The development of the compromised neonate: A Virtual Reality neonatal resuscitation program

Abstract

Background: Globally about 2.5 million newborns die annually during the neonatal period and improving and increasing the availability of neonatal resuscitation training is considered a global health priority. Neonatal resuscitation comprises interventions to preserve or initiate breathing and/or circulation. In Australia, midwives attending births are expected to maintain these skills through regular involvement in neonatal resuscitation training programs. Simulation-based education incorporating deliberate practise reflection and feedback on practice, has become central to neonatal resuscitation training.

Question: Simulation-based education can require considerable material and human resource investments that may limit access to training. Technological advancement has brought changes in neonatal resuscitation training, including the use of immersive and non-immersive virtual reality simulation techniques, can these afford new ways of learning.

Methods: The objective of this paper is to outline the development of an immersive virtual reality neonatal resuscitation program the *"compromised neonate simulation*", and describe the initial implementation and attitudes of the program amongst a small group of final year undergraduate midwifery students in one Australian University.

Discussion: It is important that health professionals are involved in the design and development of simulation-based education initiatives in areas such as neonatal resuscitation training.

Conclusion: The Integration of technology innovations such as virtual reality(VR) into midwifery skills such as neonatal resuscitation training has the potential to overcome financial barriers associated with traditional simulation-based education, SBE strategies increasing deliberate skills training in this area and improve responsiveness in these emergency situations with applications in both high income and low-income countries.

Statement of Significance: Simulation-based education can require considerable material and human resource investments that may limit access to training, the use of technology may overcome some of these issues.

What is already known: Neonatal resuscitation training is considered a global health priority, and VR simulation education is significant in material savings and human resource investments.

What this paper adds: Virtual reality has the potential to produce significant cost savings and increased stainability, technology can transform neonatal resuscitation saving lives.

Introduction

Globally it is estimated that 2.5 million newborns die annually during the neonatal period, defined as the first 28 days of life (United Nations Inter-agency Group for Child Mortality Estimation [UNIGCME], 2019). Of these 1 million newborns die within the first 24 hours of life from preventable causes such as preterm birth, intrapartum related complications and birth asphyxia (lack of breathing) (Australian and New Zealand Committee on Resuscitation [ANZCOR], 2018). Whilst most newborn deaths occur in low and middle-income countries, improving and increasing training for birth attendants in life-saving skills such as neonatal resuscitation is a global health priority (Black et al., 2016; Edgcombe, Paton, & English, 2016; UNIGCME2019).

Neonatal resuscitation is broadly defined as a set of interventions required to preserve or initiate the establishment of breathing and or circulation (ANZCOR, 2018). In Australia, it is estimated that 10% of all newborns will require some assistance to initiate breathing (ANZCOR 2018). These resuscitation practices range from technical skills such as drying and stimulation of the infant (10% of births), to more advanced technical skills such as the initiation of positive pressure ventilation (PPV) (3% of births), and cardiopulmonary resuscitation (CPR) with or without volume or cardiac medications (0.1% of births) (ANZCOR, 2018).

Equipping birth attendants with both technical and advanced-technical life-saving skills remains a global challenge (Ghoman et al., 2020; Muinga & Paton, 2019). In high-income countries, this is largely attributed to the relatively low occurrence and need for advanced neonatal resuscitation procedures (Garvey & Dempsey, 2020). Situations requiring advanced technical skills are largely unanticipated (Garvey & Dempsey, 2020; UNIGCME2019). Weinstock et al. (2005) discuss the neonatal /paediatric training paradox whereby the combination of being underprepared can lead to hesitancy and high levels of stress as a result of a deficiency in experiential opportunities. In Australia, it is recommended that all births be attended by personnel (medical doctors, midwives, nurses) trained in neonatal resuscitation skills with the maintenance of these skills being addressed at least every 12 months through neonatal resuscitation training programs (ANZCOR2018; Garvey & Dempsey, 2020).

Simulation training has become the key component of neonatal resuscitation skills training and education programs (Garvey & Dempsey, 2020). Simulation-based education (SBE) is generally defined as education strategies that replicate or replace real- world experiences, allowing for the deliberate consolidation of theoretical knowledge and practical skills in a safe environment (Garvey & Dempsey, 2020; Huang et al., 2019; Mileder, Urlesberger, Szyld, Roehr, & Schmölzer, 2014). Key components of SBE include deliberate practice, reflection and feedback on practice (Garvey & Dempsey, 2020). Originally derived from aviation training, SBE is commonly used in healthcare to develop and maintain clinical skills in health professionals and students (Garvey & Dempsey, 2020). Over time , a broad range of techniques have been employed as part of SBE in health care these include role play, the use of actors, the use of cadaveric specimens; low fidelity task trainers and mannikins; high fidelity mannikins and computer-based simulations (Lee et al., 2011; Mileder et al., 2014). SBE for neonatal resuscitation has demonstrated advantages including improved knowledge, technical skills, confidence and professional attributes, contributing to overall clinical performance and patient safety (Mileder et al., 2014). Whilst there are no reported negative effects from SBE, techniques such as low and high-fidelity simulations that use task trainers and mannikins, have been reported to require significant investment (Ghoman et al., 2020; Mileder et al., 2014; Muinga & Paton, 2019). Equipment is expensive, requiring trained personnel to run training programs and run and maintain equipment. Simulation equipment also requires facilities such as dedicated simulation laboratories contributing to the cost and high level of resources needed for this type of training (Fealy et al., 2019). These methods have also been suggested to limit accessibility to neonatal resuscitation SBE, with independent self-directed and ad hoc professional practice being impeded by organisational constraints (Fealy et al., 2019; Ghoman et al., 2020; Mileder et al., 2014). In low resource countries the costs of traditional SBE strategies are practically unaffordable (Muinga & Paton, 2019), necessitating the need for alternative SBE initiatives that are less resource-intensive and promote self-driven learning that can be deployed across large rural and remote geographical regions. One suggestion is investing in electronic, and computer-based SBE innovations (Edgcombe et al., 2016; Ghoman et al., 2020).

Advancement in the technology pertaining to SBE for neonatal resuscitation is rapidly changing. Information Technology (IT) based interventions such as mobile phone technologies and virtual reality (VR) are IT mediums gaining traction as alternative SBE methods (Fealy et al., 2019; Ghoman et al., 2020; Muinga & Paton, 2019; Williams, Jones, & Walker, 2018). Virtual Reality (VR) technology has been used to support both technical and non-technical health professional skills training and has been employed in a wide range of disciplines including surgery, medicine, radiography and nursing (Aïm, Lonjon, Hannouche, & Nizard, 2016; Bracq et al., 2019; Fealy et al., 2019).

Virtual reality is a broad term used to describe a range of computer-based simulations and are often separated into two categories (Fealy et al 2019). These include non-immerse VR and immersive VR. Non- immersive VR generally refers to desktop computer simulations where the user interacts with a virtual world using avatars and computer hardware (i.e., keyboard, mouse, camera and audio); the Second Life® program is one example (Fealy et al., 2019; Irwin & Coutts, 2015). Immersive virtual reality (IVR) refers to interactive computer-based simulations that give the user the feeling of being present or immersed within a virtual environment (Sherman & Craig, 2018). These types of computer-based simulations achieve immersion by using head-mounted displays (HMDs), giving the user direct sensory feedback (i.e., vision, hearing, touch) and allowing for responsive interactivity within the built environment (Fealy et al., 2019; Sherman & Craig, 2018).

A recent literature review investigating the use of serious games for neonatal resuscitation (Ghoman et al., 2020), suggests that IT-based simulation strategies such as VR may be able to overcome some of the challenges associated with traditional simulation methods. These include possible reductions in cost and increased accessibility of SBE for both resource-intensive and low resource institutions (Brennen et al., 2020). Moreover, VR may increase knowledge and skills development by providing immediate feedback to the user as well as providing experiences that are replicable. Immersive virtual reality may also be useful in overcoming the neonatal /paediatric paradox, providing deliberate skills training that is not only accessible but may evoke physiological responses in users such as stress, increasing preparedness for infrequent emergency situations (Francis, Gummerum, Ganis, Howard, & Terbeck, 2017).

As technology advances it is important for health professionals to be involved in the design, development and evaluation of innovative SBE strategies for the initial development and maintenance of life-saving skills such as those needed for neonatal resuscitation. Therefore, the objective of this paper is to outline the development of an immersive virtual reality neonatal resuscitation program - "compromised neonate simulation" - and describe the initial implementation and attitudes to the program amongst a small group of final year undergraduate midwifery students in one Australian University.

Design Approach

The initial concept for "the compromised neonate program" evolved out of the need to find alternative modalities to teach bachelorette degree undergraduate midwifery students the procedural skills in neonatal resuscitation. Traditionally, these procedural skills were taught within supervised clinical skills laboratories using SBE techniques such as low and high-fidelity simulation trainers and mannikins. Anecdotal student feedback from these laboratories was positive; however, students wanted more time and access to neonatal resuscitation SBE. The compromised neonate program was designed using the Australian and New Zealand Council of Resuscitation, Neonatal Resuscitation Guidelines (2018), incorporating recommended state-based health department communication strategies such as the Introduction, Situation, Background, Assessment and Recommendation (ISBAR) framework (New South Wales Health, 2019). The program draws on upon Kolb's Experiential learning framework whereby knowledge is created through experience and the transformation of these experiences through the learning cycle (Kolb & Kolb, 2017).

The compromised neonate program was conceptualised by subject matter experts in the fields of nursing and midwifery at a large Australian University, in an effort to address the time and accessibility constraints of traditional SBE. A collaboration between the University's IT - innovations team and nursing and midwifery experts was formed, with funding obtained from the university's IT department to support the development of the prototype program.

The SCRUM$_{TM}$ methodology guided the overall development process. SCRUM is a pragmatic, iterative and incremental approach that can be applied to complex product development (Sutherland & Schwaber, 2013). SCRUM is based on three key principals, 1) transparency 2) Inspection and 3) Adaption (Sutherland & Schwaber, 2013). Transparency allows for the team to collectively define the final product outcome and development endpoints. The inspection and adaption processes are characterised by four key elements including; 1) Sprint planning, 2) The daily scrum, 3) Sprint review and 4) Sprint retrospective (Sutherland & Schwaber, 2013). Sprints are considered "the heart" of the SCRUM framework. Sprint planning is conducted with the whole team with deliverables and sprint duration negotiated and directed towards achieving the product endpoint (Sutherland & Schwaber, 2013). The compromised neonate prototype was conceptualised over a period of three-months. The SCRUM development process was undertaken over a period of twelve-weeks, with planned sprints every two weeks until the development end point was reached, and the program was finalised in readiness for testing.

Software and Hardware

Unity-pro© was the software program primarily used for the development of the virtual environment. Additional software programs including 3DS Max® used to assist with design content, Ivona™ for voice synthesis, Bitbucket® as the code repository and Jira® for program control management. The digital content was made available in both non-immersive and immersive VR software platforms. This was to allow for the program to be deployed and used on a personal computer (Microsoft Windows© based) and/or for use by commercially available HMDs such as HTC VIVE™ and Samsung Oculus™ (rift/ gear) VR hardware. An important design aspect was to afford users accessibility to the program in various settings such as classrooms, skills laboratories and at home.

Figure 1: Guided and unguided mode of Compromised Neonate Care Simulation

The Compromised neonate was designed adhering to experiential learning principals whereby the learner can transition from novice to advanced learner and transform their individual learning (Kolb & Kolb, 2017). To accommodate this, the program was developed with two experiential learning options – a *"Guided"* and *"Unguided"* mode as shown in **Figure 1**.

Novice learners are recommended to select the guided mode option, where the program incorporates the use of avatar's and verbal and text prompts to guide the learner through the procedural steps of neonatal resuscitation. Once familiar with the skills and program the user may choose the unguided option to test their experience and knowledge.

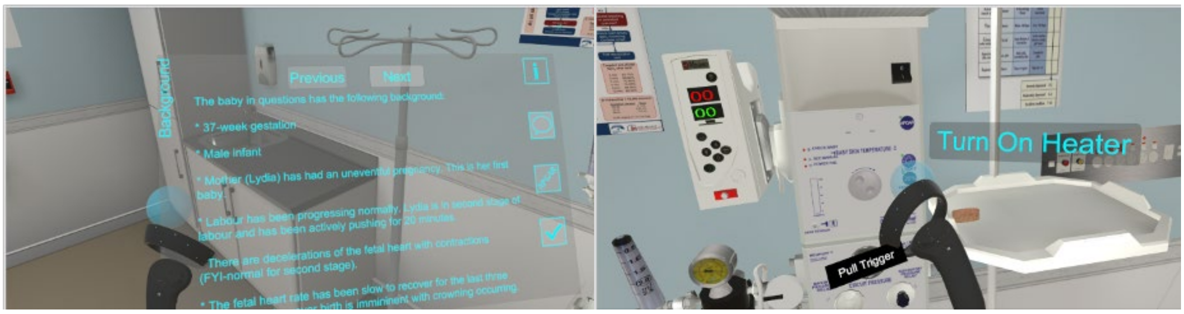

Figure 2: Users are guided by a series of technical information and instructions

Demonstrated in **Figure 2**, users are guided through the scenario with a series of events that provide relevant clinical information and technical instructions to facilitate use. In the example shown in **Figure 3**, a Windows Mixed Reality headset™ is being used with hand controllers to manipulate equipment in the virtual environment.

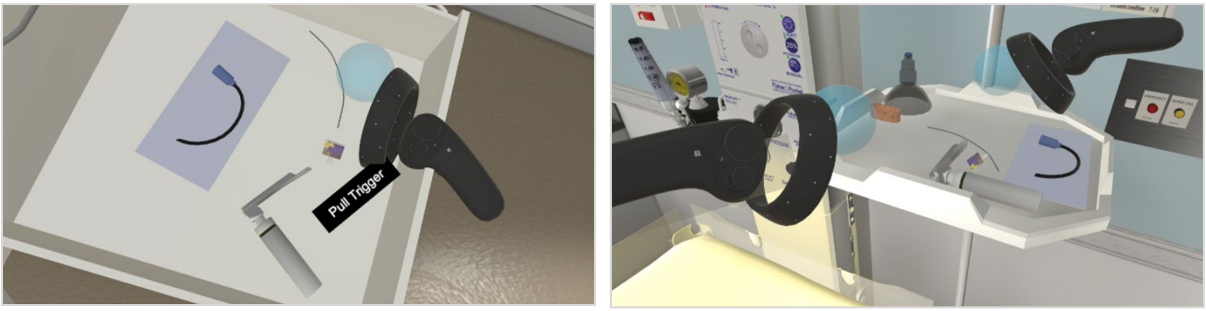

Figure 3: Users interacting with medical instruments (e.g. pick-up and relocating required items)

Users are also guided to interact with medical equipment that may be essential to achieve an effective neonatal resuscitation outcome. Users are required to locate, pick up, and relocate the required medical equipment to the resusitaire, and apply/configure this equipment correctly according to the pre-defined requirements in the simulation steps. As demonstrated in **Figure 3**, users will pull the trigger of the controller to manipulate and pick up equipment. Neonatal resuscitation can require the use of a number of varied medical instruments, these items have been replicated in the virtual environment such as the oropharyngeal airway, oxygen blender and resuscitative drugs such as adrenaline (epinephrine) and volume expanders such as normal saline. The ability to identify and work with virtual medical instruments within the VR simulation affords an enhanced experiential learning opportunity to students; a process of learning through (virtual) hands-on experience (Fealy et al., 2019; Pottle, 2019).

Figure 4: Users assist the neonate to breath using Continuous Positive Airway Pressure (CPAP) with the aid of an oropharyngeal airway mask and Neopuff ™

Figure 4 demonstrates the use of a Neopuff ™ for airway and breathing controls and providing the required first-line medications, adrenaline and normal saline in a simulated neonatal resuscitation simulation. As can be seen, users are required to work with this equipment to simulate and replicate real-life neonatal resuscitation procedures. For instance, a user within the scenario required to draw up the medications will hold the medicine using the left controller, and with the right controller operating the syringe, will fill the syringe with medicine (pulling back the plunger to the line on the syringe for the required dosage).

Figure 5: Users are able to interact with medical specialist and parent avatars

As shown in **Figure 5,** users can interact with virtual characters by establishing professional conversations, following the ISBAR communication framework to achieve the best outcome. For example, users can ask for help from a doctor should a critical situation arise within the scenario and will experience a virtual conversation with the partner/spouse explaining the situation as it unfolded, and the medical procedures and personnel that were involved in achieving a positive outcome.

Currently, the compromised neonatal resuscitation VR simulation is operated using a HMD tethered to a workstation with high-end computing and graphics power needed. It is speculated that with the expedited growth, technological advances and interest in VR learning experiences for health training, portable systems will evolve and become commercially affordable. Technology is already moving beyond hand controllers replacing these with "virtual hands" to enhance the sense of presence and intuitive interaction, getting closer to mirroring how practitioners work in the real-world clinical environment.

Implementation and Evaluation

The Compromised neonate program development was finalised in late 2017, with the initial implementation of the program occurring in early 2018, as part of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) On Accelerate program. The CSIRO program is selective and designed to assist researchers to validate new innovations and ventures over a 6-month intensive course. Authors DJ and SF participated in this program conducting initial program testing among a small (n=7) group of final year undergraduate midwifery students. The testing and data collection were approved as a quality assurance activity by the University of (blinded for peer review) Human Research Ethics Committee (QA 193). Initial testing was conducted during one neonatal resuscitation skills laboratory. Following traditional SBE, students were offered the opportunity to use the compromised neonate program in its immersive VR form and had the option of providing feedback via a survey. Eight questions were designed to gain feedback on the VR program. Seven questions were devised by researchers, asking the participants to rate their agreement with the questions (rating; Strongly Agree; Agree; Undecided; Disagree and Strongly Disagree) with one question asking for any additional comments. The questions and distribution of scores are detailed in Table 1.

Table 1. Initial program testing evaluation results (rounded to nearest %)

Questions	**Strongly Agree** (n), %	**Agree** (n), %	**Undecided** (n), %	**Disagree** (n), %	**Strongly Disagree** (n), %

I was encouraged to explore all possibilities of the VR simulation	(2) 29%	(4) 57%	(1) 14%	-	-
The VR simulation was designed from my specific level of knowledge	(2) 29%	(3) 43%	(1) 14%	(1) 14%	-
There was enough information provided to me during the VR simulation	(2) 29%	(2) 29%	(1) 14%	(2) 14%	-
The VR simulation allowed me to analyse my own behaviour and actions	(1) 14%	(4) 57%	(1) 14%	(1) 14%	-
There were opportunities during and / or after the VR simulation to obtain guidance / feedback from the teacher	(3) 43%	(1) 14%	(1) 14%	(2) 29%	-
The scenario resembled a real-life situation	(1) 14%	(3) 43%	(2) 29%	(1) 14%	-
Participating in VR simulation helped to improve my confidence in Neonatal Resuscitation	-	(5) 71%	(1) 14%	(1) 14%	-
I enjoyed the VR neonatal resuscitation simulation activity	(3) 43%	(3) 43%	-	(1) 14%	-

Overall, the initial program test revealed that participants enjoyed using the VR program, indicating that it could be used to increase confidence in neonatal resuscitation, allowed for self-analysis of behaviour and actions, allowed for teacher interaction where needed and was designed to an appropriate level of knowledge.

Discussion

This paper contributes to the growing body of research exploring the development and use of novel technology-based approaches for undergraduate student education. The conceptualisation of the neonatal resuscitation VR prototype was initially developed from anecdotal student feedback in combination with midwifery educators need to explore the use of technological that may assist to make neonatal resuscitation training more accessible for midwifery students. Initial prototype testing amongst a small cohort of final year undergraduate students suggests that the use of IVR for emergency procedural skills training may improve student confidence with neonatal resuscitation. Given the existence of the neonatal /paediatric training paradox (Weinstock et al. (2005), VR programs such as the compromised neonate may be a timely addition to simulation-based education methods, particularly for emergent, unpredictable and stressful events such as neonatal resuscitation. Wider deployment of the research prototype amongst larger and more diverse groups of health professionals is now warranted. Considerations for future research include the use of valid and reliable scales of measurement to test the effectiveness of the program to improve confidence and maintain skill competence. Testing and monitoring the effects of repeated use of the program on student stress levels, using proxy measures such as heart rate, may also be of value in establishing its usefulness in preparing students to cope with and enact lifesaving skills during emergency situations. Additionally, studies comparing the use of VR with traditional high and low fidelity SBE methods are recommended.

Initial testing suggests that the conceptualisation and development of the compromised neonate program using VR technology was an enjoyable experience with relevant content aimed at an appropriate education level to support the learning of undergraduate midwifery students. To date VR simulation has been used to support learning across a range of health care disciplines including surgery, medicine, radiography, and nursing (Aïm et al., 2016; Bracq et al., 2019; Fealy et al., 2019; Real et al., 2017; Sapkaroski, Mundy, & Dimmock, 2020). Virtual reality simulation is often incorporated into curricula to provide complementary skills training rather than as a complete replacement of existing SBE methods or expert/practitioner teaching (Bracq et al., 2019). Virtual Reality may provide students with accessible and unrestricted complementary practice opportunities and may be well-positioned to enable undergraduate midwifery students to practice and refresh their emergency clinical skills before real-world workplace learning placements or may be considered as useful for summative practical skills assessment. VR simulation may also promote independent student learning with a formative learning focus, being able to engage in experiential learning as a novice practitioner through to graduate practitioner level in a safe, repeatable and low-risk environment (Andersen, 2016; Bracq et al., 2019; Fealy et al., 2019).

The application of VR may also have broader education and training use beyond that of preparing undergraduate health care professionals such as affordance in continuing professional development and rural and remote- based learning. Of interest, a similar VR program has also been developed for use in low and middle- income countries where neonatal mortality is significantly higher (Muinga & Paton, 2019). Muinga and Paton (2019) have recently reported on work involving collaborators from the Nuffield Department of Medicine from Oxford University in the United Kingdom and the KEMRI Welcome Trust Research Programme, Nairobi Kenya, in which the use of the VR "LIFE" program enabled over 7,000 healthcare workers and medical students to undertake lifesaving procedural VR training in neonatal resuscitation at a considerably reduced cost. The cost has been reported as a barrier to the provision of simulation-based training in higher education facilities further research such as undertaking a cost analysis of VR training compared to traditional methods may also assist with future curricular integration of the technology within higher education and healthcare institutions (Fealy et al., 2019; Ghoman et al., 2020). A recent study on the use of VR for training paramedicine students conducted by Brennen et al. (2020) demonstrated that the cost of running a VR simulation was 13 times more cost-effective than traditional simulation practices. Further demonstration of cost savings amongst midwifery and other health care disciplines requires exploration.

The current COVID–19 pandemic has abruptly transformed global tertiary education sectors, rapidly shifting traditional face to face teaching to online/remote learning. This is presenting considerable challenges for the nursing and midwifery education sectors in being able to afford practical skills-based training for these students. Innovative IT approaches such as the implementation of VR may be able to overcome some of the teachings and learning barriers such as social distancing and physical assessment, by providing experiential learning in the home offering continued skills development, minimising disruption, enhanced accessibility and future-proofing the development of the global nursing and midwifery workforce. Continued exploration of novel technological enabled approaches to education such as VR and scalability of the technology within educational institutions requires exploration.

Conclusion

This concept paper has described the need for and development of the "compromised neonate" VR program designed to increase neonatal resuscitation simulation opportunities for undergraduate midwifery students. The Integration of technology innovations such as VR into nursing and midwifery skills such as neonatal resuscitation training has the potential to overcome financial barriers associated with traditional SBE strategies increasing deliberate skills training in this area and improve responsiveness in these emergency situations with applications in both high income and low-income countries. Whilst we believe the neonatal resuscitation VR (compromised neonate) is an exciting and innovative initiative, the use of VR in midwifery/neonatal education is at an early stage of development and necessitates further empirical research.

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