likert scale;[34–35,40] questionnaires;[36,40,46–49] automated skill evaluation;[22,28,33,37,39–43,45–46,50–51] observable scoring metrics;[28,38,47,49,51] written assessment;[44,49] and visual analogue scale.[49]

Retraining intervals and number of retraining sessions

The studies selected for this review used different timeframes for the first reinforcement session after initial pCPR training. Two studies performed the interventions straight after training[28,40] and one study

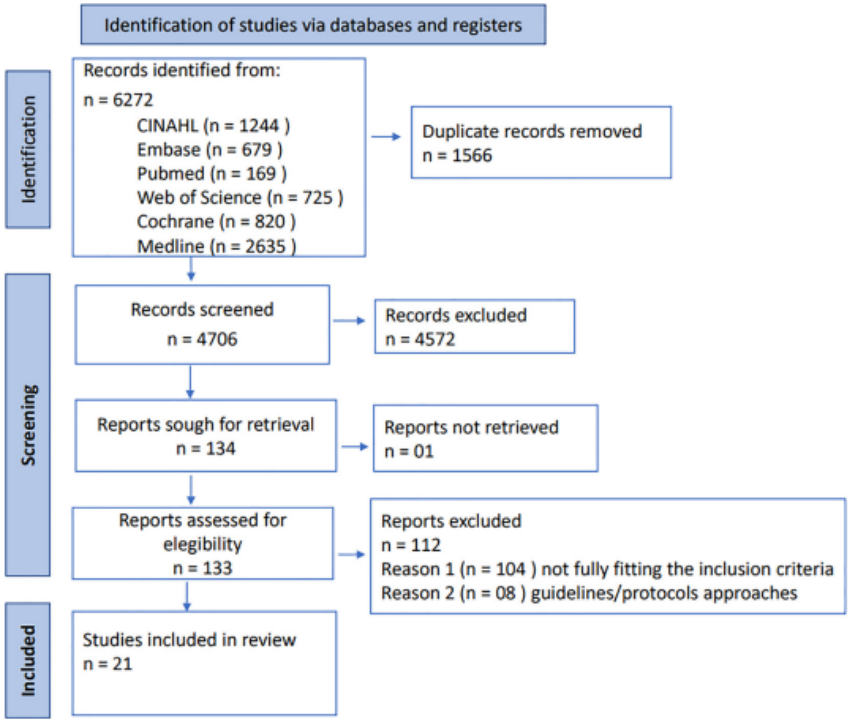

Fig. 1 – Demonstrates the PRISMA-ScR flow diagram.[31]

Table 1 – Studies characteristics, interventions and results of evidence.

Author(year), Country	*Study characteristics (design, population, sample setting)*	*Length and key points of retraining intervention*	*Outcome measures*	*Results*	*Conclusion*
Anantasit et al.[33] (2016) Thailand	Pre-post test, 38 paediatric residents, hospital	1-hour video feedback 1 week later + test 6 weeks later	pCPR skills (depth, rate, recoil) + team-basedCPR	Skills: 50% pass test 1 / 68% (p = 0.09) pass in test 2 Team-based: 46% passed test 1 / 92% (p = 0.08) pass in test 2	Improvement of skills and team-based pCPR with reinforcement of video feedback
Andreatta et al.[34] (2011), USA	Longitudinal, mixed-methods, 252 paediatric residents, paediatric nurses, pharmacists, hospital	Monthly mock codes. Each participant took part in at least one mock code, but more often they participated in two or more mock codes.	Confidence, skills, knowledge and patient outcome	Survival rates ↑ to approximately 50% (p < 0.001) and correlated with the increased number of mock codes (r = 0.87)	Frequent mock codes improve skills, confidence and patient outcome.
Auerbachet et al.[35] (2011), USA	Longitudinal, prospective, interventional, 115 paediatric and emergency medicine residents, hospital	repetitive simulation (10 min scenario + 30 min video debriefing with feedback + 10 min scenario to apply feedback) vs standard simulation (10 min scenario + 30 min video debriefing with feedback). First 6 months standard simulation; last 6 months repetitive simulation	Confidence, skills, knowledge	Perceived knowledge and skills: significantly improved between repetitive and standard (p = 0.005 and p = 0.02 respectively). Perceived confidence: not significantly different (p = 0.4)	Repetitive simulation using scenario + debrief + scenario can improve perceived knowledge and perceived skills in medical residents
Biese et al.[36] (2009), USA	pre-post, 26 paediatric and EM residents, hospital	Pre-test chest compression scenario; 20 mins screen-based high-fidelity simulated code for 4 weeks; post-test scenario	Confidence, skills, knowledge	Confidence: improved from pre to post-test (10.1 SD ± 4.9; range 0–19; p < 0.001). Overall performance: was not significant from pre-test (6.65 (±1.76) to post-test (7.04 (±1.37); p = 0.58)	Frequent screen-based simulation may be a useful adjunct in educating residents to manage paediatric resuscitations by enhancing knowledge, confidence, and some skills.
Bishop et al.[37] (2018), USA	prospective, interventional, 62 PICU nurses, hospital	Monthly training with RTF for 2 minutes. Nurses with 3 or more training sessions before their final data collection = experienced trainees Nurses with 2 or fewer training sessions = novice trainees.	Target of high-quality CPR for more than 70% based on depth and rate	As the number of training sessions increased, the percentage of CPR in the target range also increased, with less variability in performance. 29% with no training 46% after 1 session, 54% after 2 sessions, 68% after 3 sessions, 74% after 4 sessions (p = 0.001). Median percentage of time in the target area was 68% (interquartile range [IQR], 64–72) among the experienced trainees and 48% (IQR, 43–59) among novice trainees; p = 0.002).	Repeated short refresher with RTF significantly increase performance
Braun et al.[38] (2015), USA	RCT, 42 paediatric residents, hospital	Baseline performance; Repeated scenario as needed until mastery-level performance was achieved (1 h to 2 h to achieve mastery); Retest 2, 4, or 6 months later	Retention of mastery-level performance	Percentage of residents maintaining mastery-level performance showed a significant linear decline (p = 0.039), with a drop at each retesting interval. 92% retained mastery at 2 months;	Significant improvements in resuscitation performance after a single simulation-based mastery learning session. However, performance declined over time.

Table 1 (continued)

Author(year), Country	*Study characteristics (design, population, sample setting)*	*Length and key points of retraining intervention*	*Outcome measures*	*Results*	*Conclusion*
				71% at 4 months, 56% at 6 months.	Relatively frequent refresher training is needed after a single simulation-based mastery learning session.
Chang et al.[39] (2019), UK	RCT, 920 healthcare professionals expected to perform CPR, hospital	Pre-test 2 min infant CPR with RTF; practice as many times as wanted for 2 minutes during 8 months. 4 months control (no display on leaderboard) and 4 months intervention (display results on leaderboard)	Leaderboard scores, frequency of practice, CPR performance	2.14 practice episodes per participant during the control phase; 1.94 episodes per participant during the intervention (just a few participants practised more than once). No significant change in performance.	No lasting improvements in either frequency of CPR practice or CPR performance scores in the presence of a leaderboard.
Ciurzynski et al.[40] (2017), USA	Pre-post, 21 nurses, hospital	Pre-test questionnaire; 8–12 minutes, 2 rescuers simulated CPR with RTF; switch roles; (if an overall CPR performance score of 80% was not achieved, repeat CPR with RTF); debrief; post-test questionnaire and refresher at 6 months	Knowledge, CPR performance, comfort with emergency response	Knowledge: significantly improved ($p = 0.001$); knowledge was not retained at 6 months (97, SD = 6) and (85, SD = 11), $p = 0.001$; Comfort: significantly higher ($p = 0.004$); Skills: improved at 6 months but not significantly	A personalised refresher simulation every 6 months is recommended
Donogue et al.[41] (2021), USA	Observational, 253 physicians, nurses, paramedics, EM technicians, hospital	Baseline assessment; CPR self-directed skill training every 3 months where participants had to pass with a score over 75%. If not, RTF until pass; AND real-life events with chest compression monitor and videorecording.	Chest compression within guidelines for depth and rate	Statistically significant improvement for infant CPR (91.5 and 95.0 $p = 0.03$) and paediatric CPR (84.3 and 96.2 $p < 0.001$) between the first and last quarters of the study period. Independent association between a greater number of sessions and adherence to guidelines for rate. No improvement in chest compression depth during actual CPR events.	High-frequency, brief CPR training led to consistently increased performance of high-quality CPR in ongoing training sessions.
Garcia-Jorda et al.[42] (2019), Canada	Observational, 194 physicians, nurses and medical residents, hospital	2 min blinded CPR; up to 3x 2 min trials to achieve 90% with RTF; 2x monthly simulated CPR; debrief. Skill retention measured according to availability: block 1 (1–3 months); block 2 (3–6 months); block 3 (over 6 months)	CPR performance (depth, rate and recoil); Excellent CPR (retention above 90% for each metric or combined; Retention of skills	Rate: 73% trial 1; 91% trial 2; 92% trial 3 Depth and recoil: 100% trials 1, 2 and 3 Excellent CPR: 29% trial 1; 46% trial 2; 48% trial 3 Retention: Rate: baseline (97%); 1–3 months (66%); 3–6 months (69%); > 6 months (78%) Depth: baseline (99%); 1–3 months (96%); 3–6 months (94%); > 6 months (95%) Recoil: baseline (99%); 1–3 months (98%); 3–6 months (98%); > 6 months (98%)	Short rolling refresher trainings should be implemented regularly

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Table 1 (continued)

Author(year), Country	*Study characteristics (design, population, sample setting)*	*Length and key points of retraining intervention*	*Outcome measures*	*Results*	*Conclusion*
Hunt et al.[43] (2018), USA	Observational, 241 paediatric residents, hospital	Weekly 90 mins real cardiac arrest performance debrief	Excellent CPR (proportion of cycles compliant for depth, rate and chest compression fraction)	Excellent CPR 2013: 19.9 (6.9, 32.9); 2014: 41.8 (30.5, 53.0); 2015 = 44.3 (35.3, 53.3); p = 0.04 3.2 increase in the odds of excellent CPR from 2013 to 2015 [95% (1.3–8.1), P = 0.01]	Post-event debriefing program + RTF is associated with measurable improvements in actual resuscitation performance
** Jani et al.[44] (2019), USA	RCT, 24 paediatric residents, hospital	**Distributed practice** MCQ pre-course; skills stations and debrief at month 4 (intervention); MCQ and skills at month 8	Skill retention; knowledge	Intervention group performed better at 8 months than control (p = 0.04). But skills decayed from baseline to 4 months, and 4 months to 8 months; MCQ scores: significant differences from pre to follow up (p < 0.001)	Simulation-based curricula with deliberate practice and debriefing provide a potential pathway for safeguarding against the decay of resuscitation skills
** Kurosawa et al.[45] (2014), USA/Japan	RCT, 40 PICU nurses and respiratory therapists, hospital	**Distributed practice** six 30-minute (reconstructed PALS) delivered over 6 months	Skill; behavioural performance	Skill: pre= (16.3 ± 4.1 post, 22.4 ± 3.9; p < 0.001). Behavioural performance: pre= (33.3 ± 4.5 vs post, 35.9 ± 5.0; p = 0.008)	PALS-reconstructed training is feasible and more effective than standard PALS for skill performance.
** Lin et al.[46] (2018), Canada	RCT, 87 paediatric healthcare providers, hospital	**Distributed practice** Group 1: distributed CPR training with RTF at least once month (no max practice number) Group 2: traditional CPR training Retest all at 3-month and 12-month	Performance and retention based on depth, rate and recoil; excellent CPR (90% for depth, rate and recoil)	Group 1: 85% practised monthly; Performance: group 1 significantly improved at 3 months (depth, p < 0.001; rate p < 0.001; and recoil, p < 0.001) and performance was retained at 12-months. Group 2 did not improve at 3-months for compression depth and recoil decayed significantly (p = 0.030). Retention: at 12-month follow up, group 1 improved significantly compared to group 2 for proportion of excellent CPR: (19.5% vs 71.7%, p < 0.001).	Distributed short practice model with RTF improves the quality of CPR and the long-term skill retention
Mariani et al.[47] (2019), USA	Pre- and post-test, 18 paediatric nurses, hospital	Control group: baseline knowledge assessment + self-confidence survey; mock code at 9-months; knowledge assessment and self-confidence survey at 11-months; Intervention group: baseline knowledge assessment and self-confidence survey; simulation with debriefing at months 1, 5 and 9; knowledge assessment and self-confidence survey at month 11.	knowledge, skills, self-confidence	No statistically significant difference between groups at baseline; Statistically significant difference in the post-test scores (p = 0.016) with the intervention group scoring higher than the control group. No statistically significant differences in self-confidence or final scenario between the groups.	Repeated paediatric mock code simulations with structured debriefing can be an effective method to educate CPR skills.

Table 1 (continued)

Author(year), Country	*Study characteristics (design, population, sample setting)*	*Length and key points of retraining intervention*	*Outcome measures*	*Results*	*Conclusion*
Niles et al.[22] (2009), USA	Prospective, observational, 420 nurses, physicians, respiratory therapists, hospital	Refresher sessions for less than 5 minutes. Group 1: less than 2 refreshers a month; Group 2: more than 2 refreshers a month.	Time to achieve good quality CPR based on rate, depth and recoil	Time to achieve good quality CPR: refreshed $\geq$ 2 times/month (median 21 s, IQR: 15.75–30 s) was significantly less than those that refreshed < 2 times/month (median 67 s, IQR: 41.5–84 s), ($p < 0.001$)	"Rolling Refresher" bedside CPR skill training approach using "just-in-time" and "just-in-place" education is effective and well received by PICU staff.
Ojha et al.[48] (2014), Australia	Prospective, observational, 54 doctors and nurses, hospital	Observation of 6 scenarios (10 min + 5 min debrief) fortnightly	knowledge scores; self-reported confidence levels for rate, depth, recoil	Statistically significant difference in pre (69%) and post (81%) MCQ scores ($p = 0.003$). Improved self-reported confidence levels at 6 months compared with baseline (72% and 35%) $p < 0.001$.	Repeated observation of brief scenarios has significantly improved the knowledge and confidence of HCPs.
** Patocka et al.[49] (2019), Canada	RCT, 49 EMS providers, pre-hospital	**Distributed practice** Spaced PALS 3.5 h weekly over 1 month vs traditional PALS (2x 7 h)	Retention of skills; knowledge; self-efficacy	Skills improved immediately following the training in both traditional (pre, 1.3 ± 0.7 vs post, 3.1 ± 0.1.2; $p < 0.0001$) (Cohen's d = 1.8) and spaced groups (pre, 1.6 ± 1.1 vs post, 2.9 ± 1.2; $p = 0.0001$) (Cohen's d = 1.1). 3-months skills: remained significantly improved from baseline in both the traditional (pre, 1.3 ± 0.7 vs post-3-months, 2.5 ± 1.5; $p = 0.01$) (Cohen's d = 1) and spaced groups (pre, 1.6 ± 1.1 vs post-3-months, 2.5 ± 1.3; $p = 0.01$) (Cohen's d = 0.7); MCQ: no decay for spaced group at 3-months (post training, 30.3 + 0.5 vs post-3-months 29.7 ± 0.5; $p = 0.39$); but statistically significant decay in the traditional group (post training, 31.1 ± 0.5 vs post-3-months 29.6 ± 0.5; $p = 0.04$) (Cohen's d = 0.6). Self-efficacy scores: improved immediately following the course in both groups; however 3-months post-course only the spaced group's scores remained significantly above baseline scores	Resuscitation training should be replaced or supplemented with frequent, spaced practice.
Sand et al.[50] (2021), Norwich	RCT, 119 nurses, hospital	Group 1 (SS): 2-min skills station (SS) with retest at 2 and 8 months; Group 2 (SS-R): 2-min skills station + retraining at 2 months and retest at 2 and 8 months; Group 3 (IT): 2 h instructor training with	CPR quality based on rate, depth, recoil, proportion of correct compression and ventilation	SS performed a higher proportion of correct ventilations compared to IT (71% and 54% respectively, N = 63, $p = 0.04$). The remaining CPR quality parameters were statistically similar between the two groups.	CPR skill station led to similar CPR skill performance at 2 and 8 months compared to instructor led training.

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Table 1 (continued)

Author(year), Country	*Study characteristics (design, population, sample setting)*	*Length and key points of retraining intervention*	*Outcome measures*	*Results*	*Conclusion*
		retest at 2 and 8 months		SS-R had deeper compressions at 8 months (3.4 mm (7.6%, p = 0.02) and 2.8 mm 6.3%, p = 0.02). No additional benefit of retraining at 2 months could be seen at the final test. Overall test pass was approximately 17% at final evaluation for both SS-R and SS groups as compared to 7% for the IL group at 8 months, although this was not statistically significant.	
Sutton et al.[28] (2011), USA	RCT, 89 paediatric in-hospital care providers with BLS training, hospital	(1) instructor-only training; (2) automated defibrillator feedback only; (3) instructor combined with automated feedback; (4) control (no structured training). Session: baseline evaluation (60 seconds), booster training (120 seconds), and a post-training evaluation (60 seconds). 20 min in total (5 min each session x4) Control was just baseline evaluation Time: 0, 1, 3, and 6 months after training	Retention based on depth, rate, leaning, pauses	Retention of CPR skills was 2.3 times (95% CI: 1.1–4.5; p = 0.02) more likely after 2 training and 2.9 times (95% CI: 1.4–6.2; p = 0.005) more likely after 3 training sessions. The automated defibrillator feedback only group had lower retention rates compared with the instructor-only training group (odds ratio: 0.41 [95% CI: 0.17–0.97]; p = 0.043).	Brief and frequent bedside booster CPR training improves CPR skill retention.
Tofil et al.[51] (2009), USA	Pre-post, 85 paediatric residents, hospital	20 codes over 1 year: 10–15 min scenario + 5–10 min debrief	Perception of skill; confidence	Perception skill and confidence indexes improved (p < 0.0001).	Paediatric mock codes can improve resident confidence and self-assessment of their resuscitation skills.

Notes. ** Use of distributed practice as part of learning strategy prior to retraining intervention; EM: emergency medical.

requested participants to return one hour after initial training.[38] Four studies brought their participants back one week after training[33,36,43,49] and three studies two weeks after training.[22,42,48] Most study designs had the first refresher intervention at one month after training;[34,37,39,45–46,51] one study after two months;[50] one study after three months[41] and two studies brought their participants back after four months.[44,47]

The number of refresher interventions throughout the study periods also varied considerably, with most studies doing monthly refresher sessions.[34–35,37,45–46,51] Five studies offered just one refresher session after initial training;[33,38,40,44,50] three studies had weekly re-exposure of pCPR skills[36,43,49] and further three studies fortnightly.[22,42,48] Two studies offered refresher sessions every-two or three months[28,41] and one study every-four months.[47] Interestingly, one study offered participants unlimited refresher opportunities, however, it resulted in no lasting improvement of the outcome measures.[39] Based on the number of refresher interventions throughout the study periods, it was noted that the outcome measures had similar positive results for most variables in each study included, apart from five of six studies that offered just one refresher intervention after training[38,40,44,50]

Length of intervention during retraining sessions

The length of intervention in each retraining session varied considerably, ranging from 2-minutes up to 3.5 hours. For easier identification and analysis, the studies were grouped as short duration (<1h)[22,28,34–37,36–40,44–48,50–51] and long duration (≥1h).[33,38,43,49] Four studies[34,41,44,47] did not specify the length of retraining intervention, however, the interventions consisted of mock codes with/without debrief[34,44,47] and self-directed short skill training[41] and for this reason, the studies were added into the "short duration" interventions.

Short duration (retraining interventions lasting < 1 h)

Studies investigating interventions using short durations per session were the majority (17 studies). The length of intervention ranged between two to 40 minutes and the outcome measures included patient outcome;[34] knowledge;[34–36,40,44,47–48,51] skills/retention;[28,34–37,40–42,44–48,50] confidence;[34–36,40,47–48,51] frequency of practice[39] and time to achieve good quality pCPR.[22]

Patient outcome was analysed in one study[34] and resulted in improved survival rate. Of the 14 studies analysing pCPR skill metrics, seven resulted in improvement of the skills after the retraining session.[35,37,41–42,45–46,50] Participants' knowledge was assessed in eight studies and improvement seen in seven of them.[34,35,40,44,47,48,51] Retention of pCPR skills was observed in four of the six articles.[28,40,42,46] Seven articles analysed rescuer's confidence with five of those resulting in improvement.[34,36,40,48,51] Lastly, just one study in this group did not find a significant difference in outcomes at follow up.[39] Results from interventions are described in Table 1.

Long duration (retraining interventions lasting ≥ 1 h)

Four studies used longer lengths of interventions when retraining participants, with two of them lasting 1 h,[33,38] one lasting 90 minutes[43] and one lasting 3.5 h.[49] The outcome measures included skills;[33,43,49] knowledge;[49] retention of skills;[38,49] and confidence.[49] Only one study[38] did not improve the outcome measure at follow up. Results from interventions are described in Table 1.

Discussion

This research has broadly and systematically identified and analysed studies relevant to retraining schedules of paediatric resuscitation skills for healthcare professionals. The International Liaison Committee on Resuscitation (ILCOR) has stated that regular pCPR skills updates are important however, the ideal retraining interval has yet to be established as evidence is limited in both quantity and quality.[19] This review aimed to contribute to current knowledge for a further understanding of the challenges of pCPR learning and retention, from which future research can be planned. Although the researchers believe that this review will be the first step to map the gaps in knowledge and the consensus around pCPR retraining intervals for a broad overview of evidence, future research should investigate existing knowledge gaps associated with paediatric CPR training and retraining. Cost effectiveness is an important aspect that requires further exploration, particularly when retraining or refresher is delivered during clinical practice. Little is known around the impact of training or retraining strategies on patient-level outcomes as previous studies investigating variables such as survival to hospital discharge or neurological outcome are limited in both quality and quantity.[19] Another aspect that warrants further research is whether the same retraining interval is applicable throughout the career, and whether this should vary according to the skills being trained (e.g. chest compressions, ventilation, intubation). Furthermore, assessment of the optimal strategies to team-based training, non-technical skills and leadership skills would be an important addition to the current evidence to paediatric CPR training and retraining.

In this review exploring retraining schedules of paediatric resuscitation skills for healthcare professionals, although the inclusion and exclusion criteria were well defined, the findings reveal complex data with studies that do not fit precisely into the categories. Despite internal quality assurance and transparency in reporting, identifying the time schedule and length of interventions was not simple, due to differing study methods and interventions. Additionally, the lack of clarity in some studies regarding the length of retraining interventions, made it more difficult to analyse the results.

The included studies demonstrated that the initial acquisition of pCPR skills is similar, irrespectively of the training model used. Different strategies were observed, including the traditional instructor-based training;[22,28,33,41,45,49] simulation-based mock code program;[34,47,51] simulation;[32,36,38,44,48] distributed practice;[45–46,48] and training with real-time feedback.[28,33,37,39–40,42–43,50] Although the learning outcomes were similar, in the sense that learners acquired the skills, a better understanding of the impact of instructional designs on learning outcomes would enable researchers to design training programmes that translate into effective performance during real resuscitation attempts.[20] This is supported by evidence from recent reviews exploring training strategies to improve CPR performance and patient outcomes.[52–53] Lauridsen and colleagues[52] explored in their scoping review, different types of CPR training for healthcare professionals. They included aspects such as training approaches (e-learning, instructor-based, virtual reality, simulation, gamified learning); training duration and intervals; equipment and feedback (manikins, feedback devices, debriefing). The authors concluded that there is growing evidence advocating online learning and low-dose, high frequency CPR training to acquire CPR knowledge; the use of feedback devices to improve the quality of CPR skills; and team-based simulation with debriefing to enhance team perfor-

mance manging a cardiac arrest. Additionally, Yeung et al.[53] conducted a systematic review comparing spaced learning with traditional massed learning to investigate whether spaced learning strategy improves educational and clinical outcomes. Although no conclusion can be made regarding patient outcomes, the results from their review suggested that spaced learning is more effective than massed learning for performance of CPR skill after training and at follow up. Our current scoping review adds to this body of evidence but provides additional contribution through the specific focus on paediatric CPR. Similar findings were determined suggesting brief and frequent practice enhances learning of paediatric CPR.

The best training and retraining designs should be tailored to specific learning objectives, learner type and needs, or context of learning. There are recommendations related to the use of deliberate practice, mastery learning, booster training, in situ education, real-time feedback and other strategies for training and retraining.[9,20] However, despite initial learning acquisition straight after training, CPR skills normally decay within weeks after initial training.[16,54] Although some providers retain CPR skills through recurring exposure to managing cardiac arrests as part of their clinical practice,[55] most paediatric providers go through long periods of clinical practice without performing pCPR due to the low incidence of cardiac arrest in this population.[18] Therefore, it becomes very important to establish retraining intervals to ensure that pCPR skills are maintained for longer.

In this review, all studies pointed to the importance of regular retraining sessions to the retention of pCPR skills. Although there is no consensus on the optimal interval, most of the studies opted for refresher sessions on a monthly basis[34–35,37,45–46] or more frequently (weekly, fortnightly).[22,36–37,39,42–43,48–49,51] Their results indicate that frequent sessions enhance simulated pCPR outcomes with significant improvement in the outcome measures (survival rate, skills, knowledge, retention, and/or rescuer's confidence). Conversely, the studies with less than monthly refresher sessions[28,33,38,40–41,44,47,50] suggest non-improvement, or improvement in one aspect but not others, or decline of skills at follow up, with one study suggesting that retention of skills was more likely with more refresher sessions.[28] The length of intervention in each retraining session varied considerably between the studies, ranging from two minutes up to 3.5 hours. Nevertheless, it was demonstrated that, with as little as two minutes of refresher session every month, there is the potential to increase pCPR performance and retain the skills for longer. However, this cannot be directly associated with patient-level outcomes.

Although regular updates are beneficial to retention of skills, frequent retraining sessions can be associated with high dropout rates.[16] This, aligned with significant increased costs of repeated retraining and backfilling of staff in clinical areas, may affect the viability of a high frequency training in practice. Therefore, an effective balance between retraining and sustainability has yet to be established. To reduce the burden and costs of moving practitioners away from clinical areas for lengthy pCPR retraining, short duration of intervention (as established by the current study) was adopted by most researchers included in this review.[22,28,34–37,39–42,44–48,50–51] This is in alignment with other research exploring the benefits of low-dose and high-frequency or distributed practice, suggesting that retention of CPR skills may be optimised and costs reduced, by training sessions with short interventions.[14,23,28,46] Lin and colleagues[56] investigated cost-effectiveness and outcomes of distributed paediatric CPR training using real-time feedback. Their results suggest that this strategy is associated with improved CPR quality and decreased training costs when compared with conventional annual mass CPR training. Despite this, further research is needed to investigate whether distributed practice affects the need for subsequent retraining intervals.

The use of feedback devices during retraining was observed in many studies.[28,37,39–43,46,49–50] Previous research has established the benefits of such devices during adult and paediatric CPR training.[57] This was also observed in this review, with the majority achieving an improvement in outcome measures. Nevertheless, although the use of real-time feedback devices has been associated with enhanced performance during CPR training, there are conflicting interpretations regarding its efficacy during real-life resuscitation attempts.[58] Therefore, whilst it may be intuitive to presume that real-time feedback devices can improve patient outcome, this is yet to be established.

This review has demonstrated that brief and frequent pCPR retraining using simulation and additional tools such as real-time feedback devices can potentially develop skills, knowledge and confidence in pCPR performance. It is also noted that increasing the frequency of retraining sessions may result in a more successful skill retention and consequent higher-quality performance. Despite this, there is no strong evidence regarding the ideal retraining schedule. It is suggested that a more nuanced approach to pCPR retraining, based on specific learning objectives, context and learners' needs and/or performance is recommended in an attempt to maximise skill retention and improve pCPR performance.

Limitations

This study has some limitations. First, potential biases were not systematically addressed like in a systematic review. Second, the heterogeneity among study design, retraining strategies, outcome measures and length of intervention, may impact the interpretation and synthesis of the results. Third, most studies were performed in a simulated, controlled environment, making it difficult to extrapolate the results to real-life CPR performance. Fourth, despite improvement in pCPR quality and retention of the skills, the results cannot be directly associated with patient-level outcomes. Fifth, this review only includes studies after 2005, therefore, it is not known if other important evidence exists prior to 2005. Finally, despite exhaustive attempts to locate every relevant resource, one study was identified but could not be retrieved.

Conclusion

Brief and frequent pCPR retraining may result in a more appropriate skill retention and consequent high-quality performance. There is no strong evidence regarding the ideal retraining schedule however, it was demonstrated that, with as little as two minutes of refresher training every month, there is the potential to increase pCPR performance and retain the skills for longer.

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Conflict of Interests

The authors declare that there are no conflicts of interest.

Appendix 1. Search terms

The search terms were drafted by the research team and revised by an experienced librarian.

TI (train* OR retrain* OR refresh* OR teach* OR educat* OR course* OR simulation OR update OR program*) OR AB (train* OR retrain* OR refresh* OR teach* OR educat* OR course* OR simulation OR update OR program*) AND

TI ("health*care professional*" OR "health*care worker*" OR physician* OR nurse* OR doctor*) OR AB ("health*care professional*" OR "health*care worker*" OR physician* OR nurse* OR doctor*)

TI (p*ediatric OR child* OR bab* OR infant) OR AB (p*ediatric OR child* OR bab* OR infant) AND

TI (resus* OR CPR OR "cardio*pulmonary resus*" OR "life support" OR BLS OR ALS OR PALS OR EPALS OR APLS OR PILS OR PHPLS OR ATLS OR "first aid" OR "chest compress*") OR AB (resus* OR CPR OR "cardio*pulmonary resus*" OR "life support" OR BLS OR ALS OR PALS OR EPALS OR APLS OR PILS OR PHPLS OR ATLS OR "first aid" OR "chest compress*") AND

TI (retention OR retain* N3 skill OR recall OR decay OR knowledge OR confidence) OR AB (retention OR retain* N3 skill OR recall OR decay OR knowledge OR confidence).

Author details

[a]Faculty of Health and Social Sciences, Bournemouth University, Bournemouth Gateway Building, St. Pauls Lane, Bournemouth BH8 8GP, England [b]Centro Universitário São Camilo, Rua Raul Pompeia, 144, São Paulo, Brazil [c]Paediatric Emergency Medicine, St Mary's Hospital, Imperial College NHS Healthcare Trust, London, UK [d]Instituto do Coração do Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, Av. Dr. Enéas de Carvalho Aguiar, 44, São Paulo, Brazil [e]Federal University of São João del Rei, Nursing Course - Child and Adolescent Health, Divinópolis, Minas Gerais, Brazil

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5.7 Limitations

As described in the manuscript, this scoping review has some limitations that need consideration. The first limitation is related to the fact that potential biases were not systematically identified and discussed like in a systematic review. The risk of bias of a study can be defined as the "likelihood of inaccuracy in the estimate of causal effect in that study" (Viswanathan *et al.* 2017). Risk of bias assessment is intended to support the interpretation of results, categorise the strength of evidence and explain heterogeneity. However, because scoping reviews aim to provide an overview of evidence rather than critically appraise and answer a particular/precise question, risk of bias assessment is normally not performed (Peters *et al.* 2015, Sargeant and Connor 2020).

The second limitation was the challenge of interpreting the results due to the heterogeneity amid study designs, retraining approaches, outcome measures and length of intervention. However, as normally observed in this type of review, data from included studies were not directly compared based on methodological designs, outcome measures, or congregated findings. They were presented as a narrative

construct to provide a current summary of evidence in the field, and to inform the design of the next study to be conducted as part of this thesis.

The third limitation, which is commonly observed in the resuscitation field, is that most studies included in the scoping review were performed in a simulated, controlled environment, which makes it challenging to infer the conclusions to real-life CPR performance and patient outcomes. Simulation-based training has been an important educational tool and research strategy in different areas including cardiopulmonary resuscitation (Kunkler 2006). Although it allows the learner to practice and demonstrate the skills in a controlled and safe environment, the participants are not exposed to relevant features encountered in real resuscitation attempts including background noise, other bystanders, disruptions, interruptions or the pressure, difficulties and complications that normally happen during a real cardiac arrest (Perkins *et al.* 2008). Consequently, while it was demonstrated that frequent refresher sessions have the potential to enhance pCPR performance and maximise the retention of the skills for longer, this may not be directly associated with real-life pCPR skills and/or patient outcomes after a cardiac arrest.

Another limitation, which relates to the above point, is that most of the outcome measures selected in the scoping review protocol cannot be directly associated with patient-level outcomes. The outcome measures were: patient outcome; ability to deliver effective pCPR; improvement of knowledge and skills; retention of skills; and confidence. Just one study investigated patient outcome (Andreatta *et al.* 2011) thus, despite enhancing pCPR quality, retention of the skills, and improved confidence with

more frequent pCPR retraining, the results cannot be directly associated with patient-level outcomes.

5.8 Chapter Summary and Next Steps

This Chapter explores the scoping review of literature undertaken to explore the intervals and methods of paediatric CPR retraining provided to healthcare professionals. It describes the methodological approach and the evidence collected about paediatric CPR retraining and the associated outcomes including patient outcomes, quality of performance, retention of knowledge and skills, and rescuer's confidence. The author justifies the reasons why the framework was selected, explaining the relevant characteristics of a scoping review compared to systematic review.

The literature review of this research (Chapter 2) identified that CPR skills decay within weeks to months after training, making the annual retraining schedule recommended by resuscitation guidelines not effective. It was also observed that retraining timeframes advocated by previous research vary considerably, with some studies suggesting monthly re-exposure and others recommending six or 12-month intervals. Therefore, the author concluded that conducting a scoping review of the literature to identify what has been previously investigated regarding paediatric CPR retraining strategies and intervals, was an essential step to inform the design of the competence-based iCPR retraining study (Chapter 6).

Data extracted from the 21 included studies revealed a disparity in the methods used (e.g. pre/post-test, mixed-methods, interventional studies, RCT, observational studies); dissimilar retraining schedules and interventions (e.g. traditional instructor-

based training, simulation-based, distributed practice; high-fidelity manikin, real-time feedback); and a varied range of outcome measures (e.g. skill metrics - depth, rate, recoil, chest compression fraction, pauses; rescuer's confidence; knowledge; patient outcomes; retention of pCPR skills; behavioural performance; and time to achieve good quality pCPR).

In consequence, the summary of data presented some challenges with studies that did not fit precisely into the categories. Therefore, identifying the timeframes and length of interventions during retraining was challenging, due to the heterogeneity of the studies designs.

From the 21 studies included, the majority (12) opted for monthly or more frequent retraining sessions. The length of intervention in each retraining session ranged from 2-minutes up to 3.5 hours, with most studies (17) selecting shorter durations (<1h). Of this group, just one study did not find a significant improvement in the outcome measure(s) at follow-up. All 21 studies suggested that regular retraining sessions are important for acquisition and retention of pCPR skills.

According to the conclusions of this scoping review, there is no robust evidence concerning the ideal retraining schedule for pCPR. However, there is conclusive evidence that brief and frequent pCPR retraining added to simulation and relevant tools such as RTF devices may result in significant improvement in outcome measures such as quality of paediatric CPR performance, retention of knowledge and skills and rescuer's confidence in the delivery of CPR. It was observed that with as little as two minutes of retraining or re-exposure to skills every month, there is a high likelihood to enhance pCPR performance and maximise retention of the skills for longer.

Next steps

With new knowledge about consistency of iCPR performance generated by the reliability experiment (Chapter 3), a better understanding about hand dominance and fatigue during iCPR (Chapter 4), and the recent findings about retraining schedules for paediatric resuscitation skills demonstrated in this Chapter, the next step for the thesis was to investigate whether a tailored, competence-based strategy to iCPR skills retraining could result in better skill retention. This is explored in Chapter 6, and it will generate a key piece of information for the development of a new model of iCPR retraining schedule, which is the ultimate aim of this thesis.

Chapter 6 Justification of the Methods and Study Design: "Retraining Study"

6.1 Chapter Overview

This Chapter is divided into two sections: the first part details the methodological justification for STUDY 4 – "A novel infant CPR retraining strategy results in high skill retention for longer". This longitudinal, prospective, experimental study aimed at exploring the quality, retention, and decay of simulated iCPR skills delivered by healthcare students. It discusses the research approach and how the aims, objectives and outcomes of the study are addressed. It indicates the ethical considerations and participant recruitment, outlines the research methods for collecting demographic and performance data, and justifies the statistical approaches taken to analyse the results. The second section contains the published manuscript (Gugelmin-Almeida *et al.* 2022b) developed from the experimental study, as part of the integrated thesis format submission.

Since some features of this study are identical to the previous experiments of this thesis (e.g. data management, anonymity & confidentiality, and instrumented tool), a brief explanation of those topics with signposting will be provided to avoid duplication of information.

An evaluation of the limitations of the study is presented at the end of the Chapter to contextualise the results and recommend future research.

Section 1

6.2 Aims and Objectives

It has been previously discussed in the literature review of this thesis (Chapter 2) that the quality of chest compressions during iCPR delivered by lay person, BLS and highly-trained-rescuers in both simulated and real paediatric cardiac arrest events is often performed inadequately and is therefore, of suboptimal quality (Martin *et al.* 2013a, Manrique *et al.* 2020). This poor quality reduces the chances of survival to hospital discharge and/or positive neurological outcomes. Whilst the reasons for this inadequacy are multifactorial, key elements include subsequent retention and decay of skills after initial skill learning (Kleinman *et al.* 2018, Saad *et al.* 2019, Lockey *et al.* 2021). The literature review revealed that previous research has tried to identify the frequency of CPR updates in both paediatric and adult populations, in order to potentially maintain adequate and effective skills (Yang *et al.* 2012, Gugelmin-Almeida 2022b). The scoping review (Chapter 5) presented previous and current knowledge regarding retraining schedules for paediatric CPR. Nevertheless, to date, there is insufficient evidence to enable resuscitation guidelines to recommend an optimal timeframe for re-exposure of skills and this could impact iCPR skill retention. Additionally, no study has examined how a tailored strategy to iCPR retraining could improve skill retention and reduce retraining needs, and this study expected to address this knowledge gap. The aim of this study was therefore, to investigate whether an individualised, competence-based strategy to simulated iCPR retraining could result in high skill retention at follow-up. To achieve this aim, the objectives (further explained below) were to determine the amount of re-exposure

of skills needed to achieve iCPR competence, and to establish if the acquired competence is retained over time.

The elements of variability in human performance (Chapter 3) and perception of fatigue (Chapter 4) were taken into consideration so that, interpretation of changes during the 12-month period of this study could be analysed without the potential confounding factors of those elements. Moreover, the results from the scoping review of the literature (Chapter 5) provided critical insight into the development and design of this study.

To achieve the above aims, the following objectives were selected to inform the research design and processes:

- To measure simulated iCPR performance delivered by healthcare students based on the following metrics: (i) CCR, (ii) CCD, (iii) RL, and (iv) DC, to establish quality of chest compressions.
- To apply a tailored strategy of monthly retest and reinforcement of iCPR skills.
- To determine the amount of monthly retest and reinforcement of iCPR skills needed to achieve iCPR competence.
- To establish if the acquired iCPR competency is retained at follow-up.

The justification as to why these objectives were selected will be further explored in this Chapter.

6.3 Study Design

This study adopted an observational, longitudinal, prospective design and was conducted in a simulated environment within a university setting involving healthcare students. The author and the research team discussed different designs to best achieve the aims and objectives of the study. It is well established that research designs vary in their ability to investigate and test the effectiveness of interventions or treatments, with some being more appropriate than others (Evans 2003). Randomised controlled trials (RCTs) are considered high on the hierarchy of evidence due to the processes used to minimise the risk of confounding factors influencing the results (McGovern 2001). Many RCTs have been successfully applied in the field of CPR skill retention (Anderson *et al.* 2018, Sand *et al.* 2021, Oermann *et al.* 2022). However, the current study would not benefit from an RCT. RCTs by design are rigid, with individuals randomly assigned to groups. It was felt that learning/retaining CPR skill is likely to be more individual, requiring a more dynamic and nuanced approach. Each learner is not 'identical' at baseline, therefore blinded randomisation would be inappropriate. An RCT exploring different retraining schedules at pre-set intervals, as seen in previous studies with distributed practice (Lin *et al.* 2018, Oermann *et al.* 2022), would fail to take into consideration the degree of learning already achieved, and the needs of the individual.

According to Evans (2003), all established research methods and/or designs are valid and effective according to what it aims to answer under the right conditions. Therefore, the present study adopted an atypical design with a competence-based strategy to iCPR retraining, rather than pre-established intervals. The retraining

model is based on the 'mastery learning theory', where learners have the opportunity to practice key skills, receive feedback and improve performance until mastery is achieved (Cheng *et al.* 2018). Retraining is thus individualized, and is based on the quality of individual performance in achieving a predefined level of competence. It is suggested that using mastery learning to achieve a competence-based strategy to iCPR may lead to long term retention of skills, delivery of timely high-quality iCPR and subsequent cost savings due to reduced retraining. Section 6.10 explores how competence was defined for this study.

6.4 Ethics Protocol, Approval Process and Considerations

The research protocol and ethics application (Reference ID: 27402) were submitted on 8th July 2019 to BU Research Ethics Committee (UREC), which is, as explained in Chapter 3, Section 3.4, responsible for promoting best ethical practices in relation to research and research-related activities. The protocol was formulated respecting the University's research ethics code of practice (Bournemouth University 2021) and included Participant Information Sheet, Participant Consent Form, Recruitment Poster, Participant Questionnaire and Risk Assessment (Appendices 12-16).

The protocol was reviewed by the ethics panel and some points were raised that needed addressing. The ethical reviewer's comments with answers/amendments, and subsequent ethical approval (granted on 8th August 2019) are presented in appendix 17.

6.5 Risk Assessment

The understanding of the importance of risk assessment during a research project has been previously addressed in this thesis (Chapter 3, Section 3.6). Most types of

research have some associated risks and appropriate arrangements must be in place to protect participants and researchers should something go wrong during a study (Shaw and Barrett 2006). Because this experimental study had some associated risks, appropriate arrangements had to be put in place to protect participants and researchers should something go wrong during the study. A full risk assessment was undertaken (Appendix 16), and the protocol was approved on 18th September 2019.

6.6 Participant Recruitment

The participant sample selected for this study was healthcare students from BU currently enrolled in the first or second year of the following healthcare programmes: Operating Department Practice (ODP), Physiotherapy, Nursing, Paramedic Science, Occupational Therapy, Social Sciences and Midwifery. It can be suggested that they are the healthcare practitioners of the future, therefore their participation would increase the generalisability of the results. Additionally, their participation in this research could be considered as a valuable educational experience (Jager *et al.* 2017). CPR training is mandatory to healthcare students and developing this skill could enhance their future practice. Like the reliability study (described in Chapter 3), the population was intentionally constrained to one demographic aspect (healthcare students) to reflect the target population (healthcare professionals). This was intentionally performed in an attempt to reduce the chance of bias in our participant sample, following the strategy of homogeneous convenience sample for clearer generalisability (Jager *et al.* 2017). The added advantage of this method was that, if it was rolled out into practice, the newly qualified practitioners would have been

exposed to the training strategy and benefitted from the outcomes (e.g. skill retention).

A sample size of 72 was initially calculated based on Anderson *et al.* (2019) at 12-month completion, as explained in the published manuscript (Section 2 of this Chapter). However, due to an anticipated high dropout rate based on previous studies (Oermann *et al.* 2011, Anderson *et al.* 2019), a convenience sample of 118 university students was recruited.

The author has explored in this thesis (Chapter 3, Section 3.3) the concerns and potential ethical barriers arising from when students are participants in research. This includes the pressure felt by the students to participate in the research, particularly when it is led by their Faculty. Additionally, the risk associated with participation in research, which are not obvious when the students grant consent, were also previously explored. Examples are distractions and time away from their studies, due to the tasks associated with the research (Shannon 1979, Henry and Wright 2001).

In recognition to the possible risk of students feeling coerced into taking part in this iCPR retraining study, the principal investigator clarified the voluntariness and option to withdraw at any point without the need to explain. This was also clearly written in the Participant Information Sheet (Appendix 12) and Participant Consent Form (Appendix 13). Additionally, a gatekeeper was used as first point of contact for the ODP students, as the principal investigator is a lecturer for this programme (as explained in Chapter 3, Section 3.5).

To minimise the unforeseeable risk of the demands of research impacting the participants' time for their studies, they were informed about the option to withdraw without prejudice during recruitment, consent stage, prior to commencement of the study and during follow-up. This was also clearly written in the Participant Information Sheet and Participant Consent Form (Appendices 12 and 13).

Participants were recruited between September 2019 and November 2019 from BU healthcare student population via a Recruitment Poster (Appendix 14) displayed around the University (primary recruitment tool), on Brightspace (Virtual Learning Environment), word of mouth, and social media. The researcher's contact details were provided on each platform and on the posters for interested students to get in touch for more information and subsequent enrolment. In addition, the gatekeeper's contact details were also provided, due to potential recruitment of ODP students, as explained above. Multiple tools to recruit participants were selected in an attempt to reach a larger number of students and potentially reduce recruitment time. Lengthy recruitment periods or insufficient participants bring potential adverse scientific, economic, and ethical consequences, such as increased costs, cancelation or postponement of the research, and reduced statistical power with reduced sample (Kaur *et al.* 2012).

A total of 129 students contacted either the principal investigator or the gatekeeper via email, messages on social media and telephone. After the initial introduction and brief explanation of the study, potential participants were provided with an online copy of the Participant Information Sheet (Appendix 12) with full details of the research project. On the 4th of November, a sample of 122 participants was enrolled

from different healthcare programmes and a total of four participants did not turn up for the initial training session, making the final number of participants included in the study 118.

6.7 Informed Consent

As previously mentioned in Chapter 3, Section 3.8, informed consent is an important principle when humans participate in research as it enables the understanding of what taking part in the study entails and confirms their agreement to participate (Manti and Licari 2018).

On the day of initial iCPR training, prior to the commencement of the study, the principal investigator encouraged the participants to ask questions so that they could make an informed decision to take part or not in the study. Once more, the voluntary nature of the participation was emphasised. Those two aspects play a crucial role in the recruitment of participants in research. Informed consent is necessary to protect individuals from harm, safeguard their well-being and protect the basis of autonomy (Ursin 2009).

After all questions were answered, every participant was provided with a consent form to sign and date (Appendix 13) which was written in language easy to understand and minimised the possibility of coercion, helping to clarify the participant's right to voluntarily take part in the research, or refuse it without any disadvantage or consequence.

6.8 Anonymity and Confidentiality

This was a longitudinal study that involved data collection at multiple time points to measure iCPR performance over time. For this reason, correct identification of the same participants at each time point was essential so that data could be matched for comparison over time, reducing the risk of low statistical power and high type-2 error rates (Heiman 2000, Bedeian and Feild, 2002). Additionally, with the potential of losing participants across time, the principal investigator kept thorough and accurate records, which can be a challenge when data is collected anonymously (Audette *et al.* 2020).

To maintain correct records and anonymise participants' personal information, data included in the Participant Consent Form (name and surname) was collected non-anonymously and de-identified by the principal investigator prior the commencement of the study. An identification code was generated for each participant to assure anonymisation and confidentiality. This code was included in the Participant Consent Form and in each other document or data collected for the study (i.e. questionnaire, tracking spreadsheet), with the purpose of providing a de-identified data set to the research team for data analysis. The consent form was the only document containing the identification code together with participants' identification details and the principal investigator was the only person with access to the consent forms.

6.9 Data Collection Process

Due to the large number of individuals to undertake the initial iCPR training, the 118 participants were divided into nine groups of 13 or 14 people to follow the

recommendation from RCUK regarding instructor:trainee ratio (Bullock 2015) and trainee:manikin ratio (RCUK 2021d). It is recommended that ideally, each trainee has a manikin to practice and that there is adequate time to practise the skills in a simulated environment. In this study, we had 15 manikins available, thus each participant had one manikin with which to practice. The nine training sessions and the first data collection for each group occurred within one week, so that the follow-up sessions would fall within the same week, facilitating logistics for data collection and potentially reducing costs.

After signing the consent form, data relating to age, height, weight, and self-declared physical issues that could compromise performance were gathered via a questionnaire (Appendix 15) in order to create a demographic profile of the sample. This information enables the determination of whether the participants are a representative sample of the target population for generalisation purposes. It can serve as independent variables in the research design and can also be explored for their moderating effect on dependent variables (Connelly 2013). Only the demographic information that is necessary for the specific purposes of the research should be collected. There is evidence that age, height, weight and physical issues affect CPR performance (Ebbeling *et al.* 2010, Papalexopoulou *et al.* 2014, Hasegawa *et al.* 2014, Jaafar *et al.* 2015), therefore the above demographic metrics were selected for this study.

On completion of the questionnaires, participants undertook the four-stage approach 'Paediatric BLS' education package, which was provided by an RCUK qualified instructor. Although there are different methods and strategies for

paediatric CPR training, as explored in Chapter 2 (Section 2.4.1), RCUK recommends accredited life support courses for the delivery of CPR training (Lockey *et al.* 2021). Instructor-led, classroom-based has traditionally been the most common method of CPR training (Einspruch *et al.* 2007). This model offers good learning acquisition by substantially improving CPR metrics when compared to pre-training (Lynch *et al.* 2008, Hirose *et al.* 2014, Brown *et al.* 2016). For these reasons, this model was selected for the initial paediatric CPR training delivery for this study as the focus was not to explore the quality of training, but acquisition and retention of skills.

After the two-hour training, participants individually practiced the two-finger technique for the recommended 30 minutes (Bullock 2015) on an infant manikin (Laerdal® ALS Baby, Laerdal Medical, Stavanger, Norway) using compression:ventilation ratio of 30:2. This ratio was selected as per resuscitation guidelines for BLS rescuers with no duty to respond to a paediatric cardiac arrest (Van de Voorde *et al.* 2021). The instructor provided individual feedback based on visual assessment of performance.

Participants were then individually invited to a separate room for data collection where the instrumented manikin was set up (described in Section 6.11 of this Chapter). The researcher provided brief instructions on when to start and stop iCPR and was responsible to initiate and pause the software. Participants were asked to carry out simulated iCPR on the instrumented manikin for two minutes where performance data pertaining to iCPR were captured (this was called assessment). The choice of two-minute iCPR assessment was based on evidence from previous studies. Kim *et al.* 2015, Lee *et al.* 2018 and Cobo-Vázquez *et al.* 2018 demonstrated

that CPR quality is decreased after two minutes. Also, according to UK resuscitation guidelines (Greif *et al.* 2021, Lockey *et al.* 2021), chest compression is tiring and to prevent fatigue, change of providers should happen every two minutes. Additionally, the cycle of CPR when using a defibrillator/AED is two minutes. Therefore, based on clinical evidence and best practice, the researcher selected the two-minute timeframe for the study.

No feedback on performance was provided during assessment. The reason for not providing feedback is that rescuers can make real time adjustments to their CPR attempt (Kornegay *et al.* 2018), which could impact their performance. Previous studies (Martin *et al.* 2013b, Buléon *et al.* 2016, Lin *et al.* 2018, Kandasami *et al.* 2019), suggest that metrics such as CCR, CCD, RL, handoff time, fatigue, and general quality of CPR, significantly improve as a result of the use of real-time feedback during training, which could impact the results of the current study.

After the two-minute assessment was finished, the MatLab software provided a qualitative result ('PASS' or 'FAIL') based on quantitative analysis of iCPR performance. A 'PASS' was established if the participant achieved an average of compressions within the target ranges (as seen in Table 4-1, Chapter 4, Section 4.8) for CCR, CCD, RL, and DC simultaneously. These metrics have been selected because current resuscitation research and guidelines have identified them as components of chest compression that are closely related to high-quality CPR performance and because of their influence in blood flow during a cardiac arrest and patient outcome. (Maconochie *et al.* 2015, Topjian *et al.* 2020, Considine *et al.* 2020, Skellett *et al.*

2021). These metrics have been demonstrated to provide high repeated measures' reliability (Almeida *et al.* 2020).

If the average of any of the metrics remained outside its respective range, the result was considered a 'FAIL'. When a participant 'FAILED' the assessment, iCPR practice using real-time feedback was performed for one minute before an evaluation of performance was completed for two minutes. Many research methods and CPR education have implemented the use of real-time feedback devices in addition to potentialize the benefits of instructor-lead and/or simulation-based training (Perkins 2007, Lateef 2010, Pozner *et al.* 2011, Wang *et al.* 2020). As further explained in Chapter 3, Section 3.11, these devices allow for the measurement of performance by quantifying quality measures such as CCR, CCD, RL, and DC. The technology provides visual and/or audio information on CPR quality to enhance performance according to resuscitation guidelines (Gruber *et al.* 2012). Its use has been profusely investigated in resuscitation research and it has been demonstrated that the devices enhance CPR skill acquisition and performance during training and retraining for both adult and paediatric CPR (Gugelmin-Almeida *et al.* 2021a).

For any 'FAIL' in any of the assessments, even after previous 'PASSES', the participant would come back monthly for a two-minute assessment until two consecutive monthly first-time 'PASSES' were achieved. At this point, the participant was considered iCPR competent, and would return for assessment just at follow-up.

The choice of two consecutive monthly 'PASSES' was based on previous studies. Sutton and colleagues (2011) investigated if a low-dose, high-frequency, booster training programme would improve paediatric CPR retention and concluded that CPR

skills were 2.3 times more likely to be retained with two consecutive short practice sessions. Although the authors suggest that the skills were 2.9 times more likely to be retained after three sessions, this was based on a six-month period and was not investigated as consecutive sessions, as in our study. Also, by adding an extra practice session, the likelihood of participants dropping out of the study was higher, which could compromise the power of the study. Therefore, two consecutive sessions (or monthly 'PASSES') were selected. Another study examining the effects of brief monthly practice on retention of CPR skills concluded that when skills are practiced every month for short periods of time, they remain effective for 12 months, but the authors suggested that practice for two months may be sufficient. This could reduce the drop-out rates which, in their study, was up to 50% (Oermann *et al.* 2011), and reduce costs of repeated training.

In relation to the follow-up timescale to which participants returned to be reassessed, this varied between six to 10 months. Previous research and current guidelines have demonstrated that CPR skills can be maintained with monthly re-exposure of skills (Oermann *et al.* 2011, Anderson *et al.* 2019, Lin *et al.* 2018); or with re-exposure every three-months (Cheng *et al.* 2018, Panchal *et al.* 2020); or even with re-exposure of up to 6-months (Berden *et al.* 1993). Based on this evidence, aligned with the hypothesis that after achieving competence (as defined in our study), rescuers maintain iCPR skills for longer, the author selected the minimal break of six months before allowing the participants to come back for a follow-up assessment. The maximum time for follow-up was defined as 10 months as this would conclude the 12-month long study from initial training to the last follow-up assessment. The timescale of follow-up assessment was therefore between six to 10

months and was based on the staggered nature of when the participants achieved iCPR competence.

The author believed that this tailored performance approach, where reassessment and reinforcement of skills were based on participants' performance rather than a pre-determined schedule, would facilitate the understanding of the rates of learning and retention of iCPR skills. This concept would allow for sufficient flexibility to address the different learning needs of individuals.

6.10 Instrumented Tool

The equipment used to quantify iCPR performance and analyse the objectives of this study has been previously described in Chapter 3 (Section 3.11). However, because some modifications to the MatLab algorithm were subsequently performed (as explained in Chapter 4, Section 4.8), a brief summary of the instrumented tool used in this present study will be provided. The author believes that the overlapping information will facilitate the reader's understanding of the equipment used to quantify performance and provide real-time feedback to the participants when needed. For a full description of the tool and justifications please check Chapters 3 and 4 (Section 3.11 and 4.8 respectively).

In recognition of the evidence on the effectiveness of automated devices in quantifying and improving quality of CPR performance, resuscitation guidelines recommend the use of such devices during training of adult CPR skills (AHA 2017, Greif *et al.* 2021). There are several types of automated feedback devices available to correct performance during adult CPR training as seen in Chapter 2, Section 2 (Gugelmin-Almeida *et al.* 2021a). However, not all these devices provide

quantification of performance, and this characteristic was essential for the success of this current study. Automated feedback devices in the market range from metronomes providing regular frequency beats, to audio-visual feedback providing visual information or voice tones to assist the rescuer to adjust their technique according to guidelines (Bobrow *et al.* 2013, Botelho *et al.* 2016, Cortegiani *et al.* 2017, Hirakawa *et al.* 2018). For paediatric CPR, there is a limited range of automated feedback devices. AHA (2017) recognises this gap in the market and recommended that "in the future, as more devices become available for child and infant CPR, the AHA will also require the use of feedback devices in courses that teach the skills of child and infant CPR" (AHA 2017, p.1).

Previous studies investigating the quality of iCPR performance have done so by utilising a commercial infant manikin adapted or created by the researchers (Dellimore *et al.* 2013, Martin 2013, Kandasami *et al.* 2019, Alkhafaji *et al.* 2021). These devices vary in their ability to analyse and provide effective guidance on the metrics associated with high-quality iCPR (CCR, CCD, RL, and DC). The great majority provide feedback on CCR, CCD and RL without considering DC, as seen in Gugelmin-Almeida *et al.* (2021a). However, it has been explored in this thesis (Chapter 2, Section 2.3.6.4) that high-quality iCPR is dependent on effective DC to optimise venous return to the heart, myocardial perfusion, cardiac output, and cerebral blood flow (Fitzgerald *et al.* 1981, Dean *et al.* 1991, Sunde *et al.* 1998a, Babs 2006, Kim *et al.* 2020). For this reason, an automated instrumented tool developed and validated for a previous study (Martin 2013), which quantifies performance, assesses quality of iCPR, and provides guidance on all four iCPR metrics (CCR, CCD, RL, and DC) was selected for the experimental studies in this thesis (Chapters 3, 4 and 6). Additionally,

this project required the specific ability to manipulate values for the metrics related to iCPR performance, therefore having a set up where the algorithm (as explained in Section “d” below) could be manipulated, was necessary to analyse participants’ data and convert into metrics of interest.

The above-mentioned instrumented tool used to quantify iCPR performance and provide real-time feedback comprised of:

(a) Laerdal® ALS CPR infant manikin representing a three-month-old, 5kg infant, which was modified during a previous study to allow a maximum chest compression depth of 56mm (Martin 2013). The manikin was permanently attached to a wood board and placed on the floor, to mimic the conditions of out-of-hospital iCPR;

(b) two accelerometers, which are electromechanical devices that measure acceleration of a moving object, were used to measure chest displacement. The accelerometers were covered by rubber sheets to protect the device and to provide a better grip to the rescuer. One accelerometer was fixed on the manikin’s chest, on the lower third of the sternum just below the nipple line, avoiding the xiphoid process (according to a mark showing the attachment point). The other accelerometer was fixed on the board and used to act as a differential for the surface on which the iCPR was conducted. But because iCPR was performed on a hard surface (the floor), data related to accelerometer two have not influenced the results of the study as there was no surface deflection;

(c) data acquisition unit (National Instruments DAQ, Model no. NI USB 6008) to acquire the analog signal provided by the accelerometers, convert them into digital values so that they can be processed by the computer;

(d) personal computer with LabView software and MatLab. Data acquisition applications are usually controlled by a programmable software and in this study, LabVIEW (National Instruments, TX, USA) was used to write the program that converted the acceleration output into displacement. Validity of this displacement data has previously been established by Kandasamy (2017). LabVIEW is designed to operate with Matlab software (The Math Works, US), which received the displacement data and, with a modified bespoke algorithm, analysed participants' data and converted it into four metrics: average CCD, average CCR, average RL, and average DC. After converting the data into the metrics of interest, the software provided a qualitative result ('PASS' or 'FAIL') based on quantitative analysis of iCPR performance. As previously explained, a 'PASS' was reached by the achievement of an average of compressions within the target ranges for CCR, CCD, RL, and DC simultaneously. The target ranges for each metric are shown in Table 4-1 (Chapter 4, Section 4.8). If any of the metrics remained outside its respective range, the result was considered as a 'FAIL';

(e) flow sensor was part of the instrumented kit, but the data generated by it were not used in this study, as the focus was on chest compressions. The flow sensor was fixed on the wood board, with its wires placed towards the manikin's feet to avoid tripping hazard;

(f) power supply for the computer and data acquisition unit.

This instrumented tool was able to quantify participants' performance based on all four iCPR metrics (CCR, CCD, RL, and DC) and assess the quality of iCPR, establishing if a 'PASS' was achieved or not. Additionally, it provided real-time guidance for the

improvement of performance when participants did not achieve the pre-defined level of high-quality iCPR during assessment.

6.11 Outcome Measures

The four variables selected for this study (CCR, CCD, RL, and DC) are the same metrics analysed previously (Chapter 3 and Chapter 4). These metrics were identified as components of chest compression that are closely related to high-quality iCPR performance and were based on current resuscitation guidelines (Skellett *et al.* 2021) and on guidance for the uniform reporting of the measured quality of CPR (Kramer-Johansen *et al.* 2007). Each variable was individually measured during each chest compression cycle (i.e., 30 compressions) and their correspondent averages over two minutes, calculated using a bespoke algorithm in MatLab.

The primary outcome of the study was retention of iCPR competence, defined as achieving a first-time "PASS" during iCPR assessment at follow-up. This outcome would demonstrate if the proposed model of retraining based on individual competence, was an effective way to retain iCPR skills, up to the pre-defined follow-up period (six to 10 months). The secondary outcome was the length of time taken for iCPR competence to be achieved. Competence was determined by passing iCPR assessments first-time in two consecutive months, as explaining in Section 6.10 of this Chapter.

6.12 Statistical Analysis

Descriptive statistics were used to analyse and summarise characteristics of demographic data. Mean and standard deviation (SD) were applied to report data with normal distribution via the Skewness, Kurtosis and Shapiro-Wilk test. Median

with interquartile ranges [IQR], were used when assumption of normality was not met.

The baseline characteristics of those who dropped out were compared to the baseline of those remaining in the study, using an independent T-test or Mann Whitney U test, depending on the distribution of the variable. This was conducted to determine the possibility of attrition bias, which is a systematic error caused by unequal loss of participants (Bell *et al.* 2013). Participant dropouts in a study can impact the balance of confounders between those who left and those who remained in the study. Confounders are peripheral variables that are not being analysed, but may affect the variables being studied, interfering with the results (e.g. sex, fitness level). Therefore, disproportionate loss of different types of participants or with dissimilar performance at baseline, can introduce bias into the results, threatening the validity of the study (Pourhoseingholi *et al.* 2012).

The differences between groups retaining competence at follow-up were determined using the Fisher exact test, given the two nominal variables ("PASS" and "FAIL"). The groups were established according to when the participants achieved iCPR competence: group 1 achieving iCPR competence one month after training; group 2 achieving iCPR competence two months after training; group 3 achieving iCPR competence three months after training; and group 4 achieving iCPR competence four months after training. The Fisher exact test determined if there are non-random associations between variables. The results can be interpreted as the probability of having a particular outcome ("PASS" or "FAIL") based on or being influenced by the study groups (Freeman and Julious 2007).

6.13 Data Management

The strategy for data management of this thesis has been previously explained in Chapter 3, Section 3.14.

Section 2

This section presents the manuscript published in *European Journal of Pediatrics* as part of the integrated thesis format submission.

See: Gugelmin-Almeida, D., Jones, M., Clark, C., Rolfe, U., and Williams, J., 2022. A novel retraining strategy of chest compression skills for infant CPR results in high skill retention for longer. *Eur J Pediatr,* 181 (12), 4101-4109.

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RESEARCH

A novel retraining strategy of chest compression skills for infant CPR results in high skill retention for longer

Debora Gugelmin-Almeida[1,2] · Michael Jones[3] · Carol Clark[1] · Ursula Rolfe[1] · Jonathan Williams[1]

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Abstract

Infant cardiopulmonary resuscitation (iCPR) is often poorly performed, predominantly because of ineffective learning, poor retention and decay of skills over time. The aim of this study was to investigate whether an individualized, competence-based approach to simulated iCPR retraining could result in high skill retention of infant chest compressions (iCC) at follow-up. An observational study with 118 healthcare students was conducted over 12 months from November 2019. Participants completed pediatric resuscitation training and a 2-min assessment on an infant mannequin. Participants returned for monthly assessment until iCC competence was achieved. Competence was determined by passing assessments in two consecutive months. After achieving competence, participants returned just at follow-up. For each 'FAIL' during assessment, up to six minutes of practice using real-time feedback was completed and the participant returned the following month. This continued until two consecutive monthly 'PASSES' were achieved, following which, the participant was deemed competent and returned just at follow-up. Primary outcome was retention of competence at follow-up. Descriptive statistics were used to analyze demographic data. Independent t-test or Mann–Whitney U test were used to analyze the baseline characteristics of those who dropped out compared to those remaining in the study. Differences between groups retaining competence at follow-up were determined using the Fisher exact test. On completion of training, 32 of 118 participants passed the assessment. Of those achieving iCC competence at month 1, 96% retained competence at 9–10 months; of those achieving competence at month 2, 86% demonstrated competence at 8–9 months; of those participants achieving competence at month 3, 67% retained competence at 7–8 months; for those achieving competence at month 4, 80% demonstrated retention at 6–7 months.

Conclusion: Becoming iCC competent after initial training results in high levels of skill retention at follow-up, regardless of how long it takes to achieve competence.

What is Known:

- *Infant cardiopulmonary resuscitation (iCPR) is often poorly performed and skills decay within months after training.*
- *Regular iCPR skills updates are important, but the optimal retraining interval considering individual training needs has yet to be established.*

What is New:

- *Infant chest compression (iCC) competence can be achieved within one to four months after training and once achieved, it can be retained for many months.*
- *With skill reinforcement of up to 28 minutes after initial training, 90% of individuals were able to achieve competence in iCC and 86% retained this competence at follow-up.*

Keywords Infant cardiopulmonary resuscitation · Chest compression · Mannequin · Competence-based retraining · Retention of skills · Tailored retraining schedule

Abbreviations

AHA	American Heart Association
ALS	Advanced life support
BLS	Basic life support
CCD	Chest compression depth
CCR	Chest compression rate
CPR	Cardiopulmonary resuscitation

Communicated by Piet Leroy

✉ Debora Gugelmin-Almeida
almeidad@bournemouth.ac.uk

Extended author information available on the last page of the article

DC	Duty cycle
ERC	European Resuscitation Council
iCC	Infant chest compression
iCPR	Infant cardiopulmonary resuscitation
IQR	Interquartile range
RCUK	Resuscitation Council UK
RL	Residual leaning
SD	Standard deviation

Introduction

Infant cardiac arrest (up to one year of age) is a major healthcare problem, with high rates of morbidity and mortality [1–3]. High-quality infant cardiopulmonary resuscitation (iCPR) is considered critical to a positive outcome after cardiac arrest [3, 4]. However, it is often poorly performed [5, 6], predominantly because of ineffective learning, poor retention, and decay of skills over time [7, 8].

Current pediatric CPR training is an example of an input-based learning system. The minimum requirements to obtain certification depend on subjective opinion that the instructor makes about an individual's performance against some pre-set criteria [9], or via a self-assessment tool [10], without a quantitative assessment of performance. It has been suggested that this model does not result in CPR competence and often leads to poor retention, with skills declining within weeks to months after training [7, 8, 11–15]. The poor retention of skills can potentially affect performance and patient outcomes, raising the question as to why the current training strategy of yearly updates is thought to be optimal for maintaining the quality of CPR skills.

To address skill decay, researchers have investigated different models of distributed retraining schedules, suggesting that monthly retraining generates the best retention [15, 16]. However, this is associated with dropout rates of up to 50% [15] and significant increased costs of repeated training, which may affect the viability of rolling out the training into practice. When attempting to avoid skill decay, regular updates are important [8], but the optimal balance between CPR skills retraining and sustainability has yet to be established.

Previous studies have explored retraining at predefined intervals (i.e., every month); however, this fails to take into consideration the degree of learning already achieved. It might be suggested that those struggling to acquire iCPR competence are likely to require more input than those who have previously mastered the skills. Therefore, a randomized controlled trial design exploring different retraining schedules at pre-set intervals fails to take into consideration the needs of the individual. For this reason, the present study adopted a competence-based approach design to iCC retraining. This type of training model is based on the 'mastery learning strategy,' where learners have the opportunity to practice key skills, receive feedback and improve performance until mastery is achieved [17]. Retraining is then individualized and is based on the quality of their performance in achieving a predefined level of competence [17]. Using the mastery learning strategy to achieve a competence-based approach to iCC may lead to long-term retention of skills, delivery of timely high quality iCC, and subsequent cost savings due to reduced retraining. Despite the importance of ventilation during iCPR [3, 4], this study specifically focused on chest compression skills during iCPR.

The aims of this study were: (i) to determine the amount of input needed to achieve iCC competence, based on achieving four internationally recommended quality measures: chest compression depth, chest compression rate, complete chest recoil and compression duty cycle (the portion of time spent in compression); and (ii) to determine if the acquired competence is retained over time.

This is the first time an individualized design has been explored, to establish whether an outcome-based approach (competence) to a retraining schedule of iCC skills could result in skill retention, while minimizing the potential for dropouts.

Methods

A prospective, observational study was conducted over 12 months within a simulated environment. University Research Ethics Committee approval was obtained (reference ID:27,402). Following explanation of the experimental procedures, written informed consent was obtained from all participants before commencing the study. To create a demographic profile of the sample, data related to age, sex, height, weight and self-declared physical issues, that might compromise performance, were collected.

Participants

A sample size of 72 was calculated based on Anderson et al. [15] at 12-month completion, with alpha at 0.05 and beta at 0.8. However, due to an anticipated high dropout rate (based on previous studies) [15, 16], a convenience sample of 118 university healthcare students was recruited (September–November 2019). Inclusion criteria: (a) university enrolment; (b) not in their final year of study; (c) no previous pediatric CPR training. Exclusion criteria: any musculoskeletal condition requiring medical intervention or an inability to physically perform iCPR.

Equipment

Equipment comprised of an ALS Baby mannequin representing a 5 kg, three-month-old infant (Laerdal® Medical, Stavanger, Norway), modified in a previous study to allow chest compression to a physiological 56 mm depth [18]. The mannequin was attached to a wooden board and during data collection, was placed on a hard floor to eliminate the damping effect of mattress compressibility [19]. The mannequin was instrumented with two accelerometers, one at the lower third of the sternum, the other on the board, acting as a differential for the surface. The mannequin was connected to a PC via a data acquisition unit, where acceleration data were converted into displacement [20].

A bespoke MATLAB algorithm generated four metrics of chest compression during iCPR performance: chest-compression-depth (CCD), chest compression-rate (CCR), residual leaning (RL) and duty-cycle (ratio of compression:release) (DC) (see Table 1). Although participants did not receive real-time-feedback during assessment, Labview software, developed and validated for a previous study [18], provided real-time feedback if needed during practice between assessments. Therefore, the algorithm was able to assess the quality of chest compressions during iCPR and determine if the performance met the target ranges described in Table 1.

Intervention

The intervention was comprised of three aspects:

1. Training: all participants received the four-stage approach 'Pediatric Basic Life Support (BLS)' education package [9], provided by a RCUK qualified instructor. This training was completed in small groups covering aspects such as choking, recovery position, theoretical background in CPR, chain of survival, rescue breaths, chest compressions, different techniques relevant to different ages (e.g., two-thumb, two-finger, one hand, two hands), paediatric modifications, retrieving and using automated external defibrillator, etc. After two-hour training, participants practiced the two-finger compression technique for 30 min on the mannequin, using a compression:ventilation ratio of 30:2 (aligned with resuscitation guidelines for single BLS rescuers with no duty to respond to pediatric cardiac arrest) [23].
2. Assessment: all participants individually completed simulated iCPR on the mannequin for two minutes and performance data based on CCR, CCD, RL and DC were captured (this was called the 'assessment'). Instruction was provided when to start and stop but no further instruction or feedback were provided during assessment so that performance was

Table 1 Definitions of the four iCC skill elements; chest compression rate, chest compression depth, residual leaning and duty cycle. The target ranges and justifications are provided

Metric	Definition	Target range	Target range justification
Chest compression rate	The number of compressions per minute	100–120 min^{-1}	Based on European Resuscitation Council (ERC) and American Heart Association (AHA) guidelines [3, 4]
Chest compression depth	The maximum relative displacement between the two accelerometers during each compression	> 35–45 mm	ERC and AHA guidelines recommend a compression depth of at least one-third the external anterior–posterior chest diameter for an infant (approximately 40 mm) [3, 4]. Upper threshold was selected based on the hypothesis that a residual internal anterior–posterior chest depth of < 10 mm may potentially cause intra-thoracic trauma [21]. Lower threshold was selected based on this mannequin's specification (to achieve one-third the external anterior–posterior chest diameter)
Residual leaning	The incomplete release from the chest wall after each compression	< 2.5 kg	Inadequate recoil (> 2.5 kg) causes high intrathoracic and right atrial pressure, reducing coronary perfusion, venous return to the heart, and blood flow generated by the next compression [22]
Compression duty cycle	The ratio of time taken for compression relative to release	30–50%	Based on Resuscitation Council UK (RCUK) guidelines [23]. The lower threshold was selected based upon the hypothesis that a shorter duty cycle provides significant superior myocardial and cerebral perfusion in infant swine model [24]

not influenced. iCC quality was determined using a MATLAB algorithm, to establish if a "PASS" was achieved—defined as achieving an average of compressions within the target ranges for each metric, as shown in Table 1. These metrics have been demonstrated to provide high repeated measures reliability [25]. All performance metrics (CCR, CCD, RL and DC) needed to be achieved, concurrently, to be considered a "PASS".

3. Practice with real-time feedback: this step was only completed if a participant "FAILED" an assessment. Participants practiced iCPR for 1 min using real-time feedback, after which, an evaluation of performance was completed for 2-min. If the participant "FAILED" again, another block of 1-min practice plus 2-min re-evaluation was completed. No further practice was permitted. The use of real-time feedback during CPR training has been demonstrated to improve CPR quality [26] and the feedback tool used in this study has been described previously [20].

Participant flow through the study

The flow of participants through the 12-month study was determined by the individual performance during iCC assessments according to the following protocol (see Fig. 1):

Time point 0 (immediately after training)

If a 'PASS' was achieved, the participant returned the following month for a repeat assessment. However, if the participant 'FAILED,' practice with real-time feedback was completed (as explained in step 3 of the 'intervention' above). The participant then returned the following month for a repeat assessment.

Time point 1 (one month later)

Participants with a previous 'PASS' were reassessed. If another 'PASS' was achieved, they were declared iCC competent and returned just at follow-up. However, if they 'FAILED' at this time, the same process for 'FAILED' participants at time point 0 was followed.

Participants with a previous 'FAIL' at time point 0 were also reassessed. If they 'FAILED' again, the same process for 'FAILED' participants at time point 0 was repeated. If instead, a 'PASS' was achieved at time point 1, the participant returned the following month for another assessment.

Therefore, participants returned monthly until a 'PASS' was achieved for two consecutive months, after which they were declared iCC competent and returned just at follow-up. If the participant 'FAILED' any assessment, even if they had a previous 'PASS', they were required to return monthly until two consecutive 'PASSES' were achieved. Once achieved, they were declared iCC competent and were asked to return just at follow-up.

The overarching aim was to achieve iCC competence (declared as two consecutive monthly 'PASSES') and participants were grouped for analysis according to when they achieved competence.

This study was completed over a 12-month period, therefore, the follow-up period varied between six to 10 months, due to the staggered nature of when competence was achieved. At follow-up, a repeat iCC assessment was completed. No prior practice was permitted. The choice of two consecutive monthly "PASSES" was based on a previous study, which concluded that while monthly CPR re-exposure is effective for retention at follow-up, two months may be sufficient [16].

Outcome measures

Primary outcome: retention of iCC competence, defined as achieving a "PASS" during iCPR assessment at follow-up.

Secondary outcome: the length of time taken for iCC competence to be achieved.

Statistical analysis

Descriptive statistics were used to analyze demographic data. Mean (SD) values were used to report data with a normal distribution and median [IQR] values were used when the assumption of normality was not met via the Skewness, Kurtosis and Shapiro–Wilk assessment.

The baseline characteristics of those who dropped out were compared to the baseline of those remaining in the study, using an independent t-test or Mann–Whitney U test, depending on the distribution of the variable.

The differences between groups retaining competence at follow-up were determined using the Fisher exact test.

SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA) was used for statistical calculations.

Results

Study population

A total of 118 participants were enrolled in the study including 84 females (71%). The median [IQR] age was 23 [11] years, weight was 68 [17] kg and mean (SD) height was 170 (9) cm.

Trajectory of participants

A total of 87 participants (74%) completed the 12-month study. Drop-outs were due to: Covid-19 (15); long commutes (4);

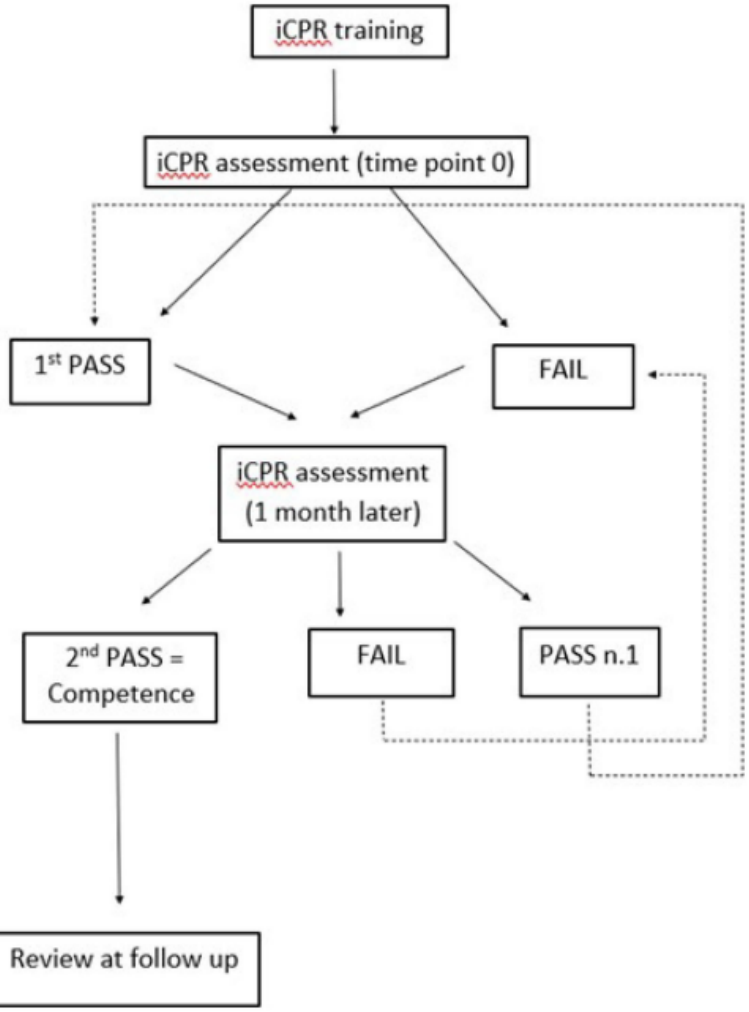

Fig. 1 demonstrating participant' flow through the 12-month study following initial iCPR training

work or placement (5) or non-contactable (7). Participants who completed the study were not statistically different from those who dropped out with respect to demographics or baseline iCC performance at time point 0, as demonstrated in Table 2.

Initial assessment results following completion of iCPR training (time point 0)

A total of 118 participants undertook iCPR training and were assessed immediately after training (time point 0). Of the 118 participants, a total of 32 (27%) 'PASSED' on the first attempt and were asked to return the following month for another assessment. The 86 (73%) participants who failed the assessment, used real-time feedback for reinforcement of skills and were also asked to return the following month for another assessment.

Group 1: Participants achieving iCC competence one month after training (time point 1).

One month after the initial training, the 32 participants who had 'PASSED' at time point 0 were invited to reassessment (time point 1). One dropped out, leaving a total of 31. Of those, 28 (90%) achieved iCC competence by passing the assessment at time point 1.

At 9–10 months follow-up, a further four participants left the study, leaving a total of 24 participants in this

group. Of those remaining, 23 (96%) demonstrated retention of competence by passing the assessment at follow-up (see Fig. 2).

Group 2: Participants achieving iCC competence two months after training (time point 2).

Two months after the initial training (time point 2), the 44 who failed at time point 0 but then passed at time point 1 were invited to reassessment. Of those, 41 (93%) achieved competence at time point 2 by passing the assessment.

At 8–9 months follow-up, of the 41 participants who achieved competence at time point 2, six left the study, leaving a total of 35 participants in this group. Of those remaining, 30 (86%) demonstrated retention of competence by achieving a pass at follow-up assessment (see Fig. 2).

Group 3: Participants achieving competence three months after iCPR training (time point 3).

Three months after the initial training (time point 3), the 12 participants who failed at time point 1 but then passed at time point 2 were invited to reassessment. All (100%) achieved competence at time point 3 by passing the assessment.

At 7–8 months follow-up, of the 12 participants who achieved competence at time point 3, three left the study, leaving a total of nine participants in this group. Of those remaining, six (67%) demonstrated retention of competence with a pass at follow-up assessment (see Fig. 2).

Group 4: Participants achieving competence four months after iCPR training (time point 4).

Four months after the initial training (time point 4), the 11 participants who failed at time point 2 but then passed at time point 3, were invited to reassessment. All (100%) achieved competence at time point 4 by passing the assessment.

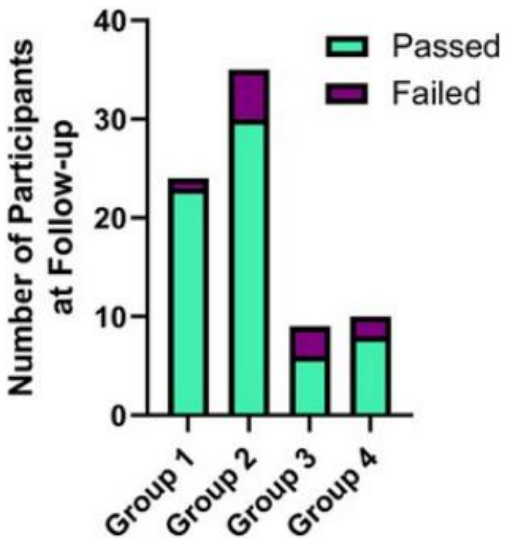

Fig. 2 demonstrating the number of participants from each group who retained iCC competence at follow-up by passing the assessment. Group 1 had 9–10 months follow-up, group 2 had 8–9 months follow-up, group 3 had 7–8 months follow-up and group 4 had 6–7 months follow-up. The number of participants who hadn't retained competence at follow-up is reported

At 6–7 months follow-up, of the 11 participants who achieved competence, one left the study, leaving 10 in this group. Eight (80%) demonstrated retention of competence with a pass at follow-up assessment (see Fig. 2).

Application of the Fisher exact test demonstrated no significant difference between groups for skill retention at follow-up ($p=0.13$), indicating that once competence was achieved, the likelihood of retaining the skills at follow-up was no different across the groups.

Table 2 Comparison between participants who completed the study and those lost at follow-up

	Completed	Leavers	P value
Number	87	31	
Age (years)	23 [11]$^{\beta}$	25 [11]$^{\beta}$	0.75^{a}
Weight (kg)	68 [16]$^{\beta}$	69 [21]$^{\beta}$	0.66^{a}
Height (cm)	170.1 (8.6)	168.2 (11.0)	0.33
Average chest compression rate at baseline (cpm)	101.3 (14.6)	101.0 (16.8)	0.92
Average chest compression depth at baseline (mm)	41.7 [4]$^{\beta}$	43.1 [4]$^{\beta}$	0.26^{a}
Average residual leaning at baseline (kg)	3.0 (0.8)	3.0 (1.2)	0.75
Average duty cycle at baseline (%)	45.7 [8.0]$^{\beta}$	47.8 [8.1]$^{\beta}$	0.60^{a}

Cpm compression per minute

[a]Mann–Whitney U test for non-parametric

[β]Median and interquartile range

Discussion

The aims of this study were to establish the amount of input required to achieve iCC competence and to determine if the acquired competence was retained at follow-up. This was achieved through an individualized 'competence-based retraining schedule,' with input based on the performance and retention of iCC skills and therefore, offers a unique approach to iCPR retraining. To the authors' knowledge, this is the first study to explore a tailored approach to iCC retraining based on individual performance. It was demonstrated that within four months of the initial training, 90% of participants had achieved iCC competence and the likelihood of the participants retaining the skills for up to 10 months was as high as 96%.

The baseline results at time point 0 indicate a similarity to previous pediatric CPR research [5, 6, 11–16, 27, 28], in that, although our participants took part in a two-hour pediatric BLS training, only 27% performed adequately (as defined in our study) immediately after training. This suggests the current input training model struggles to adequately prepare individuals to be competent and brings into question the efficacy of this model of training. Current pediatric BLS training varies significantly but commonly involves attendance at a two-hour instructor-led session every one or two years [7, 8], often without measurement of competence. The minimum requirements to obtain certification are normally visually assessed by the instructor or via a self-assessment tool [9, 10]. Although some participants may achieve the minimum requirements, previous researchers have established that performance immediately after training is consistently poor [5–8, 11–16, 27] and the skills may deteriorate within as little as one month after training [15]. It might be postulated that this traditional strategy of pediatric CPR training should, therefore, be reviewed for effectiveness.

Previous resuscitation studies have concluded that increasing the frequency of retraining may result in improvements in CPR skill retention and clinical outcomes after a cardiac arrest [7, 8]. There are, however, conflicting opinions regarding the frequency of skills re-exposure. Studies exploring the use of distributed practice or low-dose exposure at higher frequency agree that retention of CPR skills is enhanced by short period training sessions [11–14]. Similarly, evidence about mastery learning, where learners practice key skills, receive directed feedback and improve performance until mastery is attained, demonstrates that repetition paired with feedback enables learners to consistently demonstrate a predefined level of competence for a specific skill [17].

Nevertheless, the evidence as to what constitutes an ideal timeframe of repetition is inconclusive. Some studies support weekly [28] or monthly retraining [13, 15, 16], while others suggest that retraining every six [14, 29] or 12 months [30] is sufficient. In practice, the optimal reinforcement schedule is highly likely to vary depending on an individual, and this was demonstrated within the present study. Some participants were able to achieve iCC competence quickly and retain it until follow-up, while others needed more exposure to facilitate learning. Interestingly, despite the varied time frame required to achieve iCC competence, this had little effect on the likelihood of retaining competence at follow-up. This suggests that, once individuals become competent, they can retain competence for at least the duration of follow-up explored in this study. This is in contrast with other studies, which demonstrate significant decay of skills after one to six months [11–16, 28], perhaps intimating that competence was not achieved after training. Therefore, a more nuanced approach to iCPR retraining, based on an individuals' performance is recommended, in an attempt to maximize skill retention, improve performance and potentially enhance patient outcome.

The results from the current study demonstrate higher retention of iCC skills, when compared to previous studies. No 'usual training' control group was included in the current study as the literature for retention following a single point of training demonstrates unequivocally that retention of skills is poor, at just 15–20% of individuals at 12-month follow-up [13, 15]. Distributed monthly practice has demonstrated retention of skills, with 54%–58% of individuals achieving high quality CPR at 12-month follow-up [13, 15]. However, the current study demonstrated retention rates ranging from 67 to 96% demonstrating the efficacy of a tailored approach to learning.

The tailored approach adopted in the current study relied on the 2-h training (time point 0) plus additional practice using real-time feedback until competence was achieved. Cost was not considered in this study, nevertheless, additional practice is likely to result in greater costs, mainly due to individuals spending time absent from clinical areas. It was noted, however, that all individuals achieved competence within four months, so the maximum amount of additional input to achieve competence following this retraining model was up to 28 min. Therefore, for a maximal additional cost of up to 28 min, individuals were able to not only achieve competence in iCC, but also retain this competence at follow-up, potentially reducing training costs overall. It should be acknowledged that this study focused on the development and retention of iCC skills, and this may not reflect training times for the full cycle of iCPR, which includes rescue breaths.

The limitations of this study include: iCC assessments were individually performed in a simulated environment and for two minutes only. It must be acknowledged that real life CPR will be more stressful and may continue

for considerably longer. Therefore, participants were not exposed to stress, distractions or fatigue that may occur during CPR, limiting the transferability of the results to real life performances. A convenience sample of participants was recruited from a single institution, potentially limiting the generalizability of our results to a wider population. A mannequin was used to assess the quality of iCC skills. Although several studies investigating CPR performance use mannequins, it is recognized that chest compliance may not be entirely biofidelic. Ventilation and hands-off time are extremely important elements of iCPR. However, these were not investigated in this present study as the focus was chest compression quality and retention. This study did have a drop out of 26%. This is typical of this type of research, and future studies could investigate methods to minimize drop out.

Despite its limitations, this study demonstrated that achieving iCC competence after training results in high levels of skill retention at follow-up, regardless of how long it takes to achieve competence.

Authors' contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Debora Almeida and Jonathan Williams. All authors have drafted the article and revised it critically for important intellectual content. All authors read and approved the final manuscript.

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Declarations

Ethics approval Ethical approval was obtained from Bournemouth University Research Ethics Committee (reference ID:27402).

Competing interest The authors have no relevant financial or non-financial interests to disclose.

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Authors and Affiliations

Debora Gugelmin-Almeida[1,2] · Michael Jones[3] · Carol Clark[1] · Ursula Rolfe[1] · Jonathan Williams[1]

[1] Faculty of Health and Social Sciences, Bournemouth University, Bournemouth Gateway Building, St. Paul's Lane , Bournemouth BH8 8GP, England

[2] Department of Anaesthesiology, Main Theatres, University Hospitals Dorset NHS Foundation Trust - Royal Bournemouth Hospital, Castle Lane East, Bournemouth BH7 7DW, England

[3] Cardiff School of Engineering, Cardiff University, Cardiff CF23 3AA, Wales

6.14 Limitations

This study presents some limitations that deserve consideration. Like the other studies of this thesis, an infant manikin was used to evaluate the quality of chest compressions. Although the use of manikins in resuscitation research is a common practice since the early 1960s, because manikins may not exactly replicate the characteristics and chest compliance of human beings, its use may limit the generalisability of our results to real life iCPR. This limitation is also described and further explored in Chapter 3, Section 3.15.

A convenience sample of healthcare students from a single institution was selected for this study. Despite its unfavourable generalisability compared to probability samples, convenience samples account for over 92% of participants in research (Bornstein *et al.* 2013). Therefore, to optimise its benefits and to enable a clearer generalisability, we limited its disadvantages in relation to population effects and subpopulation differences. To reduce the chance of bias in our participants sample, we intentionally constrained one demographic aspect (healthcare students), to reflect the target population (healthcare professionals), following the strategy of homogeneous convenience sample, for a clearer generalisability. According to this strategy, "the more homogeneous a population, the easier (more probable) it is to generate a representative sample, even when using convenience sampling. Therefore, by intentionally constraining the sampling frame to reduce the amount of sociodemographic heterogeneity, the chance of bias in sampling, as it relates to sociodemographic characteristics of the target population, is reduced." (Jager *et al.*

2017, parag.15). However, caution is advised before generalisation of the results of our study to the wider population.

The data collection sessions (assessments) were performed individually and in a simulated context. Although simulation allows the learner to practice and demonstrate the skills in a controlled and safe environment, the participants are not exposed to relevant features encountered in real resuscitation attempts including background noise, other rescuers, distractions, interruptions, fatigue, or the stress and complications that may occur during a real cardiac arrest (Perkins *et al.* 2008).

The focus of the study was the quality of chest compressions and retention of skills, therefore rescue breaths and hands-off time were not included in the analysis, despite being very important metrics of iCPR.

iCPR assessments were performed for two minutes only, which is not likely to be the time spent delivering real iCPR. Elements such as fatigue and decrease in skills quality can be expected when iCPR is performed for longer, limiting the transferability of the results to real life resuscitation attempts.

6.15 Chapter Summary and Next Steps

This Chapter describes a longitudinal, prospective, experimental study in exploring the quality, retention, and decay of simulated iCPR skills delivered by healthcare students.

A sample of 118 participants undertook paediatric CPR training and an individualised two-minute assessment was conducted to establish if the participant achieved an average of compressions within pre-established target ranges for CCR,

CCD, RL, and DC simultaneously. The results from assessment generated a nominal outcome which could be 'PASS' or 'FAIL', depending on whether any of the iCPR metrics remained within or outside its respective range.

Participants achieving first-time 'PASSES' in two consecutive months were considered to have gained iCPR competence and returned just at follow-up, from six to 10 months later, depending on when they achieved competence. For each 'FAIL', participants practiced iCPR for one minute using automated real-time feedback. They would then come back until they achieved first-time 'PASSES' in two consecutive months, at which point they would achieve iCPR competence and return just at follow-up.

A total of 87 participants (74%) completed the 12-month study with no statistical difference between those who completed the study from those who dropped out with respect to demographics or baseline iCPR performance. The baseline results immediately after training indicated a similarity to previous paediatric CPR research in that, although 118 participants took part in the initial two-hour paediatric BLS training, only 32 (27%) 'PASSED' the assessment on the first attempt. This suggests, the current input training model struggles to adequately prepare individuals to become competent and brings into question the efficacy of this model of training. Despite the initial low 'PASS' rate, participants succeeded in achieving competence throughout the study. The time taken to achieve iCPR competence varied between one to four months after training, with 28 participants achieving competence within the first month; 41 achieving competence at month two; 12 achieving competence

at month three; and 11 at month four. Therefore, with an additional reinforcement of skills of four to 28 minutes, participants achieved iCPR competence.

Another important aspect explored in this study was retention of the acquired competence. The results indicate that, despite individuals requiring different amount of input and time to achieve iCPR competence, the retention of those skills was as high as 96% at follow-up. This suggests that the optimal reinforcement schedule is highly likely to vary depending on the individual achieving iCPR competence. Therefore, it can be argued that once individuals become competent, they can retain competence for at least the duration of follow-up explored in this study.

The clinical relevance of this study is attributed to the understanding of iCPR skill acquisition, competence, and retention of achieved competence based on individual learning needs. The method applied might be considered an outlier of an approach for CPR training/retraining studies. However, the author believes that this tailored strategy based on individual needs and the requirement to achieve competence before the participants are "signed off", is the novelty of the research.

Next steps

The new knowledge acquired from this study, suggests that for a maximal additional cost of 28 minutes, trained individuals may be able to not only achieve competence in iCPR but also retain this competence for longer. This can potentially reduce overall training costs and enhance iCPR performance. It may be argued that, in consequence, chances of survival after infant cardiac arrest may be improved. This is an important finding to support the new model of iCPR retraining proposed in this thesis.

The objectives of this thesis have been addressed and the results supported the achievement of the overall aim, which was to create a novel, tailored, competence-based strategy to iCPR retraining, with the ultimate goal of maximising retention of iCPR skills and potentially improving survival after cardiac arrest.

Through the development of this thesis, further questions related to iCPR were encountered. Although they were not part of the aims and objectives of this research, they are knowledge gaps that deserve further exploration. These knowledge gaps are outlined in Chapter 7, with suggestions for further research to enhance evidence related to the resuscitation field.

Chapter 7 General Discussion

This is an integrated format thesis, where the Chapters provide a narrative that links the studies and published manuscripts. The rationale behind the decision to develop the research following the integrated format approach, was to allow the timely dissemination of the results in order to ensure evidenced-based changes in clinical practice can be made at the earliest possible opportunity.

This integrative Chapter will present the author's reflection on positionality, and a broader evaluation of the main aspects and original findings of the thesis. Additionally, the significance of this work in the context of existing evidence in the field of infant CPR will be discussed, alongside the possible transferability of the novel findings into clinical practice and policy makers.

7.1 Reflection on positionality

One of the challenges encountered during my research journey, was my acceptance of final decisions regarding particular positions, methods or philosophy. Taking an empirical approach was a natural process for me, as it aligned with my philosophical beliefs based on positivism. However, this seemed controversial as, at different key points of the research, I was challenged with questions regarding the qualitative aspects of my topic and if a mixed-methods approach would be more effective for the development of my project.

Looking back, I now understand that the conversations about the different paradigmatic assumptions that could be used to conduct my research, were intended to encourage me to reflect on other aspects or ways to answer my research questions

and to acknowledge my own positionality with regards to social, economic, and cultural experiences. Moreover, it was part of a learning process that enabled me to make an informed decision about the foundation of the philosophical framework of my research. This reflection is normally overlooked in quantitative research (Jamieson *et al.* 2023), but it is an important aspect to be considered, as positionality can influence the selection of research questions, variables, sampling techniques, data analysis, and reporting (Wilson *et al.* 2022).

Through discussions and conversations with my supervisory team, external experts in the field, experienced researchers, and professors in my Faculty, I identified my strengths, which were not in benchtop experiments such as computational models, or in recognising that data should be interpreted in relation to the context of their production. My strengths were constructed on the application of quantitative methods to design experiments that would enable me to answer questions related to metrics associated with my topic. Moreover, I acknowledge that there will be other questions around iCPR that will not be answered by my research because they were not part of the aims of my thesis. However, despite that, I am confident that my contribution to the current body of knowledge will advance the understanding around iCPR retraining and retention of skills.

The integrated format of this thesis enabled me to submit my studies for publication throughout the development and shaping of the research. Each manuscript has been published, and the feedback from reviewers enhanced not only the manuscripts, but the construction of the thesis. The peer review and critical examination of my work

allowed me to be more confident that my research choices and decisions were not unduly impacted by my own biases.

This reflection on my strengths and abilities as an early career researcher will enhance my future development, by helping me to select what elements underpinning the Research Excellence Framework (REF) I should focus on. The REF evaluates research in UK higher education institutions, and it is based on the quality of outputs and their impact beyond academia (REF 2022). By aligning my development plan with the REF elements, the quality of my research can continuously improve.

7.2 Research Overview

The overall aim of this research was to create a novel, tailored, competence-based strategy to iCPR retraining, with the ultimate goal of maximising retention of iCPR skills and potentially improving survival rates after cardiac arrest. The author aimed to develop a retraining strategy where trainees would master their iCPR skills after initial training with reinforcement of skills over a short period of time, determined by their performance.

This idea was based on the established knowledge that, although high-quality iCPR is a life-saving technique performed to increase the chances of survival after a cardiac arrest, iCPR performance immediately after training is consistently poor, and the skills deteriorate within weeks to months after training (Niles *et al.* 2017, Lin *et al.* 2018, Saad *et al.* 2019, Chen *et al.* 2021, Lockey *et al.* 2021). Therefore, two major problems were identified. Firstly, the acquisition of the skills and secondly, the retention of this acquisition. These problems motivated this work to design a new

retraining strategy to achieve iCPR competence with the aim to maximise the retention of the acquired skills. This is important because, when a rescuer attends a cardiac arrest, their performance may not be as good as it was when they were first trained. This is particularly relevant in paediatric cardiac arrests which are fortunately uncommon events (see Chapter 2, Section 2.2.1), but this brings the added challenge in retaining iCPR skills (Binkhorst *et al.* 2018, Kleinman *et al.* 2018, Skellett *et al.* 2020).

There is a vast amount of research in adult cardiac arrest and CPR, however, literature in iCPR is scarce. Therefore, this research focused on the infant population to bridge the current gap in knowledge and to potentially improve the chances of survival from infant cardiac arrest. Although the author recognises the importance of ventilations during iCPR, the focus of this research was on the chest compression aspect of resuscitation.

To be able to design this original retraining model and achieve the overall aim, the following objectives were identified prior and throughout the development of this thesis, to inform the research design and processes. Full exploration of each objective can be found in the corresponding Chapters.

1. Identifying an effective strategy to analyse iCPR performance, reinforce skills and provide feedback (Chapter 2, Section 2).

2. Exploring consistency and variability of simulated iCPR performance (Chapter 3).

3. Determining differences in performance between the dominant hand (DH) and non-dominant hand (NH) during simulated iCPR (Chapter 4).

4. Investigating perception of fatigue during simulated iCPR for the DH and NH and its relationship with performance (Chapter 4).

5. Identifying retraining timeframes and strategies previously explored in the literature (Chapter 5, Section 2).

6. Determining the time taken to master simulated iCPR skills so that individuals become competent (Chapter 6).

7. Exploring the time that simulated iCPR skills remain effective, after competence is achieved (Chapter 6).

The following sections will explore the novel key findings constructed by this research, and a comparison against relevant literature will be offered.

7.3 Key Aspects and Original Findings

7.3.1 Novel use of four components of infant chest compression

This research has a unique aspect related to the integration of the four components of chest compression that are closely related to high-quality iCPR performance: CCR, CCD, RL, and DC (Maconochie *et al.* 2015, Topjian *et al.* 2020, Considine *et al.* 2020, Skellett *et al.* 2021). In each experimental study designed for this thesis, the four components were investigated. These CPR metrics have been recognised because of their influence in ensuring adequate blood flow during a cardiac arrest and improve patient outcomes. Comprehending the impact of these metrics and their relative relationships, is important to the improvement of CPR quality and training for optimal performance (Kramer-Johansen *et al.* 2007, Meaney *et al.* 2013, Topjian *et al.* 2020). Therefore, the results of studies that do not include all four metrics should

be interpreted with caution. When conducting the literature review in Chapter 2, the author observed that only a few studies have investigated DC during CPR, particularly in paediatric research. Furthermore, when DC was an outcome measure, the results indicated that rescuers do not meet current guidelines for this metric during resuscitation attempts (Martin *et al.* 2013a, Johnson *et al.* 2015, Wolfe *et al.* 2016). This is consistent with results based on other metrics as well, concluding that poor adherence to resuscitation guidelines of one or more of the four metrics, may result in ineffective CPR performance, leading to a reduced chance of return of spontaneous circulation and/or survival to hospital discharge (Cutler *et al.* 2014, Johnson *et al.* 2015, Duval *et al.* 2019).

The relationship between CPR metrics has been previously explored due to their potential association with patient outcomes (Wolfe *et al.* 2016). According to Johnson *et al.* (2015), DC was inversely associated with CCD and correlated with CCR such that a lower DC corresponded to deeper compression and slower rate. This suggests that the proportion of time spent actively compressing the chest during the downstroke of compression, is likely to influence other important CPR metrics. Previous studies indicate that compression depth and rate that meet guidelines are associated with better clinical outcomes (Stiell *et al.* 2012, Idris *et al.* 2012, Vadeboncoeur *et al.* 2014, Duval *et al.* 2019). However, these studies did not analyse DC, and therefore it is not clear if the clinical prognosis was only due to adherence to depth and rate, or if DC values impacted performance.

For this reason, and to maximise the accuracy of interpretation of results, one of the novelties of this integrated thesis was to ensure that data on all four metrics were

reported in every study. The device used (described in Chapter 3, Section 3.11) was previously validated, and was able to assess the quality of iCPR, quantify participants' performance and provide guidance on each of the four iCPR metrics (CCR, CCD, RL, and DC). Additionally, the experiments required a specific ability to manipulate values for the above-mentioned metrics to account for new finding related to the metrics, as seen in Chapter 3. The selected feedback device, therefore enabled the researcher to manipulate an algorithm so that participants' data could be analysed and converted into the four metrics of interest, for a more accurate interpretation of the results of iCPR quality. This was a significant aspect for the development of an effective retraining model to improve performance and optimise retention of iCPR skills.

7.3.2 Consistency and variability of simulated iCPR performance

This was the first time that repeated measures' reliability and variability in CPR performance has been explored in the resuscitation field. Although comparison with literature is challenging as such exploration has not been reported previously, the results from this study provided original insights into consistency of iCPR performance. Repeated measures' reliability and variability in CPR performance was used in this study because it is recognised as an important aspect in motor learning research (Ringsted 2010, Wulf *et al.* 2010). In addition, the lack of previous investigations around consistency of CPR skills has the potential to impact the interpretation of results and subsequent patient outcomes. It could be conjectured that differences reported in CPR performance after training, reported in previous studies as skill decay (McKenna and Glendon 1985, Oermann *et al.* 2011, Stanley *et*

al. 2021), could be explained by natural variations and/or inconsistent performance, instead of skill decay.

Following this line of enquiry, the author believed that this concept should be investigated. These understandings would aid the quantification of changes in iCPR performance that are higher than natural variability. This knowledge could then support the development of resuscitation training designs, resuscitation research and interpretation of data on iCPR skill decay.

Chapter 3 described the methodological approach of this study and presented the published manuscript for full details. The key and novel findings generated from the study concluded that iCPR is a highly repeatable skill that can be performed consistently. This provided the evidence that any subsequent changes in performance that occurred after training, were not attributed to natural variability or inconsistent performance; they were true change in performance. However, it is important to note that, although each metric resulted in good repeatability, which supports the conclusion that iCPR is highly repeatable, the values for RL and DC demonstrated higher variability than CCR and CCD, suggesting less consistency for those metrics.

One explanation as to why the variability is greater for RL and DC may be the reinforcement of depth and rate during CPR training and in media campaigns about CPR. For example, the concept of “push hard and fast” has been presented to the wide population in different media campaigns, including in the UK, through the TV advert from British Heart Foundation (BHF 2016). This provides or reinforces the knowledge of the importance of correct depth and rate during CPR, but with no

mention to DC or RL. It should be acknowledged that these two aspects are less known and possibly more difficult to understand than CCD and CCR. Additionally, during basic life support training, RL and DC particularly receive less attention and this may result in participants/rescuers concentrating more in CCD and CCR.

It may be suggested that in the future, campaigns that raise awareness of CPR, should introduce the concepts of full chest decompression and 1:1 ratio for compression:decompression. That way, potential rescuers may become familiar with the concept of chest recoil and may recognise the importance of compressing and releasing the chest proportionally.

7.3.3 Quality indices of iCPR metrics may reduce consistency and repeatability considerably and should be interpreted with caution

Another significant original finding of this study was based on the degree of correlation between repeated measures for the quality indices (QI) of iCPR metrics. QI have been used to assess quality of CPR performance in previous research (Nishiyama *et al.* 2010, Pozner *et al.* 2011, Martin *et al.* 2013a). It represents the proportion of CPR performance that reaches a pre-set target value, based on resuscitation guidelines. It provides a further understanding of data collected, within a context of CPR quality, i.e. 'good quality' or 'bad quality'. QI can be specific for each metric of interest or a representation of the overall CPR quality, depending on the research protocol (Martin *et al.* 2013a).

Although this concept has been previously utilised in CPR research regarding skill decay, there has been no investigation of natural variation of performance when chest compression metrics are converted into QI, potentially resulting in erroneous

conclusions. This suggestion was evidenced by the findings of this research. The study conducted and explained in Chapter 3, demonstrated that when iCPR metrics are converted into QI, consistency and repeatability reduce considerably for some metrics, bringing into question the validity of results from previous studies (Sutton *et al.* 2011, Martin *et al.* 2013a, Lin *et al.* 2018). It was observed that, to be certain of real improvement or decay of skills when QI are used, much larger changes in performance are required, particularly for CCR, RL and DC, as demonstrated in Chapter 3, Section 2. Although QI assist with a better understanding of performance data by converting numbers into quality metrics ('good quality iCPR' or 'bad quality iCPR'), the higher variance in outcome measures should therefore be considered in future studies.

The reason for this aspect of QI may be explained by the "hard cut-off" attributed to each metric, based on resuscitation guidelines. For example, when calculating QI for duty cycle, if the rescuer performed chest compressions with DC mostly at 49%, sometimes at 50% and sometimes at 48%, although their performance may be clinically adequate at an average of 49%, this metric will be considered as 'poor quality'. This is because it was performed somewhere around the boundary, but not at the recommended cut-off value of 50%, as established by resuscitation guidelines (Maconochie *et al.* 2020, Skellett *et al.* 2021).

This finding brings to the question whether a 'hard cut-off' of the boundaries for each iCPR metric should be challenged. Should a sliding-scale be adopted to analyse data related to performance quality? Would this be a more accurate way of determining the quality index for each metric and consequently a more truthful interpretation of

iCPR performance? This concept could be investigated in further research so that QI can continue to be used as a measure of performance where 'good-quality iCPR' or 'bad-quality iCPR' would be a true representation of performance.

7.3.4 The differences in performance and its relationship with perception of fatigue between the dominant hand (DH) and non-dominant hand (NH) during simulated iCPR using the two-finger technique (Chapter 4).

The results of this study provided a significant novel contribution to knowledge relating to the two-finger (TF) technique, which is used for a sole rescuer during iCPR. The study was conducted as part of this integrated thesis based on a knowledge gap identified as a result of an earlier study (Chapter 3) in which participants enquired if swapping hands to alleviate fatigue would be considered an acceptable practice. Although this was not allowed during the mentioned study, the author concluded that this was an important aspect that needed further investigation. To the author's knowledge, there has been no previous study that has explored whether the swapping of hands when using the TF technique might impact overall iCPR quality, and if there might be significant differences between the dominant compared with the non-dominant hand. Although the effect of hand dominance has previously been explored during CPR in adults and older children (Wang *et al.* 2015, Kim *et al.* 2016, Jo *et al.* 2017), until the present date, there has been no investigation to compare DH and NH during iCPR performance using the TF technique. This was a key factor that needed further exploration, considering that current resuscitation guidelines still advocate the use of TF technique as an alternative method for a single rescuer

performing iCPR, but without mention on which hand to use (DH or NH) (Skellett *et al.* 2021).

The original knowledge generated by this study adds to the current paediatric CPR research field and offers two major conclusions. The first one is that there is no significant difference in iCPR performance between the DH and the NH for each of the four metrics (CCD, CCR, RL, and DC) when the TF technique is used during three-minute iCPR. This suggests that rescuers can swap hands after each two-minute cycle of iCPR, without compromising performance and/or quality of iCPR. This conclusion is consistent with some data related to one-hand technique during paediatric CPR (Oh *et al.* 2014, Kim *et al.* 2015), but opposes the findings from Kim *et al.* 2016 where different fingers were compared for the right hand and left hand. Although the authors suggested that the right hand demonstrated significantly superior performance when compared to the left hand, this was not attributed to hand dominance. Additionally, the outcome measures used in their study included quality indices. As explained in the section above (7.2.2), when converting CPR values into QI, a greater variance in outcome measures is noted, which could have impacted their results.

An important aspect associated with hand dominance that warrants further exploration, is a phenomenon known by inter-manual transfer. This may have impacted the results of the study in Chapter 4 and consequentially, the conclusion that iCR performance between the DH and NH is not significantly different. The inter-manual transfer phenomenon suggests that a motor skill learned with one hand may impact the task executed with the other, untrained hand (Halsband and Lange 2006).

In our study, the participants learned and practiced iCPR with the hand they felt comfortable with. The instructor did not establish which hand to use. It is understood that people execute motor tasks with their DH, and this can be explained by suggestions that motor control and accuracy are normally more efficient for the DH (Elliot *et al.* 1993, Wang *et al.* 2011, Schaffer and Sainburg 2017). As part of our experiment, the participants executed iCPR with the DH and the NH after a one-minute interval (or the other way round according to randomisation). It can be suggested that the concept of skill transfer of a motor task could have narrowed down the differences in results from the DH and NH, particularly for those who learned and practiced iCPR with the DH and were randomised to do the initial test with the DH. Despite that, the method selected for this study can be closely associated with real out-of-hospital resuscitation attempts, where rescuers are expected to minimise pauses during iCPR performance, will unlikely have assistance from another rescuer and will therefore, have minimal time between swapping hands.

A second major conclusion and novel knowledge generated by this study was that, although the participants could perform iCPR similarly with the DH and the NH, as explained above, the perception of fatigue represented by VAS, was significantly higher with the NH after three-minute performance. This original finding suggests that the exertion to sustain similar performance during iCPR using the TF technique is higher for the NH. It must be acknowledged though, that the participants from our study performed three-minute iCPR before pausing. This timeframe was selected in an attempt to instigate fatigue (as explained in Chapter 4, Section 4.7) but this is not consistent with current resuscitation guidelines that recommend two-minute cycles

during infant resuscitation attempts (Skellett *et al.* 2021). While it cannot be concluded that perception of fatigue would be significantly different between DH and NH in a situation where two-minute iCPR was provided before pauses in chest compression, the novel finding generated by this study is still relevant when iCPR is delivered out-of-hospital, as rescuers may perform iCPR for much longer with short pauses for rescue breaths.

The two conclusions from this study suggest that, albeit a slight association between iCPR performance and perception of fatigue, this had no impact on quality of performance. Although a higher perception of fatigue was observed with the NH, rescuers can be confident in their ability to deliver similar quality iCPR skills with both hands when resuscitating an infant using the TF technique.

7.3.5 Achieving iCPR competence and maintaining the skills for longer using a new retraining model (Chapter 6).

Another important and original aspect of this research was the demonstration that iCPR competence can be achieved and maintained by a retraining schedule based on the degree of learning previously attained, added to the quality of individual performance.

Currently, the principles underlying the training standards are that individuals with different levels of ability (some demonstrating CPR competence and others requiring a greater input from trainers and/or increased need of practice on manikins) should receive CPR training/retraining designed within the context of wider organisational demands and pressures; priorities; available resources; and based on their staff roles and responsibilities. This happens without a clear indication of how frequently

training/retraining should occur and without considering prior learning and participants' learning needs (Lockey *et al.* 2021). Most organisations deliver a pre-determined annual, two-hour BLS training or every two years for paediatric BLS, depending on the practitioner's role. However, with CPR skills and knowledge decaying just weeks to months after training (Kleinman *et al.* 2018, Saad *et al.* 2019, Lockey *et al.* 2021), it raises the question as to how optimal yearly updates are for maintaining the quality of paediatric CPR skills. Additionally, the current input-based training model struggles to adequately prepare individuals to become CPR competent. This type of training may suggest rescuers' acquisition of skills at point of training, which is normally based on the instructor's visual assessment of the participant's performance. However, rescuers need the opportunity to practice iCPR skills based on their level of ability until competence is achieved, so that retention of skills can be maximised for a better-quality performance when rescuing an infant in cardiac arrest (Donogue *et al.* 2021). It can be suggested therefore, that current CPR training provides opportunities to rescuers to perform the skills at the time of training but does not provide sufficient exposure for sustained learning (Oermann *et al.* 2011).

As previously mentioned in Chapter 2, Section 2.4.1, it has been acknowledged that identifying training and retraining models that enhance learning acquisition and retention of CPR skills is important to enhance performance and improve patient outcome after cardiac arrest (Donogue *et al.* 2021). This research has contributed to closing this gap in knowledge by creating a tailored iCPR retraining strategy that resulted in 90% of the rescuers achieving iCPR competence within four months after initial training; and nearly all maintaining competence at follow-up.

The original retraining model suggested in this thesis consisted of three aspects: two-hour paediatric CPR training; two-minute simulated iCPR assessment to determine quality of performance (e.g. achieving a "PASS"); and additional short (one-minute) practice using real-time feedback if a "PASS" was not achieved during assessment. If a "PASS" was achieved first-time during assessment, the rescuer should return for follow-up assessment in the next month, so that competence could be confirmed. Competence was established by two consecutive monthly first-time "PASSES". The full strategy is further explained in Chapter 6 and presented in the published manuscript (Chapter 6, Section 2).

This strategy is aligned to the 2020 resuscitation guidelines (Cheng *et al.* 2020) that recommend a low-dose, high-frequency CPR training/retraining. Although some studies already support the use of this strategy (Niles *et al.* 2009b, Sutton *et al.* 2011), this thesis is the first to use a tailored model to iCPR retraining based on individual performance. The reinforcement of skills (real-time-feedback and assessment) happened between four to 28 minutes, depending on how many practice/assessments the rescuer needed. Competence (two consecutive first-time monthly "PASSES") was achieved within one to four months after training, again, depending on the individual performance. This reinforces the statement that individual's learning needs differ, impacting on how long it takes for iCPR competence to be achieved and in addition, how long the skills are retained.

The repeated assessment or repeated testing (e.g. up to three times until a "PASS" is achieved, as explained in Chapter 6, Section 6.9) applied in this retraining model has been demonstrated to improve learning outcomes (Wulf *et al.* 2010) and skill

retention (Spreckelsen *et al.* 2017), as the learners take on an active role in their practice. This appears to result in a more powerful learning experience when compared to the traditional input-based training, where learners take on a more passive role. This phenomenon can be explained by 'testing-effect' where retrieval of skills during testing may improve retention more effectively than repeated training (Kromann *et al.* 2009, Roediger and Karpicke 2018, Kovács *et al.* 2019). Additionally, the stress response generated by tests/assessments may also improve learning and retention of skills due to neuronal changes (Joëls *et al.* 2011).

The combination of the above-mentioned theories (distributed practice, mastery learning, testing-effect), aligned with the concepts explored in this research (the use of real-time feedback, consistency of iCPR performance, effects of hand dominance and perception of fatigue) contributed to the effectiveness of this proposed novel retraining model that used an individualised, competence-based retraining to iCPR skills. The results demonstrated excellent achievement of iCPR competence for participants, with the maximum additional time needed to reinforce the skills of 28 minutes, which was distributed within four months after initial training.

Added to the high level of rescuers achieving competence within four months of initial training, the research also demonstrated that almost all the participants retained their iCPR competence up to 10 months. Therefore, with up to an extra 28 minutes after initial training, participants were able to not only achieve iCPR competence, but also retain the skills at follow-up. This is a significant improvement when compared to previous research in the field which demonstrates considerably lower retention of skills of 15% to 58% (Niles *et al.* 2017, Lin *et al.* 2018, Anderson *et*

al. 2019, Oermann *et al.* 2022), which might indicate that competence was not achieved after training. Therefore, based on the results of this thesis, the author recommends a tailored approach to iCPR retraining, according to individual performance and needs. This can, as demonstrated in this research, maximise retention of iCPR skills, improve performance and may potentially improve patient outcomes after a cardiac arrest.

7.4 Transferability to Practice

The overall aim of this research was to create a novel, tailored, competence-based strategy to iCPR retraining, with the goal of maximising retention of iCPR skills to potentially improve survival of infants after cardiac arrest. This is an important aspect in the resuscitation field and clinical practice, and particularly relevant to infant patients who have predominantly poor outcomes, with undesirable high rates of both mortality and morbidity (Donoghue 2005, Park *et al.* 2010, Nitta *et al.* 2011, Meyer *et al.* 2012, Lee *et al.* 2019b).

With evidence suggesting ineffective learning, poor retention, and decay of CPR skills over a short period of time (Niles *et al.* 2017, Cheng *et al.* 2018, Anderson *et al.* 2019, Lockey *et al.* 2021), finding a retraining strategy that provides an optimal balance between learning, retention of skills, time away from clinical practice, costs, and overall sustainability, is the key to the viability of implementing the retraining programme into practice. The first three aspects of this optimal balance were demonstrated by this research, with high achievement of iCPR competence within a short time and longer retention of competence. Therefore, it can be argued that once individuals become competent, they can retain competence for longer, reducing

training needs and time away from clinical areas, potentially increasing sustainability of this model of retraining.

Although cost (fourth aspect) was not investigated in this research, the author recognises that it is an important facet in clinical practice, as resources in health and social care are normally limited. Therefore, funds used on training and staff development should be carefully considered, with cost-benefit or cost-effectiveness analysis (Brown *et al.* 2002). Despite this, the new knowledge acquired from this study suggests that, for a maximal additional cost of 28 minutes, trained individuals may be able to not only achieve competence in iCPR but also retain this competence for longer. This can potentially decrease training costs overall as the long-term retention of skills with reduced training exposure/time will keep the staff in clinical areas for longer.

The clinical relevance and novelty of this thesis is attributed to the demonstration that iCPR competence and retention of skills are based on individual learning demands. The author recommends that a tailored approach to iCPR retraining based on individual performance, automated assessment, and the requirement to achieve iCPR competence, should be the basis for iCPR retraining strategies of all healthcare students, practitioners, and laypeople. This can, as demonstrated in this research, maximise retention of iCPR skills, improve performance and may potentially improve patient outcomes after a cardiac arrest.

7.5 Strengths and Limitations

There are many strengths to this thesis. First, it builds upon previous evidence supporting the effectiveness of low-dose, high frequency CPR training, mastery

learning and the use of real-time feedback to enhance the learning processes associated with resuscitation training and retraining. More importantly, it closes some research gaps that existing studies have not explored before. Many studies have used RCT designs to explore retraining strategies, however, RCTs by design are rigid, with individuals randomly assigned to groups. As learners are not 'identical' at baseline, the author believes that blinded randomisation would be inappropriate, as it would fail to take into consideration the degree of learning already achieved and the needs of the individual. For this reason, this study used a more dynamic and nuanced strategy to iCPR retraining, which demonstrated to be effective.

Another strength is the unique aspect related to the integration of the four components of chest compression that are closely related to high-quality iCPR performance: CCR, CCD, RL, and DC (Maconochie *et al.* 2015, Topjian *et al.* 2020, Considine *et al.* 2020, Skellett *et al.* 2021). In each experimental study designed for this thesis, the four components were investigated. These CPR metrics have been recognised because of their influence in blood flow during a cardiac arrest and patient outcome. Comprehending the impact of these metrics and their relative relationships is important to the improvement of CPR quality and training/retraining, so that performance can be optimised (Kramer-Johansen *et al.* 2007, Meaney *et al.* 2013, Topjian *et al.* 2020).

Building on from the above aspect, the instrumented tool used for the experimental studies of this thesis, was able to assess the quality of iCPR, quantify performance and provide guidance on all the four iCPR metrics (CCR, CCD, RL, and DC). Additionally, as previously explained in Chapter 3, Section 3.11, the manikin was

modified during a previous study to allow the depth of compression to be increased from 40mm, which is the original manikin specification, up to 56mm, which is the physiological internal anterior-posterior chest depth of a three-month-old infant. Not many devices are commercially available for quantification of iCPR performance, and they vary considerably in their ability to analyse and quantify the metrics associated with high-quality iCPR (CCR, CCD, RL, and DC). The great majority provides feedback on CCR, CCD and RL without considering DC, as seen in Gugelmin-Almeida *et al.* (2021a). However, it has been explored in this thesis (Chapter 2, Section 2.3.6.4) that high-quality iCPR is dependent on effective DC to optimising venous return to the heart, myocardial perfusion, cardiac output, and cerebral blood flow (Fitzgerald *et al.* 1981, Dean *et al.* 1991, Sunde *et al.* 1998a, Babbs 2006, Kim *et al.* 2020). Therefore, another strength associated with this research is the use of this modified and validated manikin that was able to provide data on the four metrics of interest.

The retraining study described in Chapter 6, which ultimately resulted in the design of the novel iCPR retraining model proposed by this thesis, had a large sample size of 118 participants. The population sample was intentionally constrained to one demographic aspect (healthcare students) following the strategy of homogeneous convenience sample for clearer generalisability (Jager *et al.* 2017). The added advantage of this method was that, if the retraining model was rolled out into practice, the newly qualified practitioners would have been exposed to the training strategy and benefitted from the outcomes (e.g. skill retention).

Moreover, this thesis focuses not only on how to effectively achieve iCPR competence based on individual performance, but also on retention of the acquired

skills at a follow-up, which was scheduled based on the staggered time of when competence was achieved. This tailored approach to follow-up, which could be used as reassessment and/or reinforcement of skills if this model of retraining is implemented in clinical practice, would support the needs of current healthcare demands related to professional development costs, practitioners' time away from clinical areas and staff motivation. This strategy would allow for sufficient flexibility to address the different learning needs of individuals and demands of clinical practice.

Despite its strengths, this research has some limitations that warrant further discussion and lead to opportunities for further research in this field. The experimental studies conducted for this research utilised infant manikins so that participants could practice the skills and the researcher could evaluate iCPR performance. Although CPR training has incorporated manikins to enhance quality since the early 1960s (Rosen 2013, Laerdal Medical 2016, Damewood 2016), it is recognised that they may not replicate the anatomical characteristic of human beings including tissue rigidity, cervical spine mobility and chest compliance (Hesselfeldt 2005, Cook *et al.* 2007). Additionally, different types and variations between manikins have been identified (Laerdal 2016, Health Simulation 2019, WHO 2021), which may impact the results of different studies using manikins and limit the transferability to real life performance.

Another important aspect that needs some consideration is the simulated context in which the studies were conducted. Although simulation allows the learner to practice and demonstrate the skills in a controlled and safe environment, the participants are

not exposed to relevant features encountered in real resuscitation attempts including background noise, other rescuers, distractions, interruptions, fatigue or the stress and complications that may occur during a real cardiac arrest (Perkins *et al.* 2008, McDonald *et al.* 2010, Sainio *et al.* 204, Rad and Rad 2017), impacting generalisability of results. In addition, the Hawthorne effect should not be discarded as the participants knew that they were observed during assessment, which could have affected their performance.

A number of metrics were analysed in the studies, resulting in a large number of bivariate comparisons. The analysis did not factor in how each variable (e.g. compression duty cycle) could have influenced another (e.g. residual leaning). Consequently, if a relationship between variables was existent, it was not investigated in this research, as no correlation for multiple comparisons were made. However, although this may have potentially raised the chance of type-1 error (Lee and Lee 2018), the *p*-values were calculated and reported, and the majority of the findings were non-significant.

The final and important aspect that brings some limitations to this thesis is that important parameters such as ventilation, hands-off time and non-technical skills were not included in the analysis. Despite these aspects being very important in paediatric CPR, the focus was infant chest compressions quality, achievement of competence and retention of skills. Not analysing ventilation or hands-off time does not change the conclusions of this thesis. The results are valid, original, and relevant. However, there is a potential opportunity for further research. Ventilation could be

incorporated in this novel model of retraining and further analysis combining chest compressions and rescue breaths should be explored.

The next Chapter of this thesis will present the conclusions and recommendations for future research.

Chapter 8 Conclusions, Future Research and Dissemination

8.1 Conclusions

This final Chapter will offer conclusions derived from this research and provide directions for further studies, based on the new state of knowledge resulted by this thesis. Additionally, the author will inform how the results and recommendations can be disseminated so that stakeholders, policy makers and consequently patients can benefit from this research.

This thesis has added substantial new knowledge to the field of resuscitation training/retraining. It contributed to the understanding of the importance of achieving iCPR skill competence after initial training, so that the acquired skills can be maintained for longer. The research demonstrated that learners vary in their ability and time taken to acquire the skills and achieve competence. This is based on their individual needs and prior learning. Despite that, once competence was achieved, learners retained the skills for longer, which is a considerable improvement on the current state of CPR skill retention research. The data presented in this thesis demonstrate the importance of designing retraining strategies with exposure to iCPR skills tailored to individual needs. It was observed that some individuals need more input and time to achieve competence than others. Yet, retention of the acquired skills was not impacted, as almost every participant retained the skills for the duration of the study. This suggests that, when the rescuer is required to perform iCPR months after achieving competence, high-quality performance can then be delivered, potentially improving the patient's chances of survival.

Other key elements were generated by this thesis and contributed to the achievement of the overall aim of this research. An important aspect is the indication that automated real-time feedback devices are effective tools for improving CPR skill acquisition, retention, and quality of performance during training and simulated practice and should therefore, be utilised more frequently in training and simulation. However, although it may be assumed that these devices would lead to improvement in patient outcomes when used during a real cardiac arrest, this has still to be established.

Consistency of iCPR performance was also a key aspect to inform the development of this thesis. Understanding variability in iCPR performance was essential to establish natural variations and real changes in performance. The results demonstrate that iCPR skills are consistent and reliable, which supports the conclusion that changes in performance observed after training, are not due to natural variations in human performance, but real changes i.e. improvement or decay of skills. This is an essential information to enable researchers and rescuers to interpret changes and establish the quality and effectiveness of individual performance. However, when skill metrics are converted into quality indices, which is a common practice in CPR research (e.g. good quality or bad quality CPR), the results demonstrated that variability increases and reliability of iCPR skills reduce, indicating that the hard 'cut off' at the quality boundaries should be reviewed.

Another key novel contribution from this research is the conclusion that quality of iCPR performance is not significantly different between the dominant and non-dominant hand when the TF technique is used. However, it was found that

perception of fatigue was higher for the non-dominant hand, indicating that the effort to maintain similar quality is greater for the non-dominant hand. This suggests that, although rescuers may feel more fatigued when delivering iCPR with their non-dominant hand, they can be confident that the quality of their infant resuscitation skills is similar, regardless of the hand used.

The combination of the results from the studies developed for this thesis provides evidence to support the effectiveness of this line of research. The studies forming the bulk of this thesis have been peer-reviewed and published, enabling dissemination of the new knowledge to stakeholders, policy makers, academics, clinicians, rescuers, and the wider society (van Teijlingen *et al.* 2022). The implementation of this novel tailored, competence-based strategy for retraining of iCPR skills could improve the quality of iCPR performance, maximise retention of skills, and potentially save more lives of infants who have cardiac arrests.

Although recommendations for further research will be discussed in Section 8.2 below, despite the important contribution to knowledge generated by this thesis, future projects are aligned so that the results can benefit clinical practice and patient care. The next stage is to use the evidence from this research and work in partnership with a simulation manufacturer to enhance one of their simulation models. As explained in Chapter 3, Section 3.11, not many devices are commercially available for quantification of iCPR performance. Additionally, these devices vary in their ability to analyse and quantify the metrics associated with high-quality iCPR (CCR, CCD, RL, and DC). The great majority provides feedback on CCR, CCD and RL without considering DC, as seen in Gugelmin-Almeida *et al.* (2021a). However, it has been explored in this

thesis (Chapter 2, Section 2.3.6.4) that high-quality iCPR is dependent on effective DC to optimising venous return to the heart, myocardial perfusion, cardiac output, and cerebral blood flow (Fitzgerald *et al.* 1981, Dean *et al.* 1991, Sunde *et al.* 1998a, Babs 2006, Kim *et al.* 2020). For this reason, the partnership between the simulation company and the author/research team, will ensure the knowledge from this thesis can be applied to the enhancement of their infant manikin in terms of biofidelity, quantification of iCPR performance and implementation of a real-time feedback with the above-mentioned characteristics.

Another step for this research is to design a large RCT comparing the new model of iCPR training with the current training strategy. This will generate evidence to support a roll-out study into clinical areas with healthcare practitioners. After that, a future implementation of this novel, tailored, competence-based retraining strategy into the NHS and other worldwide healthcare systems can potentially be achieved.

8.2 Recommendations for Future Research

To better understand the implications of the results of this thesis, in both practical and theoretical terms, future studies could address the many questions that remain unanswered and would benefit from further investigation.

An important aspect is the transferability of results to patient-level outcomes. The results from this research are applicable to simulated performance, therefore they cannot be directly associated with patient-level outcomes. Future research to associate educational strategies and patient outcomes such as return of spontaneous circulation, survival to hospital discharge and/or neurological outcome would be an important addition to current evidence.

Another gap in knowledge that was not investigated in the studies conducted for this research but is a crucial aspect of paediatric resuscitation is rescue breaths or ventilations. The studies in this thesis focused on chest compressions during iCPR. Despite the relevance in paediatric resuscitation, rescue breaths were not included in the data analysis. Therefore, it is suggested that further studies should explore the influence of rescue breaths on iCPR performance.

Regarding hand dominance during infant resuscitation, this study provided important new information about the impact of hand dominance and hand fatigue in the delivery of iCPR. A three-minute interval of infant chest compression was selected, which may not represent real resuscitation attempts where a single rescuer performs iCPR for longer periods of time. Therefore, it is suggested that further studies explore levels of fatigue during extended iCPR using the TF technique, as fatigue may increase and potentially impact quality of performance.

Further research is also needed on the use of RTF devices. Although the use of these devices has been associated with enhanced performance during CPR training (as demonstrated in Chapter 2), there are conflicting interpretations regarding its efficacy during real-life resuscitation attempts. Therefore, whilst it may be intuitive to presume that RTF devices can improve patient outcome, this is yet to be established.

Another component of the new knowledge acquired from this research suggests that for a maximal additional cost of 28 minutes, trained individuals may be able to not only achieve competence in iCPR but also retain this competence for longer. It may be argued that this can potentially reduce training costs overall and enhance iCPR

performance. However, this was not investigated in this research, thus future studies may analyse the costs associated with the proposed retraining model. An important additional aspect related to the initial training is that only 32 participants achieved competence after the instructor-led training adopted in this research. The other 86 participants used real-time feedback and repeated testing for reinforcement of skills to eventually achieve competence. It could be suggested thus that the initial training is not effective in enabling rescuers to achieve competence. Therefore, the initial training could be replaced by other method of training as discussed in Chapter 2, Section 2.4, in addition to real-time feedback and repeated testing based on individual performance. This strategy could potentially enhance the initial learning acquisition. Training in the medical field can be expensive, therefore finding effective and efficient training methods that can result in cost savings is a legitimate and important motive for many researchers.

A large sample size of healthcare students from a single institution was selected to take part in this study. The tailored, competence-based strategy adopted in the current study should be investigated in a multi-centre study involving healthcare practitioners, to check whether the new model to iCPR skills retraining could also result in better skill retention.

8.3 Dissemination

The new knowledge resulted from this thesis has already been disseminated through the publication of five manuscripts. This enables the readers to gain access to new evidence so that changes in clinical practice can be implemented. Additionally,

participants who requested a summary of the results for each study, will be provided with the link of the published manuscript and a summary of the results when the manuscript is not available as open access. Furthermore, all channels for dissemination of research have been used, including social media platforms, personal contacts, scholarly collaboration networks and BURO (Bournemouth University Research Online), the University's institutional repository.

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APPENDICES

Appendix 1 - Participant Information Sheet – Reliability study

Participant Information Sheet

Project: Exploring infant cardiopulmonary resuscitation (CPR) skills delivered by healthcare students

Invitation

You are being invited to take part in a research project about infant Cardiopulmonary Resuscitation (CPR). It is important for you to understand why the research is being done and what it will involve, before you decide to participate or not. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

This research project is being carried out by Bournemouth University (BU) academics including Debora Almeida, lecturer in the Operating Department Practice (ODP) programme, Dr Jonathan Williams, Head of Education and Principal Lecturer in the Physiotherapy programme and Dr Carol Clark, Associate Professor and Head of Department – Human Science and Public Health. In addition, Dr Mike Jones from Cardiff University will be involved in the project.

Who is organising/funding the research?

The research is being organised by Bournemouth University.

What is the purpose of the project?

The purpose of this project is to measure the elements of chest compressions during simulated CPR on an infant manikin. These elements are internationally recognized to be fundamental to achieve a high-quality CPR and improve survival outcomes. They are: chest compression rate, chest compression depth, chest release force and ratio between chest compression and chest release. By measuring the elements of chest compression individually, we can have an overall view of the quality of CPR skills delivered by healthcare students. Added to that, we want to analyse the consistency of the CPR performance after a set timeframe. In other words, if the students are able to repeat the same skills in different occasions.

Why have I been chosen?

We are seeking healthcare students at Bournemouth University who are able to perform simulated CPR during a short length of time on an infant manikin located at Bournemouth University on 4 different occasions.

Do I have to take part?

It is up to you to decide whether or not to take part. Participation is always voluntary and if you do decide to be part of this research, you will be given this information sheet to keep and will be asked to sign a Participation Agreement Form and a Non-Disclosure Agreement. You can stop taking part in an activity at any point and you can withdraw at any time up to the point when the data are processed because after that, data become anonymous, and your identity cannot be determined.

You do not have to give a reason if you wish not to take part and deciding to take part or not, will not impact upon or adversely affect your education or studies at Bournemouth University.

What would taking part involve?

Participants will be Bournemouth University healthcare students for this project. They will be asked to complete a short questionnaire, including age, height, weight

and physical issues that could affect performing CPR. After been trained by an instructor for about 45 minutes, the participants will have the chance to practice the skills on an infant manikin before being asked to carry out simulated CPR on an infant manikin for 2 minutes, where data relevant to the elements of CPR will be collected (please see description under "What is the purpose of this project?"). This same exercise will be repeated on the same day after 15/30 minutes. The participants will then be asked to return in one week and two weeks (for about 10 minutes each session) to repeat the two minutes simulated CPR.

What are the advantages and possible disadvantages or risks of taking part?

The advantage for participants is that it will provide them with an opportunity to further develop their CPR skills by training and practicing on an infant manikin. Furthermore, they will receive a report/feedback of their performance (individual data collected from the manikin and written feedback from the instructor) on completion of the last day to inform their practice.

The predicted advantages for society are the understanding of the rescuer's ability to perform the same task repeatedly, aiming to investigate the way those skills are delivered by healthcare students. This research project will assist with early data analysis that will be used to inform a future project on CPR performance.

We will seek to minimise any risks to participants by providing expert advice on how to perform the skills.

How will my information be kept?

All personal data relating to this study will be held for 5 years from the date of publication of the research. You will not be able to be identified from the data in any reports or publications. BU will hold the information collected about you in hard copy in a secure location and on a BU password protected computer or a secure network where held electronically.

Except where it has been anonymised, we will restrict access to your personal data to those individuals who have a legitimate reason to access it for the purpose or purposes for which it is held by BU. As well as BU staff working on the research project, a senior lecturer from Cardiff University, who is an external collaborator, will also have access to your personal, anonymised data.

The information collected about you may be used in an anonymous form to support other research projects in the future and access to it in this form will not be restricted. It will not be possible for you to be identified from this data. Anonymised data will be added to BU's Data Repository (a central location where data is stored) and which will be publicly available.

If you have any questions about how we manage your information or your rights under the data protection legislation, please contact the BU Data Protection Officer on dpo@bournemouth.ac.uk.

What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The information in the questionnaire will be: age, height, weight, and physical issues that could compromise performance such as knee or back pain. We need this information to analyse the links between variations in performance. Sensor data will be collected in 4 different occasions to quantify the elements of CPR skills performed during 2 minutes. This information will be used to explore the consistency and variations in performance.

For further information about the BU Research Participant Privacy Notice please refer to (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy)

Contact for further information

If you have any questions or would like further information, please contact Debora

Almeida almeidad@bournemouth.ac.uk ; Dr Jonathan Williams jwilliams@bournemouth.ac.uk or Dr Carol Clark cclark@bournemouth.ac.uk

Complaints

If you have any complaints about this research please contact Professor Vanora Hundley, Deputy Dean Research and Professional Practice by email to researchgovernance@bournemouth.ac.uk

Finally…

If you decide to take part, you will be given a copy of this information sheet and a signed participant agreement form to keep.

Thank you for considering taking part in this research project!!

Appendix 2 - Participant Consent Form – Reliability study

Bournemouth University

Participant Consent form

Exploring infant cardiopulmonary resuscitation (CPR) skills delivered by healthcare students

Researchers: Debora Almeida almeidad@bournemouth.ac.uk , Dr Jonathan Williams jwilliams@bournemouth.ac.uk , Dr Carol Clark cclark@bournemouth.ac.uk

In this form, we ask you to confirm whether you agree to take part in the project. We also ask you to agree to some specific uses of your identifiable information, which we will only do with your consent.

You should only agree to take part in the project if you understand what this will mean for you. If you complete the rest of this Form, you will be confirming to us that:

- You have read and understood the Project Participant Information Sheet and have been given access the BU Research Participant Privacy Notice which sets out how we collect and use personal information (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy)
- You have had the opportunity to ask questions;
- You understand that:

- Taking part in the research will include performing CPR on an infant manikin in 4 different occasions.
- Your participation is voluntary. You can stop participating in research activities at any time without giving a reason, and you are free to decline to answer any particular question(s).
- If you withdraw from participating in the Project, you may not always be able to withdraw all of your data from further use within the Project, particularly once we have anonymised your data and we can no longer identify you.
- Data you provide may be included in an anonymised form within a dataset to be archived at BU's Online Research Data Repository.
- Data you provide may be used in an anonymised form by the research team to support other research projects in the future, including future publications, reports or presentations.

Consent to take part in the Project	***Yes***	***No***
I agree to take part in the Project on the basis set out above	☐	☐

Name of Participant _____

Date ____/____/____ Signature_____

Name of Researcher _____

Date____/____/____ Signature_____

Appendix 3 - Recruitment Poster - Reliability study

Can you perform infant CPR?

- Would you like to take part in a research project that aims to analyse infant CPR skills performance?
- You will be asked to perform simulated CPR on an infant manikin for 2 minutes on 3 different occasions.
- This will provide you with an opportunity to further develop you CPR skills and receive a report of your performance.
- Interested? Contact Debora Almeida almeidad@bournemouth.ac.uk
- If you are an ODP student please contact Lesley Elcock lelcok@bournemouth.ac.uk

almeidad@bournemouth.ac.uk

Appendix 4 - Participant Questionnaire - Reliability study

Bournemouth University

Participant Questionnaire

Exploring infant cardiopulmonary resuscitation (CPR) skills delivered by healthcare students

Thank you for taking part in this research project which aims to measure the elements of CPR skills (chest compression rate, chest compression depth, chest release force and ratio between chest compression and chest release) delivered by healthcare students and the consistency of the CPR performance after a set timeframe.

Please answer the following questions that will be used to complement the data collected during your CPR performance.

1.) What is your age?

2.) What is your height?

3.) What is your weight?

4.) Do you have any physical issue/condition that restricts you from kneeling on the floor?

□ yes □ no

5.) Do you have any physical issue/condition that restricts you from performing simulated CPR?

□ yes □ no

6.) Have you had any wrist, shoulder, knee or spinal injury requiring medical intervention in the last 12 months?

□ yes □ no

7.) Are you physically able to perform simulated CPR on a manikin for 2 minutes?

□ yes □ no

Appendix 5 - Risk assessment - Reliability study

Bournemouth University

Risk Assessment Form

About You & Your Assessment	
Name	Debora Almeida
Email	almeidad@bournemouth.ac.uk
Your Faculty/Professional Service	Faculty of Health & Social Sciences
Is Your Risk Assessment in relation to Travel or Fieldwork?	No
Status	Approved
Date of Assessment	05/11/2018
Date of the Activity/Event/Travel that you are Assessing	14/01/2019

What, Who & Where	
Describe the activity/area/process to be assessed	Reliability of iCPR
Locations for which the assessment is applicable	seminar room
Persons who may be harmed	Staff, Student, Visitors

Hazard & Risk	
Hazard	Cross contamination of bodily fluids via manikin / Skin irritation from disinfecting agent (wipes)
Severity of the hazard	Medium
How Likely the hazard could cause harm	Medium
Risk Rating	Medium
Control Measure(s) for Cross contamination of bodily fluids via manikin / Skin irritation from disinfecting agent (wipes): Manufacturers recommended cleaning wipes used on manikin after each use – instruction given to students on use of wipes each session. Following cleansing all users must ensure manikin is dry before re-use (eliminate skin irritation).	
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low	
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low	
The residual risk rating is calculated as: Low	
Hazard	Postural hazards during practice of CPR
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low
Control Measure(s) for Postural hazards during practice of CPR: ensure participant is given the option to practice CPR with the manikin on the floor or on a table (wherever is more comfortable) ensure participants receive instructions about a safe posture during CPR ensure the participants are aware of their limitations and stop doing the activity if they feel any pain or discomfort.	

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	sore/bruised knees
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for sore/bruised knees:

ensure the participant receives verbal instruction about how to place knees for a more comfortable position

ensure the person uses a mat (such as yoga mat) when kneeling on the floor to practice CPR

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	Slips/trips
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Slips/trips:

any trip hazards that cannot be removed are clearly marked with hazard tape

ensure cables are covered and hidden; Manikin to be stored away when not in use/ Students and staff to be alerted and aware of tripping hazard when using equipment ensure manikin is well visible at all times
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low
The residual risk rating is calculated as: Low

Review & Approval

Any notes or further information you wish to add about the assessment	
Names of persons who have contributed	Debora Almeida
Approver Name	John Tarrant
Approver Job Title	Senior Lecturer
Approver Email	tarrantj@bournemouth.ac.uk
Review Date	

Uploaded documents

No document uploaded

Appendix 6 - Ethics Protocol – Reliability Study

Research Ethics Checklist

About Your Checklist	
Ethics ID	22558
Date Created	10/10/2018 14:15:47
Status	Approved
Date Approved	15/11/2018 10:49:28
Date Submitted	12/11/2018 16:54:14
Risk	High

Researcher Details	
Name	Debora Almeida
Faculty	Faculty of Health & Social Sciences
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, EngD, EdD)
Course	Postgraduate Research - HSS
Have you received funding to support this research project?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	Dr Jonathan Williams, Dr Carol Clark, Dr Mike Jones (external)

Project Details	
Title	Exploring Infant Cardiopulmonary Resuscitation (CPR) Skills delivered by Healthcare Students
Start Date of Project	24/09/2018
End Date of Project	03/09/2019
Proposed Start Date of Data Collection	14/01/2019
Original Supervisor	Jonathan Williams
Approver	Research Ethics Panel

Summary - no more than 600 words (including detail on background methodology, sample, outcomes, etc.)

Cardiac arrest is a sudden cessation in heart function, triggered by an electrical dysfunction of the heart and consequent disruption of cardiac rhythm (arrhythmia), leading to interrupted blood flow to the brain and other vital organs. It is a common condition associated with significant morbidity, mortality and extensive healthcare costs (Wilkins *et al.* 2017). In the UK alone, there are over 30,000 out-of-hospital cardiac arrests, including infants (until 1 year old), each year and it has been reported that less than one in ten victims survive (Perkins and Brace-McDonnell 2015). In addition, data from the UK National Cardiac Arrest Audit (NCAA) indicates that in-hospital cardiac arrest occurs in 1.6 per 1000 hospital admissions with rate of survival to hospital discharge of 18.4% (Nolan *et al.* 2014).

Positive outcomes from cardiac arrest depend on the effective delivery of resuscitation techniques, including cardiopulmonary resuscitation (CPR), but despite the importance of those skills, delivery of CPR is often challenging and the quality in trained rescuers is variable (Martin *et al.* 2013a, Wallace *et al.* 2013, Stiell *et al.* 2014). There is a growing body of literature stating that CPR is often performed incorrectly, inconsistently and is suboptimal quality when compared to established guidelines (Pozner 2018).

Based on available literature and seeking to close the gap between knowledge and practice, the main research project intends to investigate current approaches to learning and delivering CPR and to explore enhancement of learning and retention of CPR using real
time feedback. However, prior to this, establishing variability in human performance is critical to be able to interpret change in performance. Therefore, the aim of this preliminary study will be to determine the repeated measures reliability and variability of individuals repeatedly performing simulated infant CPR within the same day and between days.

This study will adopt an experimental, observational design and be conducted within a university setting. Data relating to age, height, weight and self-declared physical issues which could compromise performance will be gathered in order to create a demographic profile of the sample.

Informed written consent will be gained following written explanation of experimental procedures.
Participants will be at BU for this project. They will complete the short questionnaire, sign the consent form and, after been trained by a qualified instructor for 1 hour (using national guidelines), the participants will have the chance to practice the skills on an infant manikin before being asked to carry out simulated CPR on the manikin for 2 minutes, where data relevant to the elements of CPR will be collected. This same exercise will be repeated on the same day after 15/30 minutes. The participants will then be asked to return in 1 week and 2 weeks (for about 10 minutes each session) to repeat the 2 minutes simulated CPR.
Chest compressions (CC) will be measured using infant CPR manikin fitted with 2 accelerometers (small sensors which measure acceleration). Data provided from these devices is converted into four metrics: CC depth, CC rate, leaning, duty cycle.
Outcomes: findings will disseminated as a journal article (target - journal 'Resuscitation'); results will be sent to the Resuscitation Council UK; presentation at an international conference (e.g. European Resuscitation Council Congress); internal PGR seminars and conferences and there is the potential to include an event at the festival of learning.

Filter Question: Does your study involve Human Participants?

Participants	
Describe the number of participants and specify any inclusion/exclusion criteria to be used	
Sample size calculation was based on the procedure outlined in Zou (2012) and the estimated sample size is 25.The inclusion/exclusion criteria will be determined as questions collected alongside the demographic data:1.Exclusion criteria: shoulder, wrist, knee or spinal injury requiring medical intervention in the last 12 months2.Inclusion criteria: healthcare students who are physically able to kneel and perform chest compression for 2 minutes.	
Do your participants include minors (under 16)?	
Are your participants considered adults who are competent to give consent but considered vulnerable?	Yes
If Yes, provide details (e.g. recipient of health or care services etc., cognitive impairment, prison inmates, BU students - see related help guide)	
If ODP students are recruited, they will be reassured by the gatekeeper that they do not need to feel coerced to take part and their decision will not impact upon or adversely affect their education or studies at Bournemouth University. After recruitment, the students will also be reassured by the researchers that the relationship will be participants/researcher and NOT student/lecturer.	
Is a Disclosure and Barring Service (DBS) check required for the research activity?	No

Recruitment	
Please provide details on intended recruitment methods, include copies of any advertisements.	
Participants will be recruited from the BU healthcare student population via a poster displayed around the university (primary recruitment tool) and on Brightspace. Participants will be provided with an information sheet at least 24hrs prior to asking for signed written consent. Due to the potential recruitment of ODP students, a gatekeeper will be used (one of the researchers is an ODP lecturer). However the study is open to all BU healthcare students.	
Do you need a Gatekeeper to access your participants?	Yes
Please provide details, including their roles and any relationship between Gatekeepers and participant(s) (e.g. nursing home manager and residents)	
Lesley Elcock - programme lead for Operating Department Practice - recruitment only. This is only needed to give potential ODP students a separate and independent point of contact to the study PI. Recruitment is open to all other university students and due to no prior relationship, no additional gatekeepers are necessary.	

Data Collection Activity	
Will the research involve questionnaire/online survey? If yes, don't forget to attach a copy of the questionnaire/survey or sample of questions.	Yes
How do you intend to distribute the questionnaire?	
face to face	
Will the research involve interviews? If Yes, don't forget to attach a copy of the interview questions or sample of questions	
Will the research involve a focus group? If yes, don't forget to attach a copy of the focus group questions or sample of questions.	No
Will the research involve the collection of audio materials?	No
Will your research involve the collection of photographic materials?	No
Will your research involve the collection of video materials/film?	No
Will the study involve discussions of sensitive topics (e.g. sexual activity, drug use, criminal activity)?	No
Will any drugs, placebos or other substances (e.g. food substances, vitamins) be administered to the participants?	No
Will the study involve invasive, intrusive or potential harmful procedures of any kind?	No

Could your research induce psychological stress or anxiety, cause harm or have negative consequences for the participants or researchers (beyond the risks encountered in normal life)?	No
Will your research involve prolonged or repetitive testing?	No

Consent	
Describe the process that you will be using to obtain valid consent for participation in the research activities. If consent is not to be obtained explain why.	
Prior to any data collection, participants will be provided with written information about the study and an agreement/consent form. There will be an opportunity to discuss the study with the principal investigator. The voluntary nature of the participation will be emphasised. All consent forms will be signed by the participant and the researcher together prior to entering the data collection room.. All participants will be offered a copy of the signed consent form for their keeping.	
Do your participants include adults who lack/may lack capacity to give consent (at any point in the study)?	
Will it be necessary for participants to take part in your study without their knowledge and consent?	No

Participant Withdrawal
At what point and how will it be possible for participants to exercise their rights to withdraw from the study?
Participants will receive an Information Sheet and Agreement Form (with link to "research participant privacy notice"), explaining that participation is voluntary, that they can stop taking part in an activity at any point and that they can withdraw without having to give a reason, at any time up to the point when the data are processed because after that, data become anonymous, and their identity cannot be determined.
If a participant withdraws from the study, what will be done with their data?
We will follow BU research participant privacy notice and withdraw the data from the research project, depending on the stage of the project.

Participant Compensation	
Will participants receive financial compensation (or course credits) for their participation?	No
Will financial or other inducements (other than reasonable expenses) be offered to participants?	Yes
Please provide details	
The participants will receive a report/feedback of their performance (individual data collected from the manikin and written feedback from the instructor) on completion of the last day to inform their practice.	

Research Data	
Will identifiable personal information be collected, i.e., at an individualised level in a form that identifies or could enable identification of the participant?	Yes
Please give details of the types of information to be collected, e.g. personal characteristics, education, work role, opinions or experiences	
Will the personal data collected include any special category data, or any information about actual or alleged criminal activity or criminal convictions which are not already in the public domain?	No
Will the information be anonymised/de-identified at any stage during the study?	Yes
Will research outputs include any identifiable personal information i.e., data at an individualised level in a form which identifies or could enable identification of the individual?	
Please give brief details of how you will address the need for data minimisation or explain why you do not think this relates to the personal information you will be collecting.	
We minimised the scope of data to be collected by including only what is necessary as a mechanism to describe our participants. Data may be identifiable at point of collection only (limited access just to the PI) and will be anonymised by removing direct identifiers and aggregating variable (such as age) before being analysed and shared with other researchers in the study. From this point, data will not be identifiable and the identifiable format will be manged according to BU policy.	

Storage, Access and Disposal of Research Data	
During the study, what data relating to the participants will be stored and where?	Age, height and weight will be collected via a questionnaire and anonymised after collection. Raw data (questionnaires) will be stored in a BU locked filling cabinet.
How long will the data relating to participants be stored?	Raw data (questionnaires) will be stored until the point of anonymisation and the anonymised information is transferred to a BU password protected computer.Anonymised data will be stored for 5 years after the publication of the study
During the study, who will have access to the data relating to participants?	Researcher and supervisors will have access to anonymised data only
After the study has finished, what data relating to participants will be stored and where? Please indicate whether data will be retained in identifiable form.	No personal data will be stored after the study has finished

After the study has finished, how long will data relating to participants be stored?	No personal data will be stored after the study has finished
After the study has finished, who will have access to the data relating to participants?	No personal data will be stored after the study has finished
Will any identifiable participant data be transferred outside of the European Economic Area (EEA)?	No
How and when will the data relating to participants be deleted/destroyed?	At point of collection, a hard copy document (questionnaire) will contain personal data. This will be anonymised when transferred to a password protected computer. The hard copy documents (questionnaires) will be kept in a BU locked filling cabinet until anonymisation is performed. After that, the documents will be placed in confidential waste bags so that they can be securely shredded before being disposed of appropriately, according to BU policy.
Once your project completes, will any anonymised research data be stored on BU's Online Research Data Repository "BORDaR"?	Yes

Dissemination Plans	
Will you inform participants of the results?	

Final Review	
Are there any other ethical considerations relating to your project which have not been covered above?	

Risk Assessment	
Have you undertaken an appropriate Risk Assessment?	Yes

Attached documents
PhD - Ethics -repeatability study -participant agreement form.docx - attached on 08/11/2018 11:03:58

PhD - ethics -participant information sheet - final.docx - attached on 08/11/2018 11:15:05
PhD poster last version.pptx - attached on 12/11/2018 16:27:19
PhD ethics - questionnaire - final (1).docx - attached on 12/11/2018 16:29:44

Appendix 7 - Participant Information Sheet – Dominant Hand Study

Bournemouth University

Participant Information Sheet

Project: Difference between dominant and non-dominant hand during infant CPR using the two-finger technique (TFT)

Invitation

You are being invited to take part in a research project about infant Cardiopulmonary Resuscitation (iCPR). It is important for you to understand why the research is being done and what it will involve, before you decide to participate or not. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

This research project is being carried out by Bournemouth University (BU) academics including Debora Almeida, lecturer in the Operating Department Practice (ODP) programme and PhD Candidate, Dr Jonathan Williams, Head of Education and Principal Lecturer in the Physiotherapy programme and Dr Carol Clark, Associate Professor and Head of Department – Human Science and Public Health.

Who is organising/funding the research?

The research is being organised by Bournemouth University.

What is the purpose of the project?

The purpose of this project is to investigate if there is a significant difference between the dominant and non-dominant hand during simulated infant CPR (iCPR). Positive outcomes from infant cardiac arrest depend on the effective delivery of resuscitation techniques, including good quality iCPR, which is crucial in generating circulation to vital organs and providing adequate cerebral and coronary perfusion. The latest guideline for iCPR recommends the use of two finger technique (TFT) for a lone rescuer when performing CPR on an infant in cardiac arrest. However, there is no specification on which hand to use (dominant or non-dominant or either) and

because there is a belief that the quality of TFT might be influenced by factors such as finger strength or hand strength and fatigue, we believe that there is a need to investigate if the quality of iCPR would be influenced by the use of dominant or non-dominant hand, as the mechanisms of chest compression force generation may differ between them.

Why have I been chosen?

We are seeking students at Bournemouth University who are able to perform simulated iCPR using their dominant hand and non-dominant hand during a short length of time (3 minutes each hand) on an infant manikin located at Bournemouth University.

Do I have to take part?

It is up to you to decide whether or not to take part. Participation is always voluntary and if you do decide to be part of this research, you will be given this information sheet to keep and will be asked to sign a Participation Agreement Form. We want you to understand what participation involves, before you make a decision on whether to participate.

If you or any family member have an on-going relationship with BU or the research team, e.g. as a member of staff, as student or other service user, your decision on whether to take part (or continue to take part) will not affect this relationship in any way.

Can I change my mind?

Yes, you can stop participating in study activities at any time and without giving a reason.

If I change my mind, what happens to my information?

After you decide to withdraw from the study, we will not collect any further information from or about you.

With regards to information we have already collected before this point, your rights to access, change or move that information are limited. This is because we need to manage your information in specific ways in order for the research to be reliable and accurate. Further explanation about this is in the *Personal Information* section below.

What would taking part involve?

Participants will be Bournemouth University students for this project. You will be asked to complete a short questionnaire, including sex, age, height, weight, dominant hand and physical issues that could affect performing iCPR. After practicing CPR skills on an infant manikin, you will be asked to perform simulated iCPR for 3 minutes using your dominant hand, followed by further 3 minutes using your non-dominant hand, where data relevant to the elements of iCPR (chest compression depth, chest compression rate, release force and pauses) will be collected via a computer attached to the manikin. This will enable us to investigate the difference between dominant and non-dominant hand on the elements of iCPR

What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The information in the questionnaire will be: sex, age, height, weight, dominant hand and physical issues that could compromise performance such as shoulder, arms, hands or back pain. We need this information to analyse the links between variations in performance. Sensor data will be collected on 2 different occasions to quantify the elements of iCPR skills performed during 3 minutes. This information will be used to explore if there is a significant difference between the dominant and non-dominant hand during simulated iCPR using TFT.

What are the advantages and possible disadvantages or risks of taking part?

The advantage for you is that this exercise will provide you with an opportunity to further develop your CPR skills by training and practicing on an infant manikin and receiving feedback.

The predicted advantages for society are the understanding of the rescuer's ability to perform the same task with both hands, aiming to investigate the way those skills are affected by fatigue. This research project will assist with early data analysis that will be used to inform a future project on iCPR performance.

We will seek to minimise any risks to participants by providing expert advice on how to perform the skills.

How will my information be managed?

Bournemouth University (BU) is the organisation with overall responsibility for this study and the Data Controller of your personal information, which means that we are responsible for looking after your information and using it appropriately. Research is a task that we perform in the public interest, as part of our core function as a university.

Undertaking this research study involves collecting and/or generating information about you. We manage research data strictly in accordance with:

- Ethical requirements; and
- Current data protection laws. These control use of information about identifiable individuals, but do not apply to anonymous research data: "anonymous" means that we have either removed or not collected any pieces of data or links to other data which identify a specific person as the subject or source of a research result.

BU's Research Participant Privacy Notice sets out more information about how we fulfil our responsibilities as a data controller and about your rights as an individual under the data protection legislation. We ask you to read this Notice so that you can fully understand the basis on which we will process your personal information.

Research data will be used only for the purposes of the study or related uses identified in the Privacy Notice or this Information Sheet. To safeguard your rights in relation to your personal information, we will use the minimum personally-identifiable information possible and control access to that data as described below.

You will not be able to be identified from the data in any reports or publications without your specific consent. Otherwise your information will only be included in these materials in an anonymous form i.e., you will not be identifiable.

Research results will be published as scientific articles and conference papers aimed at relevant Journals such as "Resuscitation", "Archives of Disease in Childhood", "Emergency Medicine Journal" and relevant conferences or congresses such as "Resuscitation Council UK Conference" or "European Resuscitation Council Congress".

Security and access controls

BU will hold the information we collect about you in hard copy in a secure location and on a BU password protected secure network where held electronically.

Personal information which has not been anonymised will be accessed and used only by appropriate, authorised individuals and when this is necessary for the purposes of the research or another purpose identified in the Privacy Notice. This may include giving access to BU staff or others responsible for monitoring and/or audit of the study, who need to ensure that the research is complying with applicable regulations

Further use of your information

The information collected about you may be used in an anonymous form to support other research projects in the future and access to it in this form will not be

restricted. It will not be possible for you to be identified from this data. To enable this use, anonymised data will be added to BU's Data Repository: this is a central location where data is stored, which is accessible to the public.

Keeping your information if you withdraw from the study

If you withdraw from active participation in the study, we will keep information which we have already collected from or about you, if this has on-going relevance or value to the study. This may include your personal identifiable information. As explained above, your legal rights to access, change, delete or move this information are limited as we need to manage your information in specific ways in order for the research to be reliable and accurate. However if you have concerns about how this will affect you personally, you can raise these with the research team when you withdraw from the study.

Retention of research data

Project governance documentation, including copies of signed participant agreements: we keep this documentation for a long period after completion of the research, so that we have records of how we conducted the research and who took part. The only personal information in this documentation will be your name and signature, and we will not be able to link this to any anonymised research results.

Research results

As described above, during the course of the study we will anonymise the information we have collected about you as an individual. This means that we will not hold your personal information in identifiable form after we have completed the research activities.

Contact for further information

If you have any questions or would like further information, please contact Debora Almeida almeidad@bournemouth.ac.uk ; Dr Jonathan Williams jwilliams@bournemouth.ac.uk or Dr Carol Clark cclark@bournemouth.ac.uk

Complaints

If you have any complaints about this research please contact Professor Vanora Hundley, Deputy Dean Research and Professional Practice by email to: researchgovernance@bournemouth.ac.uk

Finally…

If you decide to take part, you will be given a copy of this information sheet and a signed participant agreement form to keep.

Thank you for considering taking part in this research project!!

Appendix 8 - Participant Consent Form – Dominant Hand Study

Bournemouth University

Participant Consent Form

Difference between dominant and non-dominant hand during infant CPR using the two-finger technique (TFT).

Name, position and contact details of researcher: Debora Almeida, PhD Candidate email: almeidad@bournemouth.ac.uk

Name, position and contact details of supervisor: Dr Jonathan Williams, email: jwilliams@bournemouth.ac.uk and Dr Carol Clark, email cclark@bournemouth.ac.uk

To be completed prior to data collection activity

Section A: Agreement to participate in the study

You should only agree to participate in the study if you agree with all of the statements in this table and accept that participating will involve the listed activities.

I have read and understood the Participant Information Sheet (v1) and have been given access to the BU Research Participant Privacy Notice which sets out how we collect and use personal information (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy).
I have had an opportunity to ask questions.

I understand that my participation is voluntary. I can stop participating in research activities at any time without giving a reason and I am free to decline to answer any particular question(s).
I understand that taking part in the research will include the following activities as part of the research: • Performing CPR on an infant manikin for 3 minutes with your dominant hand plus 3 minutes with your non-dominant hand
I understand that, if I withdraw from the study, I will also be able to withdraw my data from further use in the study **except** where my data has been anonymised (as I cannot be identified) or it will be harmful to the project to have my data removed.
I understand that my data may be included in an anonymised form within a dataset to be archived at BU's Online Research Data Repository.
I understand that my data may be used in an anonymised form by the research team to support other research projects in the future, including future publications, reports or presentations.

	Initial box to agree
I consent to take part in the project on the basis set out above (Section A)	

Name of participant (BLOCK CAPITALS)	Date (dd/mm/yyyy)	Signature
Name of researcher (BLOCK CAPITALS)	Date (dd/mm/yyyy)	Signature

Appendix 9 - Participant Questionnaire – Dominant Hand Study

Bournemouth University

Participant Questionnaire

Difference between dominant and non-dominant hand during infant CPR using the two-finger technique (TFT)

Thank you for taking part in this research project which aims to investigate if there is a significant difference between the dominant and non-dominant hand during simulated infant CPR (iCPR).

Please answer the following questions that will be used to complement the data collected during your iCPR performance.

1.) What is your age? _____

2.) Are you:

□ female □ male □ prefer not to say

3.) What is your height? _____

4.) What is your weight? _____

5.) What is your dominant hand?

□ right □ left

6.) Do you have any physical issue/condition that restricts you from performing simulated CPR on an infant manikin?

□ yes □ no

7.) Have you had any finger, hand, wrist, arm, shoulder, or spinal injury requiring medical intervention in the last 12 months?

□ yes □ no

8.) Are you physically able to perform simulated CPR on a manikin for 3 minutes?

□ yes □ no

Appendix 10 - Risk Assessment – Dominant Hand Study

Bournemouth University

Risk Assessment Form

About You & Your Assessment	
Name	Debora Almeida
Email	almeidad@bournemouth.ac.uk
Your Faculty/Professional Service	Faculty of Health & Social Sciences
Is Your Risk Assessment in relation to Travel or Fieldwork?	No
Status	Approved
Date of Assessment	18/09/2019
Date of the Activity/Event/Travel that you are Assessing	16/10/2019

What, Who & Where	
Describe the activity/area/process to be assessed	Simulated cardiopulmonary resuscitation (CPR) on an infant manikin for 3 minutes with dominant hand and 3 minutes with non-dominant hand. The manikin will be placed on the floor and there will be a computer attached to the manikin
Locations for which the assessment is applicable	outdoor areas, seminar rooms
Persons who may be harmed	Staff, Student

Hazard & Risk	
Hazard	sore/bruised knees
Severity of the hazard	Low
How Likely the hazard could cause harm	Low

Risk Rating	Low
Control Measure(s) for sore/bruised knees: ensure the participant receives verbal instruction about how to place knees for a more comfortable position ensure the person uses a mat (such as yoga mat) when kneeling on the floor to practice CPR	
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low	
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low	
The residual risk rating is calculated as: Low	
Hazard	Slips/trips
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low
Control Measure(s) for Slips/trips: ensure manikin is securely placed in the middle of the stand and well visible ensure cables are covered and hidden; any trip hazards that cannot be removed are clearly marked with hazard tape	
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low	
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low	
The residual risk rating is calculated as: Low	
Hazard	Tripping over the manikin
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low
Control Measure(s) for Tripping over the manikin:	

Manikin to be stored away when not in use/ Students and staff to be alerted and aware of tripping hazard when using equipment

ensure manikin is well visible at all times

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	Postural hazards during practice of CPR
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Postural hazards during practice of CPR:

ensure participant is given the option to practice CPR with the manikin on the floor or on a table (wherever is more comfortable)

ensure participants receive instructions about a safe posture during CPR

ensure the participants are aware of their limitations and stop doing the activity if they feel any pain or discomfort

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Review & Approval

Any notes or further information you wish to add about the assessment	
Names of persons who have contributed	Debora Almeida
Approver Name	Auto Approved by Debora Almeida
Approver Job Title	[Not Applicable]

Approver Email	Auto Approved by almeidad@bournemouth.ac.uk
Review Date	

Uploaded documents
No document uploaded

Appendix 11 - Ethics Protocol – Dominant Hand Study

Bournemouth University

Research Ethics Checklist

About Your Checklist	
Ethics ID	27970
Date Created	17/09/2019 14:40:23
Status	Approved
Date Approved	03/10/2019 17:50:32
Date Submitted	02/10/2019 11:40:20
Risk	High

Researcher Details	
Name	Debora Almeida
Faculty	Faculty of Health & Social Sciences
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, EngD, EdD)
Course	Postgraduate Research - HSS
Have you received funding to support this research project?	No

Project Details	
Title	Difference between dominant and non-dominant hand during infant CPR using the two finger technique
Start Date of Project	12/09/2019
End Date of Project	17/03/2020

Proposed Start Date of Data Collection	16/10/2019
Original Supervisor	Jonathan Williams
Approver	Research Ethics Panel

Summary - no more than 600 words (including detail on background methodology, sample, outcomes, etc.)

Cardiac arrest is a significant worldwide health problem associated with considerable morbidity, mortality and extensive healthcare costs.

In the UK, there are over 30,000 out-of-hospital cardiac arrests (OHCA) yearly and, according to the UK National Cardiac Arrest Audit (NCAA), in-hospital cardiac arrests (IHCA) occur in 1.6 per 1000 hospital admissions. Paediatric cardiac arrest incidence has been estimated at around 6,000 cases per year in the UK where infants (one month to one-year-old), comprise the majority of these occurrences. The reported survival to discharge rates range between 2% and 18.4% for both OHCA and IHCA and paediatric victims have particularly poor outcomes, with undesirable high-rates of both mortality and morbidity, making cardiac arrest in the infant population, a substantial public health problem.

Positive outcomes from infant cardiac arrest depend on the effective delivery of resuscitation techniques, including good quality infant cardiopulmonary resuscitation (iCPR), which is crucial in generating circulation to vital organs and providing adequate cerebral and coronary perfusion. The latest guidelines for iCPR recommends the use of two fingers technique (TFT) for a lone rescuer when performing CPR on an infant in cardiac arrest (Maconochie *et al.* 2015). However, there is no specification on which hand to use (dominant or non-dominant or either) and because there is a belief that the quality of TFT might be influenced by factors such as finger strength or hand strength and fatigue, we believe that there is a need to investigate if the quality of iCPR would be influenced by the use of dominant or non-dominant hand, as the mechanisms of chest compression force generation may differ between them.

Based on available literature and seeking to close the gap between knowledge and practice, the aim of this experimental, observational study, is to investigate if there is a significant difference between the dominant and non-dominant hand during simulated iCPR using TFT.

Outcomes: findings will be disseminated as a journal article; results will be sent to the Resuscitation Council UK; presentation at an international conference (e.g. European Resuscitation Council Congress); internal PGR seminars and conferences and there is the potential to include an event at the festival of learning.

Filter Question: Does your study involve Human Participants?

Participants

Describe the number of participants and specify any inclusion/exclusion criteria to be used

Based on a theoretical difference of 15% and a standard deviation of 20%, with alpha of 0.05 and power set to 80% and sample size of 21 is needed. Exclusion criteria: shoulder, wrist, hand, knee or spinal injury requiring medical intervention in the last 12 months or if the participants are unable to perform CPR for any reason.	
Do your participants include minors (under 16)?	No
Are your participants considered adults who are competent to give consent but considered vulnerable?	No
Is a Disclosure and Barring Service (DBS) check required for the research activity?	No

Recruitment	
Please provide details on intended recruitment methods, include copies of any advertisements.	
Potential participants will be engaging in an event where they will be learning and practising adult and paediatric CPR. Participants of those activities will then be asked by the CPR instructor if they would like to take part on the research. If they show an interest, they will be directed to the principal investigator who will explain the study, give them a PIS and, if they decide to take part, the written consent will be signed.	
Do you need a Gatekeeper to access your participants?	Yes
Please provide details, including their roles and any relationship between Gatekeepers and participant(s) (e.g. nursing home manager and residents)	
Due to the potential recruitment of ODP students, the CPR instructor of the event will act as a Gatekeeper and recruit every potential participant.	

Data Collection Activity	
Will the research involve questionnaire/online survey? If yes, don't forget to attach a copy of the questionnaire/survey or sample of questions.	Yes
How do you intend to distribute the questionnaire?	
face to face	
Will the research involve interviews? If Yes, don't forget to attach a copy of the interview questions or sample of questions	
Will the research involve a focus group? If yes, don't forget to attach a copy of the focus group questions or sample of questions.	No
Will the research involve the collection of audio materials?	No
Will your research involve the collection of photographic materials?	No
Will your research involve the collection of video materials/film?	No

Will the study involve discussions of sensitive topics (e.g. sexual activity, drug use, criminal activity)?	No
Will any drugs, placebos or other substances (e.g. food substances, vitamins) be administered to the participants?	No
Will the study involve invasive, intrusive or potential harmful procedures of any kind?	No
Could your research induce psychological stress or anxiety, cause harm or have negative consequences for the participants or researchers (beyond the risks encountered in normal life)?	No
Will your research involve prolonged or repetitive testing?	No

Consent	
Describe the process that you will be using to obtain valid consent for participation in the research activities. If consent is not to be obtained explain why.	
Prior to data collection, participants will be provided with verbal and written information about the study and an agreement/consent form. There will be an opportunity to discuss the study with the principal investigator. The voluntary nature of the participation will be emphasised. All consent forms will be signed by the participant and the researcher together prior to data collection. All participants will be offered a copy of the signed consent form for their keeping.	
Do your participants include adults who lack/may lack capacity to give consent (at any point in the study)?	No
Will it be necessary for participants to take part in your study without their knowledge and consent?	No

Participant Withdrawal
At what point and how will it be possible for participants to exercise their rights to withdraw from the study?
Participants will receive a Participant Information Sheet and Agreement/consent form (with link to "research participant privacy notice"), explaining that participation is voluntary, that they can stop taking part in the activity at any point and that they can withdraw without having to give a reason, at any time up to the point when the data are processed because after that, data become anonymous, and their identity cannot be determined.
If a participant withdraws from the study, what will be done with their data?
We will follow BU research participant privacy notice and withdraw the data from the research project, depending on the stage of the project.

Participant Compensation	
Will participants receive financial compensation (or course credits) for their participation?	No

Will financial or other inducements (other than reasonable expenses) be offered to participants?	No

Research Data	
Will identifiable personal information be collected, i.e., at an individualised level in a form that identifies or could enable identification of the participant?	Yes
Please give details of the types of information to be collected, e.g. personal characteristics, education, work role, opinions or experiences	
personal characteristics such as age, sex, dominant hand, weight and height will be collected in order to create a demographic profile of	
the sample	
Will the personal data collected include any special category data, or any information about actual or alleged criminal activity or criminal convictions which are not already in the public domain?	No
Will the information be anonymised/de-identified at any stage during the study?	Yes
Will research outputs include any identifiable personal information i.e., data at an individualised level in a form which identifies or could enable identification of the individual?	No
Please give brief details of how you will address the need for data minimisation or explain why you do not think this relates to the personal information you will be collecting.	
We minimised the scope of data to be collected by including only what is necessary as a mechanism to describe our participants. Data may be identifiable at point of collection only (limited access just to the PI) and will be anonymised by removing direct identifiers and aggregating variable (such as age) before being analysed and shared with other researchers in the study. From this point, data will not be identifiable and the identifiable format will be manged according to BU policy.	

Storage, Access and Disposal of Research Data	
During the study, what data relating to the participants will be stored and where?	Personal data including sex, age, weight, height and dominant hand will be collected as paper copy in form of a questionnaire with a codename and then scanned and saved as “pdf” files. This electronic data will be kept in a BU password protected computer and securely backed-up. The original paper copies will be securely destroyed/shredded straight after the electronic copies are saved
How long will the data relating to participants be stored?	Data will be retained for 5 years after final completion of the research.
During the study, who will have access to the data relating to participants?	Data with the codename will be accessed only by the principal investigator.

	Anonymised data will be accessed by the other investigators involved in the study
After the study has finished, what data relating to participants will be stored and where? Please indicate whether data will be retained in identifiable form.	Electronic data (described above) will be stored in a BU password protected computer.
After the study has finished, how long will data relating to participants be stored?	Electronic data (described above) will be retained for 5 years after final completion of the research.
After the study has finished, who will have access to the data relating to participants?	The principal investigator will be the only person to have access to the data relating to the participants.
Will any identifiable participant data be transferred outside of the European Economic Area (EEA)?	No
How and when will the data relating to participants be deleted/destroyed?	Paper copies of personal data and paper copies of consent forms will be securely shredded after digitalisation (first 2 months of the study) and secure paper destruction service bin used; digitalised personal data, digitalised consent form and other general electronic data will be destroyed after 5 years of final completion of the research following IT services consultation and advice.
Once your project completes, will any anonymised research data be stored on BU's Online Research Data Repository "BORDaR"?	Yes

Dissemination Plans	
Will you inform participants of the results?	

Final Review	
Are there any other ethical considerations relating to your project which have not been covered above?	No

Risk Assessment	
Have you undertaken an appropriate Risk Assessment?	Yes

Attached documents
Dominant hand study -participant agreement form final.docx - attached on 23/09/2019 14:24:52
Dominant hand study - questionnaire - final.docx - attached on 23/09/2019 14:25:05
Dominant hand study -participant information sheet with changes.docx - attached on 01/10/2019 14:12:00

Appendix 12 - Participant Information Sheet – Retraining Study

Bournemouth University

Participant Information Sheet

Project: Establishing an effective infant CPR retraining schedule to minimise skill decay and maximise retention

Invitation

You are being invited to take part in a research project about infant Cardiopulmonary Resuscitation (iCPR). It is important for you to understand why the research is being done and what it will involve before you decide to participate or not. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

This research project is being carried out by Bournemouth University (BU) academics including Debora Almeida, lecturer in the Operating Department Practice (ODP) programme, Dr Jonathan Williams, Head of Education and Principal Lecturer in the Physiotherapy programme and Dr Carol Clark, Associate Professor and Head of Department – Human Science and Public Health. In addition, Dr Mike Jones from Cardiff University will be involved in the project.

Who is organising/funding the research?

The research is being organised by Bournemouth University.

What is the purpose of the project?

The purpose of this project is to measure quality of chest compressions during simulated iCPR and retention/decay of this skill for 12 months. The elements that form chest compression are chest compression rate (number of compressions per minute), chest compression depth (how far down the chest is displaced), complete chest recoil (allowing the chest to come back to its original position before each compression) and duty cycle (ratio between chest compression and chest relaxation) and they are internationally recognized to be fundamental to achieve a high-quality

iCPR and improve survival outcomes. By measuring the elements of chest compression individually, we can have an overall view of the quality of iCPR performance. Added to that, we want to analyse the retention of the iCPR performance after a set timeframe. In other words, how long it takes for the participants to forget iCPR skills.

Why have I been chosen?

We are seeking undergraduate students at Bournemouth University who are able to learn and perform simulated iCPR during a short length of time on an infant manikin located at Bournemouth University on different occasions (based on individual performance).

Do I have to take part?

It is up to you to decide whether or not to take part. Participation is always voluntary and if you do decide to be part of this research, you will be given this information sheet to keep and will be asked to sign a Participation Agreement Form. You can stop taking part in an activity at any point and you can withdraw at any time up to the point when the data are processed because after that, data becomes anonymous, and your identity cannot be determined.

You do not have to give a reason if you wish not to take part and deciding to take part or not, will not impact upon or adversely affect your education or studies at Bournemouth University.

What would taking part involve?

You will be Bournemouth University student for this project. You will be asked to complete a short questionnaire, including age, height, weight, dominant hand and physical issues that could affect performing iCPR. After been trained by an instructor for about 1 hour (Paediatric Basic Life support (BLS) - Resuscitation Council UK – paediatric/infant BLS - 2015), you will have the chance to practice the skills on an infant manikin before being asked to carry out simulated iCPR on an infant manikin for 2 minutes, where data relevant to the elements of CPR will be collected (assessment) (please see description under “What is the purpose of this project?”).

If you achieve excellent quality iCPR (in other words, a “PASS” = ≥ 80% of compressions within guidelines for the 4 quality measures) during this assessment, you will come back the following month for another 2 minutes assessment. If you pass again (“PASS” = ≥ 80% of compressions within guidelines for the 4 quality measures), you have achieved 2 consecutive monthly “PASSES”.

After 2 consecutive monthly “PASSES”, you will return 3 months later for another assessment. If a “PASS” is achieved after the 3 months, you will return every 3 months for an assessment, until the end of the 12-month study.

If you “FAIL” (< 80% of compressions within guidelines for the 4 quality measures) any assessment, you will have the chance to practice for 2 minutes using real-time feedback and repeat the assessment until a “PASS” is achieved (up to 3 consecutive trials or until too tired). If you still don’t “PASS”, you will be asked to return the following month.

For any “FAIL”, you will come back monthly for practice plus assessment until 2 consecutive monthly “PASSES” are achieved. Just after the 2 consecutive ‘PASSES’, you will be allowed to follow to the next phase (3 months). This tailored performance approach, will enable us to understand the rate of retention/decay of infant CPR skills.

What are the advantages and possible disadvantages or risks of taking part?

The advantage for you is that it will provide you with an opportunity to further develop your iCPR skills by training and practicing on an infant manikin with real-time feedback. Furthermore, you will receive report/feedback of your performance (individual data collected from the manikin and written feedback) on completion of the study and a certificate on completion of the training to inform your practice and to enable you to deliver real infant CPR.

The predicted advantage for society is the understanding of the timeframe where iCPR skills take to decay and become ineffective.

We will seek to minimise any risks to participants by providing expert advice on how to perform the skills.

How will my information be kept?

All personal data relating to this study will be held for 5 years from the date of publication of the research. You will not be able to be identified from the data in any reports or publications. BU will hold the information collected about you in hard copy in a secure location and on a BU password protected computer or a secure network where held electronically.

Except where it has been anonymised, we will restrict access to your data to those individuals who have a legitimate reason to access it for the purpose or purposes for which it is held by BU. As well as BU staff working on the research project, a senior lecturer from Cardiff University, who is an external collaborator, will also have access to your anonymised data.

The information collected about you may be used in an anonymous form to support other research projects in the future and access to it in this form will not be restricted. It will not be possible for you to be identified from this data. Anonymised data will be added to BU's Data Repository (a central location where data is stored) and which will be publicly available.

If you have any questions about how we manage your information or your rights under the data protection legislation, please contact the BU Data Protection Officer on dpo@bournemouth.ac.uk.

What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The information in the questionnaire will be: age, height, weight, dominant hand and physical issues that could affect performing CPR such as knee or back pain. We need this information to analyse the links between variations in performance. Sensor data will be collected in different occasions to quantify the elements of CPR skills performed during 2 minutes. This information will be used to explore the retention and decay in performance.

For further information about the BU Research Participant Privacy Notice please refer to (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy)

Contact for further information

If you have any questions or would like further information, please contact Debora Almeida almeidad@bournemouth.ac.uk ; Dr Jonathan Williams jwilliams@bournemouth.ac.uk or Dr Carol Clark cclark@bournemouth.ac.uk

Complaints

If you have any complaints about this research please contact Professor Vanora Hundley, Deputy Dean Research and Professional Practice by email to researchgovernance@bournemouth.ac.uk

Finally…

If you decide to take part, you will be given a copy of this information sheet and a signed participant agreement form to keep.

Thank you for considering taking part in this research project!!

Appendix 13 - Participant Consent Form - Retraining Study

Bournemouth University

Participant Agreement form

Establishing an effective infant CPR retraining schedule to minimise skill decay and maximise retention

Researchers: Debora Almeida almeidad@bournemouth.ac.uk , Dr Jonathan Williams jwilliams@bournemouth.ac.uk , Dr Carol Clark cclark@bournemouth.ac.uk

In this form, we ask you to confirm whether you agree to take part in the project. We also ask you to agree to some specific uses of your identifiable information, which we will only do with your consent.
You should only agree to take part in the project if you understand what this will mean for you. If you complete the rest of this Form, you will be confirming to us that:

- You have read and understood the Project Participant Information Sheet and have been given access the BU Research Participant Privacy Notice which sets out how we collect and use personal information (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy)

- You have had the opportunity to ask questions;

- You understand that:

    - Taking part in the research will include receiving infant CPR training and performing CPR on an infant manikin for 2 minutes on different occasions (varying from 5 times to 12 times in a 12-months period). The amount of times will be determined according to your performance, which is explained in the "Participant Information Sheet" under "What would taking part involve?".

    - Your participation is voluntary. You can stop participating in research activities at any time without giving a reason, and you are free to decline to answer any particular question(s).

    - If you withdraw from participating in the Project, you may not always be able to withdraw all of your data from further use within the Project,

particularly once we have anonymised your data and we can no longer identify you.

- Data you provide may be included in an anonymised form within a dataset to be archived at BU's Online Research Data Repository.

- Data you provide may be used in an anonymised form by the research team to support other research projects in the future, including future publications, reports or presentations.

Consent to take part in the Project	***Yes***	***No***
I agree to take part in the Project on the basis set out above	☐	☐

Name of Participant _____

Date ____/____/____ Signature_____

Name of Researcher _____

Date____/____/____ Signature_____

Appendix 14 - Recruitment Poster - Retraining Study

Come and learn infant CPR skills!!!!

- Would you like to take part in a research project that aims to analyse retention of infant CPR skills?
- It is open to BU students who haven't been trained in infant CPR.
- You will receive training in infant CPR and will be asked to perform simulated CPR on an infant manikin for 2 minutes on different occasions (varying from 5 times to 12 times in a 12 months period). The interval will be determined according to your performance.
- This will provide you with an opportunity to further develop you CPR skills and receive a report of your performance.
- Interested? Contact Debora Almeida almeidad@bournemouth.ac.uk
- If you are an ODP student, please contact Emil Siwadi on esiwadi@bournemouth.ac.uk

almeidad@bournemouth.ac.uk

Appendix 15 - Participant Questionnaire - Retraining Study

Bournemouth University

Participant Questionnaire

Establishing an effective infant CPR retraining schedule to minimise skill decay and maximise retention

Thank you for taking part in this research project which aims to measure the elements of infant CPR skills: chest compression rate (number of compressions per minute), chest compression depth (distance between original position of the chest and end of the compression phase), complete chest recoil (allowing the chest to come back to its original position before each compression) and compression duty cycle (ratio between chest compression and chest relaxation) delivered by undergraduate students and the retention of the infant CPR performance after a set timeframe.

Please answer the following questions that will be used to complement the data collected during your infant CPR performance.

1.) What is your age? _____

2.) What is your height in cm? _____

3.) What is your weight in Kg? _____

4.) Are you right or left-handed? _____

5.) Do you have any physical issue/condition that restricts you from kneeling on the floor?

□ yes □ no

6.) Do you have any physical issue/condition that restricts you from performing simulated CPR?

□ yes □ no

7.) Have you had any wrist, shoulder, knee or spinal injury requiring medical intervention in the last 12 months?

□ yes □ no

8.) Are you physically able to perform simulated CPR on a manikin for 2 minutes?

□ yes □ no

Appendix 16 - Risk Assessment - Retraining Study

Bournemouth University

Risk Assessment Form

About You & Your Assessment	
Name	Debora Almeida
Email	almeidad@bournemouth.ac.uk
Your Faculty/Professional Service	Faculty of Health & Social Sciences
Is Your Risk Assessment in relation to Travel or Fieldwork?	No
Status	Approved
Date of Assessment	18/09/2019
Date of the Activity/Event/Travel that you are Assessing	04/11/2019

What, Who & Where	
Describe the activity/area/process to be assessed	Students individually performing simulated cardiopulmonary resuscitation (CPR) on an infant manikin for 2-5 minutes.
Locations for which the assessment is applicable	seminar room
Persons who may be harmed	Staff, Student, Visitors

Hazard & Risk	
Hazard	Postural hazards during practice of CPR
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Postural hazards during practice of CPR:

ensure participant is given the option to practice CPR with the manikin on the floor or on a table (wherever is more comfortable)

ensure participants receive instructions about a safe posture during CPR

ensure the participants are aware of their limitations and stop doing the activity if they feel any pain or discomfort.

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	sore/bruised knees
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for sore/bruised knees:

ensure the person uses a mat (such as yoga mat) when kneeling on the floor to practice CPR

ensure the participant receives verbal instruction about how to place knees for a more comfortable position

With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low

With your control measure(s) in place - how likely is it that the hazard could cause harm? Low

The residual risk rating is calculated as: Low

Hazard	Cross contamination of bodily fluids via manikin / Skin irritation from disinfecting agent (wipes)
Severity of the hazard	Medium
How Likely the hazard could cause harm	Medium
Risk Rating	Medium

Control Measure(s) for Cross contamination of bodily fluids via manikin / Skin irritation from disinfecting agent (wipes):

Manufacturers recommended cleaning wipes used on manikin after each use – instruction given to students on use of wipes each session. Following cleansing all users must ensure manikin is dry before re-use (eliminate skin irritation).
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low
The residual risk rating is calculated as: Low

Hazard	Slips/trips
Severity of the hazard	Low
How Likely the hazard could cause harm	Low
Risk Rating	Low

Control Measure(s) for Slips/trips: ensure manikin is well visible at all times ensure cables are covered and hidden; Manikin to be stored away when not in use/ Students and staff to be alerted and aware of tripping hazard when using equipment any trip hazards that cannot be removed are clearly marked with hazard tape
With your control measure(s) in place - if the hazard were to cause harm, how severe would it be? Low
With your control measure(s) in place - how likely is it that the hazard could cause harm? Low
The residual risk rating is calculated as: Low

Review & Approval	
Any notes or further information you wish to add about the assessment	
Names of persons who have contributed	Debora Almeida
Approver Name	Jonathan Williams
Approver Job Title	[Not Applicable]

Approver Email	
Review Date	

Uploaded documents
No document uploaded

Appendix 17 - Ethics Protocol - Retraining Study

Bournemouth University

Research Ethics Checklist

About Your Checklist	
Ethics ID	27402
Date Created	10/06/2019 09:40:31
Status	Approved
Date Approved	08/08/2019 18:21:56
Date Submitted	05/08/2019 16:31:59
Risk	High

Researcher Details	
Name	Debora Almeida
Faculty	Faculty of Health & Social Sciences
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, EngD, EdD)
Course	Postgraduate Research - HSS
Have you received funding to support this research project?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	Dr Jonathan Williams, Dr Carol Clark, Dr Mike Jones (external)

Project Details	
Title	Establishing an effective infant CPR retraining schedule to minimise skill decay and maximise retention
Start Date of Project	08/07/2019

End Date of Project	21/06/2021
Proposed Start Date of Data Collection	23/09/2019
Original Supervisor	Jonathan Williams
Approver	Research Ethics Panel

Summary - no more than 600 words (including detail on background methodology, sample, outcomes, etc.)

Cardiac arrest is a significant worldwide health problem associated with considerable morbidity, mortality and extensive healthcare costs (Wilkins *et al.* 2017, Wong *et al.* 2019). In the UK, there are over 30,000 out-of-hospital cardiac arrests (OHCA) yearly and the reported survival to discharge rates range between 2% and 18.4%. Paediatric victims (noticeably infants) have particularly poor outcomes, with undesirable high-rates of both mortality and morbidity, making cardiac arrest in the infant population, a substantial public health problem (Bush *et al.* 2006, Perkins and Brace-McDonnell 2015, Hawkes *et al.* 2017).

Positive outcomes from infant cardiac arrest depend on the effective delivery of resuscitation techniques, including good quality infant cardiopulmonary resuscitation (iCPR), which is crucial in generating circulation to vital organs and providing adequate cerebral and coronary perfusion (Lurie *et al.* 2016). This is established by achieving four internationally recommended quality measures: chest compression depth; chest compression rate; complete chest recoil; and compression duty cycle (Kramer-Johansen *et al.* 2007, Meaney *et al.* 2013, Maconochie *et al.* 2015, Niles *et al.* 2018). However, it has been demonstrated that the quality of chest compressions during iCPR delivered by lay person, basic life support (BLS) and highly-trained-rescuers in both simulated and real paediatric cardiac arrest events is often performed inadequately and is therefore, of suboptimal quality, reducing the chances of survival (Wallace *et al.* 2013, Stiell *et al.* 2014, Perkins *et al.* 2017, Nolan *et al.* 2018).

Whilst the reasons for inadequate quality of iCPR are multifactorial, key elements include subsequent retention and decay of skills after initial skill learning. Several studies have established an urgent need to identify the frequency of iCPR updates in order to maintain adequate and effective skills (Niles *et al.* 2009a, Sutton *et al.* 2011, Cheng *et al.* 2018, Lin *et al.* 2018) however, no study has examined how a tailored approach could improve retention and reduce retraining needs and associated costs, and this study aims to address this knowledge gap.

This study will adopt a longitudinal, prospective, observational, experimental design and be conducted at Bournemouth University. Data relating to age, height, weight, dominant hand and self-declared physical issues which could compromise performance will be gathered in order to create a demographic profile of the sample.

Informed written consent will be gained following written explanation of experimental procedures. Participants will then complete the short questionnaire and, after been trained by a qualified instructor for 1 hour (using national guidelines), will practice the skills on an infant manikin before being asked to carry out simulated iCPR on the

manikin for 2 minutes (assessment), where data relevant to the elements of CPR will be collected.
If the participant achieves excellent quality CPR ("PASS" = ≥ 80% of compressions within guidelines for the 4 quality measures) during assessment, they will come back the following month for 2 minutes assessment, reaching 2 consecutive monthly "PASSES".
After 2 consecutive monthly "PASSES", the participant will return 3 months later for 2 minutes assessment. If a "PASS" is achieved in this assessment, this exercise will be repeated quarterly until the end of the 12-month study.
If the participant "FAILS" (< 80% of compressions within guidelines for the 4 quality measures) any assessment, they will practice for 2 minutes using real-time feedback and repeat the assessment until a "PASS" is achieved (up to 3 consecutive trials or until too tired). If still doesn't "PASS", return the following month.
For any "FAIL", the participant will come back monthly for practice plus assessment until 2 consecutive monthly "PASSES" are achieved. Just after the 2 consecutive 'PASSES', the participant will be allowed to follow to the next phase (3 months).
This tailored performance approach, will enable us to understand the rate of retention/decay of infant CPR skills.
Outcomes: findings will be disseminated as a journal article (target - journal 'Resuscitation'); results will be sent to the Resuscitation Council UK, European Resuscitation Council and American Heart Association; presentation at an international conference (e.g. European Resuscitation Council Congress), internal PGR seminars and conferences; a new re-training schedule will be proposed and sent to local NHS trusts.

Filter Question: Does your study involve Human Participants?

Participants	
Describe the number of participants and specify any inclusion/exclusion criteria to be used	
Initial sample size calculation of 72. However, due to a high dropout rate (based on previous studies), we aim to recruit 108 participants. Inclusion criteria: (a) students enrolled at BU; (b) not have received previous training in paediatric or infant basic life support. Exclusion criteria: shoulder, wrist, knee or spinal injury requiring medical intervention in the last 12 months or if the participants are unable to perform CPR for any reason.	
Do your participants include minors (under 16)?	
Are your participants considered adults who are competent to give consent but considered vulnerable?	No
Is a Disclosure and Barring Service (DBS) check required for the research activity?	No

Recruitment
Please provide details on intended recruitment methods, include copies of any advertisements.

Participants will be recruited from the BU student population via a poster displayed around the university (primary recruitment tool), on Brightspace and social media. Participants will be provided with an information sheet at least 24h prior to asking for signed written consent. Due to the potential recruitment of ODP students, a gatekeeper will be used (one of the researchers is an ODP lecturer). However, the study is open to all BU students.

Do you need a Gatekeeper to access your participants?	Yes

Please provide details, including their roles and any relationship between Gatekeepers and participant(s) (e.g. nursing home manager and residents)
Emil Siwadi - programme lead for BSc (Hons) Operating Department Practice - recruitment only. This is only needed to give potential ODP students a separate and independent point of contact to the study PI. Recruitment is open to all other university students and due to no prior relationship, no additional gatekeepers are necessary.

Data Collection Activity	
Will the research involve questionnaire/online survey? If yes, don't forget to attach a copy of the questionnaire/survey or sample of questions.	Yes
How do you intend to distribute the questionnaire?	
face to face	
Will the research involve interviews? If Yes, don't forget to attach a copy of the interview questions or sample of questions	
Will the research involve a focus group? If yes, don't forget to attach a copy of the focus group questions or sample of questions.	No
Will the research involve the collection of audio materials?	No
Will your research involve the collection of photographic materials?	No
Will your research involve the collection of video materials/film?	No
Will the study involve discussions of sensitive topics (e.g. sexual activity, drug use, criminal activity)?	No
Will any drugs, placebos or other substances (e.g. food substances, vitamins) be administered to the participants?	No
Will the study involve invasive, intrusive or potential harmful procedures of any kind?	No
Could your research induce psychological stress or anxiety, cause harm or have negative consequences for the participants or researchers (beyond the risks encountered in normal life)?	No
Will your research involve prolonged or repetitive testing?	No

Consent	
Describe the process that you will be using to obtain valid consent for participation in the research activities. If consent is not to be obtained explain why.	
Prior to data collection, participants will be provided with written information about the study and an agreement/consent form. There will be an opportunity to discuss the study with the principal investigator. The voluntary nature of the participation will be emphasised. All consent forms will be signed by the participant and the researcher together prior to entering the data collection room. All participants will be offered a copy of the signed consent form for their keeping.	
Do your participants include adults who lack/may lack capacity to give consent (at any point in the study)?	
Will it be necessary for participants to take part in your study without their knowledge and consent?	No

Participant Withdrawal
At what point and how will it be possible for participants to exercise their rights to withdraw from the study?
Participants will receive an Information Sheet and Agreement Form (with link to "research participant privacy notice"), explaining that participation is voluntary, that they can stop taking part in an activity at any point and that they can withdraw without having to give a reason, at any time up to the point when the data are processed because after that, data become anonymous, and their identity cannot be determined.
If a participant withdraws from the study, what will be done with their data?
We will follow BU research participant privacy notice and withdraw the data from the research project, depending on the stage of the project.

Participant Compensation	
Will participants receive financial compensation (or course credits) for their participation?	No
Will financial or other inducements (other than reasonable expenses) be offered to participants?	No

Research Data	
Will identifiable personal information be collected, i.e., at an individualised level in a form that identifies or could enable identification of the participant?	Yes
Please give details of the types of information to be collected, e.g. personal characteristics, education, work role, opinions or experiences	
We will be collecting personal characteristics via the questionnaire including gender, age, weight, height and dominant hand.	

Will the personal data collected include any special category data, or any information about actual or alleged criminal activity or criminal convictions which are not already in the public domain?	No
Will the information be anonymised/de-identified at any stage during the study?	
Will research outputs include any identifiable personal information i.e., data at an individualised level in a form which identifies or could enable identification of the individual?	
Please give brief details of how you will address the need for data minimisation or explain why you do not think this relates to the personal information you will be collecting.	
We minimised the scope of data to be collected by including only what is necessary as a mechanism to describe our participants. Data may be identifiable at point of collection only (limited access just to the PI) and will be anonymised by removing direct identifiers and aggregating variable (such as age) before being analysed and shared with other researchers in the study. From this point, data will not be identifiable and the identifiable format will be manged according to BU policy.	

Storage, Access and Disposal of Research Data	
During the study, what data relating to the participants will be stored and where?	Personal data including gender, age, weight, height and dominant hand will be collected as paper copy in form of a questionnaire with a codename and then scanned and saved as “pdf” files. This electronic data will be kept in a BU password protected computer and securely backed-up. The original paper copies will be securely destroyed/shredded straight after the electronic copies are saved
How long will the data relating to participants be stored?	Data will be retained for 5 years after final completion of the research.
During the study, who will have access to the data relating to participants?	Identifiable data will be accessed only by the principal investigator. Anonymised data will be accessed by the other investigators involved in the study
After the study has finished, what data relating to participants will be stored and where? Please indicate whether data will be retained in identifiable form.	Electronic personal data (described above) will be stored in a BU password protected computer.
After the study has finished, how long will data relating to participants be stored?	Electronic personal data (described above) will be retained for 5 years after final completion of the research.
After the study has finished, who will have	The principal investigator

access to the data relating to participants?	
Will any identifiable participant data be transferred outside of the European Economic Area (EEA)?	No
How and when will the data relating to participants be deleted/destroyed?	Paper copies of personal data will be securely shredded after digitalisation (first 2 months of the study) and secure paper destruction service bin used; paper copies of consent forms will be securely shredded after 5 years of final completion of the research and secure paper destruction service bin used; digitalised personal data and other general electronic data will be destroyed after 5 years of final completion of the research following IT services consultation and advice.
Once your project completes, will any anonymised research data be stored on BU's Online Research Data Repository "BORDaR"?	Yes

Dissemination Plans	
Will you inform participants of the results?	

Final Review	
Are there any other ethical considerations relating to your project which have not been covered above?	

Risk Assessment	
Have you undertaken an appropriate Risk Assessment?	Yes

Attached documents
Retraining study - participant information sheet with tracked changes.docx - attached on 05/08/2019 16:31:17
Retraining study -participant agreement form with tracked changes.docx - attached on 05/08/2019 16:31:24
Retraining study questionnaire no changes needed (2).docx - attached on 05/08/2019 16:31:31
Retraining Study Poster with changes.pptx - attached on 05/08/2019 16:31:45