




Early-stage innovation report

Development and introduction of a mixed realities playkit: decreasing the incidence of general anaesthesia for paediatric MRI

Jill Thompson ¹, Dylan Yamada-Rice,² Sean Thompson,³ Louise Murray ⁴, Matthew Taylor⁴

¹Faculty of Health, The University of Sheffield, Sheffield, UK
²School of Art, Design and Architecture, The University of Plymouth, Plymouth, UK
³Dubit UK, Leeds, UK
⁴Anaesthetics, Sheffield Children's Hospital NHS Foundation Trust, Sheffield, UK

Correspondence to

Dr Jill Thompson, The University of Sheffield, Sheffield, South Yorkshire, UK; jill.thompson@sheffield.ac.uk

Received 23 January 2023

Accepted 27 August 2023



© Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY. Published by BMJ.

To cite: Thompson J, Yamada-Rice D, Thompson S, *et al*. *BMJ Innov* Epub ahead of print: [please include Day Month Year]. doi:10.1136/bmjinnov-2023-001083

DEFINITIONS

Augmented reality (AR): technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.¹

Virtual reality (VR): simulated three-dimensional environment that enables users to explore and interact with a virtual surrounding in a way that approximates reality, as it is perceived through the user's senses. Users may need to wear devices such as headsets or goggles to interact with the environment.²

INTRODUCTION**Background**

MRI has a wide range of diagnostic uses in the global paediatric population including oncological, neurological and cardiovascular imaging.³ MRI has emerged as a key imaging modality in paediatric practice because of the potential diagnostic advantages of increased image quality and also due to a reduction in radiation exposure compared with CT scanning.³ Acquisition of images can take between 10 and 120 min depending on the nature of the scan, which necessitates the patient lying still for a considerable period of time. Furthermore, the scanner room is a noisy environment; switching of gradient fields within the main magnet creates an acoustic noise of up to 80 decibels, requiring ear defenders to prevent acoustic injury.⁴ These issues can lead to

WHAT ARE THE NEW FINDINGS

- ⇒ An augmented/virtual reality combined with physical play MRI playkit has been developed to help reduce the incidence of general anaesthesia for MRI imaging in children.
- ⇒ The playkit uses a mixture of virtual reality and augmented reality in addition to physical play in the form of a cardboard model scanner, which children build with the help of their families to provide a focal point for discussions and alleviate anxiety ahead of an MRI scan with the aim of helping children to undergo an MRI without a general anaesthetic.
- ⇒ The kit allows for familiarisation with the MRI scanner, opportunities to practise staying still, preparing for high noise levels and simulating the entire MRI process through a series of interactive games which reduce anxiety levels for patients and their parents/carers.

HOW MIGHT IT IMPACT ON HEALTHCARE IN THE FUTURE

- ⇒ Children and their families report that the playkit helped them to prepare for the MRI scan.
- ⇒ If implemented nationally, the playkit could create opportunities to improve patient safety, provide economic savings in terms of reduced scanning times and waiting lists for paediatric MRI, as well as optimising anaesthetic resource usage.

problems in certain patient populations, particularly paediatrics; children often find it difficult to lie still for long periods and can experience levels of anxiety which prevent them tolerating the scan. Traditionally, children have been offered general anaesthesia (GA) to enable MRI scans; however, recent research and safety concerns have driven an initiative to reduce the number of paediatric MRIs performed under GA.

There are also economic implications for the reduction of GA for MRI: the longest waiting list in radiology at our hospital, Sheffield Children's Hospital, is for MRI scans under GA, and delays in performing scans lead to delays in diagnosis and treatment for children and their families, as well as increased usage of scanning time which further impacts the MRI waiting list. Additionally, a reduction in the requirement of GA for paediatric MRI reduces the need for an anaesthetist, enabling their use elsewhere—for example, to help reduce the backlog in elective surgery waiting lists.

It is widely accepted that play can reduce children's anxiety about medical interventions and can reduce the need for sedation and anaesthesia for certain interventions/procedures.⁵ Play in hospital enables children to be 'happier, less stressed and fearful', which in turn helps them to build resilience and cope with medical treatment. A literature review by the children's charity Starlight found that, through play, children can build positive associations and memories of treatment and hospital care that can have a lasting impact on their engagement with future treatment.⁵

Concern about paediatric general anaesthesia (GA) for MRI scans

A Healthcare Safety Investigation Branch (HSIB) report published in 2020 highlighted the risks involved in the routine use of GA for paediatric MRI. A child being treated for growth hormone deficiency, autism and learning difficulties underwent an MRI under GA for the investigation of recurrent headaches.⁶ Unfortunately, the child had a sudden unexpected deterioration during the scan due to the effects of a previously undetected cardiomyopathy. The child was stabilised and transferred to the local paediatric intensive care unit but died 3 days later. This event highlighted national safety risks regarding care pathways, human factors, awareness and training pertaining to patients with autism/learning difficulties, as well as consent and clinical practice guidelines when undertaking MRI scans under GA.⁶ A working party was convened to evaluate practices with the aim of developing clearer guidance on consenting patients for an MRI under GA.

Concerns regarding neurodevelopment after paediatric GA

Several studies published in the early 2000s examined animal models of GA, and raised concerns that exposure to GA in infancy/childhood may cause adverse neurodevelopmental effects. In a 2003 study,

7-day-old rats were exposed to 6 hours of GA using isoflurane, nitrous oxide and midazolam. Concerningly, the study found evidence of widespread neuronal apoptosis in brain tissue, and resultant cognitive and behavioural problems.⁷ Animal models, especially those in which subjects were exposed to a significantly prolonged anaesthetic with agents that are no longer the first choice for the modern anaesthetist, are difficult to translate to humans. Nevertheless, in 2017 the US Food and Drug Administration (FDA) released a warning and issued labels for all GA agents, detailing concerns over effects on neurodevelopment when used in babies and children.⁸

The GAS study is the only randomised trial in humans published so far to assess the effects of general anaesthesia in infancy on neurodevelopment.⁹ The study, which compared babies undergoing inguinal hernia repair in infancy under either a regional technique or a sevoflurane-based GA, reassuringly found no difference in neurodevelopmental outcomes by the ages of 2 and 5, as assessed by validated development and IQ assessments by certified clinical child psychologists.⁹

Evidence is lacking of the effects of having more than one anaesthetic, or prolonged exposure to GA agents in infants/young children. However, cohort studies such as MASK and PANDA have suggested adverse effects on neurocognitive functioning following multiple GAs.¹⁰ Introduction of the MRI playkit may therefore offer benefits in children who may require more than one scan in childhood—for example, those with chronic disease. In the following section we describe how the playkit was developed and some early acceptability testing with children.

PLAYKIT DEVELOPMENT METHODS

Physical play: the MRI scanner

The playkit was developed as a solution to assisting children aged 4–10 years to undergo MRI scanning without a GA. It contains a flat-packed cardboard kit for building into a small toy MRI scanner (figure 1),



Figure 1 Cardboard MRI scanner.



Figure 2 Augmented reality (AR) mode.

which is deliberately designed to be slightly too difficult for a child to be able to build alone, thus encouraging them to seek the help of a parent/carer. Parent/carer involvement is important because parental levels of anxiety often directly affect those of their child.⁵ The design allows the child to use their own toys, such as soft toys or small figures, to further explore the model and encourage further play, storytelling and creativity to aid familiarity with the scanner and scanning process.¹¹ Furthermore, because this part is made of cardboard, it encourages repeated play with no requirement for independent access to technology; young children may not have their own smartphone.

Augmented play: undertaking the 'scan'

A smartphone can be slotted into the side of the cardboard MRI scanner model and the 'AR' app is selected. Children then take on the role of the radiographer, scanning their toy with the addition of scanning noises to replicate the MRI experience. After completion of the 'scan', children can swipe through various aspects of the 'acquired' scan images (figure 2). Research conducted by the team that developed the playkit has shown that children in the target age group preferred to see examples of real MRI images rather than an illustrated/animated version.¹¹

Also included in the playkit is a cardboard VR headset (age-appropriate) which, along with the app, can allow children to take part in a virtual walkthrough of the hospital (figure 3), culminating in them 'entering' the MRI scanner itself. This includes four interactive games to prepare the child for various aspects of their journey, such as checking in, being weighed, removing ferromagnetic objects from clothing and staying still for the scan itself. This latter aspect makes use of the gyroscope in the mobile phone to play a game which relies on the child staying still in order to maximise the number of virtual butterflies settling on a virtual flower (figure 4).¹¹

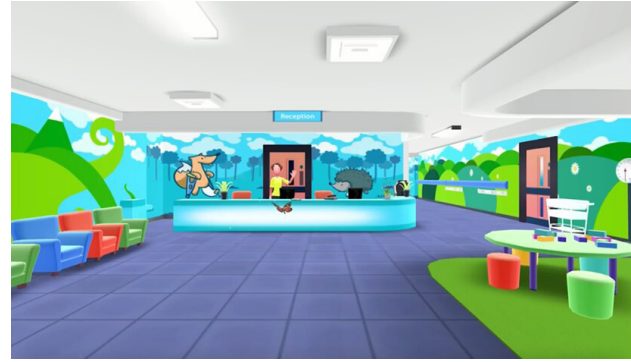


Figure 3 Virtual reality (VR) mode: hospital walkthrough.

Research methods

Playkit development coincided with five iterative stages of research with children and families: (1) initial concept research with primary school children; (2) exploring parental perspectives of MRI through a questionnaire; (3) character design development with children; (4) user testing with non-patients; and (5) full playkit testing with patients (n=13) and their parents/carers. This final stage comprised interviews undertaken with children (and their parent/carer) before and after their MRI scan.

Children were recruited via Sheffield Children's Hospital. All children were booked to come for an MRI scan. Two children had previous experience of MRI. Children were sent the playkit through the post a week before their MRI scan. A couple of days after they had received the playkit, JT or DYR undertook an online interview with the child and their parent/carer to discuss their reflections about their upcoming MRI scan and to hear their thoughts about the playkit. A follow-up interview was then conducted about a week after the child had their MRI scan. During this interview, the child and their parent/carer were asked about their experiences of the MRI and to reflect on what aspects (if any) of the playkit they had found useful in preparing them for the MRI.

Online interviews were transcribed and analysed by JT and DYR using thematic framework analysis.¹² Full

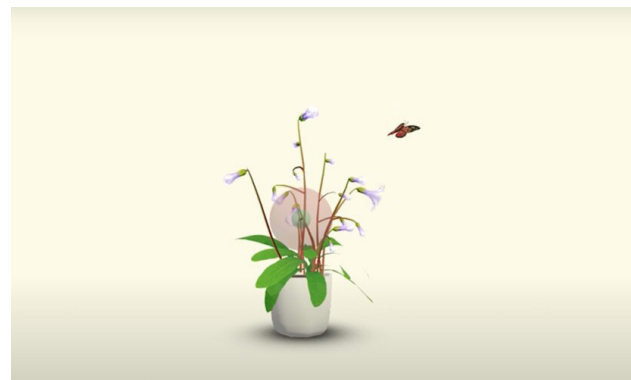


Figure 4 Virtual reality (VR) mode: interactive game to practise staying still.

methods are available.¹¹ We report here on the final stage interview data.

RESULTS

Findings and benefits for patients and parents/carers

Interview data collected during the final stage of the research suggested the playkit helped some children (and their parent/carers) to prepare to undertake an MRI and also helped to relieve anxiety during the scan.¹¹ Patients who were interviewed after their scan said that recalling aspects of the playkit during their scan helped them to remain calm and still. For some children, recalling the butterflies landing on the virtual plant helped them to remain still and remembering the scan images that the radiographers would be looking at helped to alleviate anxiety.¹¹

Child: The MRI model did help because it helped me understand what they were doing, so I was thinking about that when I was in the scanner, thinking about what they could actually see.

Parent: She was so much calmer this time. I do think it really did help actually. She wasn't half as nervous, was you. With [name removed] it really helped her to understand what she was actually looking at from seeing the scans. So obviously it did really help, didn't it?

Child: Yep. (Participant A5 post-scan)

For other children, the playkit helped prepare them for what an MRI scanner would look like and the noise that it would make.

Interviewer: Did it help you know what to expect?

Participant: Yeah, because I knew what the machine would look like. I just didn't expect it to be that big! (Participant C5 post-scan)

I thought the one [noise] on the phone was a bit louder ... the thing that shows how loud it is going to be, I think it helped me a lot. (Participant A4 post-scan)

There appeared to be differences across the age spectrum in terms of which aspects of the playkit children found most appealing, with the older children seemingly preferring the VR aspects and the younger children drawn to the physical play aspects of the kit and the AR. Further research may help to explore this.

Findings and recommendations for parents from creating the MRI playkit

Children use play to make sense of the world around them, and results from data collected as part of the development of the MRI playkit suggest that children benefit most when their parent/carer is actively involved in building the kit with them. Because of this, the playkit was deliberately designed to be slightly too difficult for a child to build alone. Findings showed that this opportunity to build the kit together gave children and parents a key moment to discuss the upcoming MRI scan and address together any associated worries.¹¹

It [building the playkit] gets you talking about it and then we went on to search out some more videos on YouTube (Parent of participant C3 pre-scan).

I had the chance to discuss it with him. You know, that's what's going to happen. You have to stay still and it's going to feel long but it's all about ... So yes, that was really good ... because we had zero knowledge (Parent of participant A4 post-scan)

However, some parents/carers and their children found the construction of the cardboard kit difficult, with some reporting that they didn't manage to complete the build.

We tried, but I have to say, well we found it impossible. I don't know if anyone else has been able to do it? But his dad tried and gave up and I was like 'I'm sure I can do this' and I couldn't do it. It was so complicated! (Parent of participant A3 post-scan)

As such, further refinement of the kit and the build instructions are required to ensure that they are accessible.

Findings and recommendations for healthcare professionals

Both children and parents reported that they had previously felt anxiety about the child having an MRI because of the unknowns involved. The playkit was designed to help familiarise the child and parent/carer with the MRI scanner itself, as well as the loud noises associated with the scanning process. The children studied also suggested that they would like to have detailed factual information about the MRI scan, which is an important recommendation for healthcare professionals who are working with children in these spaces.

DISCUSSION

The development of the mixed realities MRI playkit addresses a significant global problem within paediatric anaesthesia and presents an opportunity for a change in practice to reduce the number of paediatric GAs and improve efficiency and resource usage within radiology and anaesthetic departments. Although evidence is lacking on the harmful effects of repeated anaesthetics in childhood, cohort studies in humans have suggested that repeated GAs in children can lead to adverse neurodevelopmental effects. Given that around one in 10 children in high-income countries will need a GA at some point before the age of 3, we suggest that reducing the GA rate for MRIs presents a clear benefit, avoiding the requirement of GA for a non-invasive procedure by alleviating MRI-associated anxiety. The AR/VR/physical MRI playkit may also have a compound benefit effect on children requiring repeated MRI scans; further research is needed to assess this hypothesis.

Future directions of this novel project may include a possible extension of this concept to other aspects

of anaesthetic care—for example, to help prepare children coming into an admissions unit for elective surgery, transfer to theatre, intravenous access, induction, recovery and discharge. This would require necessary re-purposing of the design of the AR/VR app and model but holds significant promise for the future. Following the positive qualitative results of this local project, we suggest a clinical trial across anaesthetic departments nationally and internationally, and we encourage the uptake and rollout of the MRI playkit on a wider scale.

Twitter Jill Thompson @JillCThompson

Acknowledgements Images provided by DYR in collaboration with Dubit UK.

Contributors DYR and ST conceived the original idea for the project. ST led the design of the app. JT and DYR undertook the research. JT, DYR, ST, LM and MT discussed the findings and implications. All authors contributed to the writing of the paper.

Funding This work was funded through INNOVATE UK grant number 104547.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by North East Tyne and Wear South Research Ethics Committee. IRAS project ID: 270367. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution 4.0 Unported (CC BY 4.0) license, which permits others to copy, redistribute, remix, transform and build upon this work for any purpose, provided the original work is properly cited, a link to the licence is given, and indication of whether changes were made. See: <https://creativecommons.org/licenses/by/4.0/>.

ORCID iDs

Jill Thompson <http://orcid.org/0000-0001-9256-1208>

Louise Murray <http://orcid.org/0000-0002-7881-9628>

REFERENCES

- 1 Oxford Learner's Dictionary. Definition of augmented reality, Available: <https://www.oxfordlearnersdictionaries.com/definition/english/augmented-reality>
- 2 TechTarget. Definition: Virtual reality, Available: <https://www.techtarget.com/whatis/definition/virtual-reality>
- 3 Gatidis S, Bender B, Reimold M, *et al.* PET/MRI in children. *Eur J Radiol* 2017;94:A64–70.
- 4 Wilson SR, Shinde S, Appleby I, *et al.* Guidelines for the safe provision of anaesthesia in magnetic resonance units. *Anaesthesia* 2019;74:638–50.
- 5 Gulyurtlu S, Jacobs N, Evans I, *et al.* The impact of children's play in hospital. Starlight; 2020. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.starlight.org.uk/assets/documents/Starlight_ImpactOfPlay_Report_Oct20.pdf
- 6 Healthcare Safety Investigation Branch (HSIB). Undiagnosed cardiomyopathy in a young person with autism; 2020. Available: <https://www.hsib.org.uk/investigations-and-reports/undiagnosed-cardiomyopathy-in-a-young-person-with-autism/>
- 7 Jevtic-Todorovic V, Hartman RE, Izumi Y, *et al.* Early exposure to common anesthetic agents causes widespread neurodegeneration in the developing rat brain and persistent learning deficits. *J Neurosci* 2003;23:876–82.
- 8 U.S. Food and Drug Administration. FDA drug safety communication: FDA approves label change for use of general anaesthetic and sedation drugs in young children. 2017. Available: <https://www.fda.gov/drugs/drug-safety-and-availability/fda-drug-safety-communication-fda-approves-label-changes-use-general-anesthetic-and-sedation-drugs>
- 9 McCann ME, de Graaff JC, Dorris L, *et al.* Neurodevelopmental outcome at 5 years of age after general anaesthesia or awake regional anaesthesia in infancy (GAS): an international, multicentre, randomised, controlled equivalence trial. *Lancet* 2019;393:664–77.
- 10 Vutskits L, Culley DJ. GAS, PANDA, and MASK: no evidence of clinical anesthetic neurotoxicity! *Anesthesiology* 2019;131:762–4.
- 11 Yamada-Rice D, Thompson J, Love S, *et al.* Mixed realities playkit to prepare children for an MRI scan: findings for health, families and industry. 2022. Available: <http://dubit.us/mri>
- 12 Ritchie J. Carrying out qualitative analysis. In: *Qualitative Research Practice: A Guide for Social Science Students and Researchers*. 2003: 219–62.