Authors

D.M. Hudson [a],*,
C. Heales [b],
S.J. Vine [c]

[a] InHealth Group, High Wycombe, UK
[b] Medical Imaging, College of Medicine and Health, Exeter University, Exeter, UK
[c] College of Sports and Health Sciences, Exeter University, Exeter, UK

* Corresponding author. InHealth Group, Beechwood Hall, Kingsmead Road, High Wycombe, Bucks, HP11 1JL, UK.

E-mail address: Darren.hudson@inhealthgroup.com (D.M. Hudson).

Scoping Review: How is Virtual Reality being used as a tool to support the experience of undergoing Magnetic Resonance Imaging?

Introduction

Magnetic resonance imaging (MRI) has been one of the most significant developments in diagnostics over the last 30 years [1], with demand increasing year on year within the UK [2]. Due to the design of MRI scanners, the imaging technique involves patients lying within a cylindrical shaped superconducting magnet with receive coils placed over the areas of interest to obtain an image. This by its very nature can be daunting for patients and induce fear or anxiety [3], further exacerbated by the levels of noise involved, and having to lie flat and still for significant periods of time [4]. Other contributory factors can be associated with the unknown of what to expect and apprehension over what the scan may show [5,6].

Background

Experiencing anxiety is a natural response caused by what an individual perceives as a threat or source of stress [7]. Within MRI this most commonly presents, or is referred to, as claustrophobia, a situational phobia [8] triggered by aspects associated with the imaging technique. Although clithrophobia, related to the fear of being trapped and unable to escape as opposed to feeling confined or having lack of space, may also be applicable[9].

Reported rates of claustrophobia vary greatly between scanner design and examination type, with a systematic review and meta-analysis [10] showing the reported prevalence to range from 0.46%-5.29%, with greater occurrence associated with scanning of the head or neck. The calculated effect size of their meta-analysis was 1.18%, meaning that 1-2 patients per 100 experienced claustrophobia. Studies show that in the UK over 50% of scanners are traditional narrow bore (60cm) systems with over 25% being over 10 years old

[11]. Hence 20 years on, the issue of claustrophobia, and therefore the impact upon MRI scan outcomes, is still very much relevant in clinical practice.

The implications of experiencing claustrophobia when undergoing an MRI scan are variable; for some it will mean not being able to tolerate any scan at all [12], for others it may be the examination is abandoned part way through, or for those able to tolerate being within the scanner there may still be issues around patient movement and degradation of image quality [13,14]. Ultimately this experience can potentially have an adverse impact on the patient's diagnosis and onward management [10], as well as impacting on heightened anxiety should they need any further scans [15]. From a service delivery perspective, there can also be cost and productivity implications leading to lost revenue, wasted scanner time and reduced throughput [15,16], which is of concern in the current climate with imaging backlogs and lack of scanners across the UK [11,17].

Supporting patients with scan related anxiety, or situational claustrophobia, is based on understanding their fear, its rationale, and their ability to face the situation. The expectancy model of fear [18] provides some explanation around the responses to a situation based on one's expectation of what could happen and the reasons for thinking that. Response to a fear is not simply based on anticipated outcomes but also the self-efficacy someone has to cope with the situation [19]. Therefore, management of avoidant behaviour is based on primary appraisal of the level of potential threat, balanced with the secondary appraisal of being able to manage it. When an individual feels they have the resources to cope means they see the situation as a challenge but if they feel they do not have the ability to manage the situation it is then perceived more as a threat [20]. The perception of either is important as the common outcome of facing a threatening situation is avoidance; in this context removing oneself from the situation could equate to not starting or not completing

a scan. However if perceived as a challenge, an individual is more motivated to face their fear, resulting in a successful scan[21].

The aim of any intervention therefore needs to address these cognitions about the experience, moving to a state of challenge and being able to manage, as opposed to necessarily treating the source of the phobia or anxiety itself [19]. In relation to MRI, interventions cited in the literature are commonly targeted on adequate preparation around what to expect [22–24], or use of distraction techniques during the procedure, such as music and fragrance [25]. In other cases, it is around strategies to tolerate the examination, based on addressing patients' thoughts and fears [4,5] and shifting the balance of their self-efficacy.

Munn & Jordan[22] in a systematic review of interventions found that scanner design, staff training, changing patient position, use of fragrance, provision of information and cognitive behavioural strategies all had a positive impact. However, there was significant heterogeneity in effectiveness across the studies with no significant effect size, likely due to variation in study designs compared. Medicines such as benzodiazepines have also been used to manage phobias for some time now but increasingly due to caution around their safe use [26], this is being reduced which has implications in practice. Therefore, the need for non-medication-based tools to support patient experience, in particular sufferers of claustrophobia, are still important; one of which is the use of virtual therapeutics through virtual reality (VR).

VR is defined as *'a computer-generated digital environment that can be experienced and interacted with as if that environment were real'* (pg 9)[27]. Whilst predominantly developed in the field of gaming, it is also being used to provide a safe space for high-risk training and increasingly in a therapeutic setting, such as for pain management and

psychological interventions[28]. The use of VR is in essence built around understanding and communication, with the key concepts of immersion (so that users feel engaged within it) and presence (the sense of being wherever is being displayed)[27,28].

Within the realms of claustrophobia and other anxiety disorders, VR has been used as an alternative to *in vivo* exposure and an adjunct to the delivery of cognitive behavioural therapy[29]. In this context, the use of virtual environments allows patients to experience fear inducing stimuli whilst in a safe space. Traditional approaches with VR in claustrophobic patients have involved the use rooms or elevators which can be easily changed in size to induce a response and aid therapy over repeated sessions[30].

Therefore, the aim of this scoping review was to explore how VR is being used to specifically support patients undergoing MRI, and thereby better understand the current extent of evidence available to inform further developments and focus of research.

Methodology

For the search of the literature the research databases together with the search terms used are outlined in Table 1. The search terms were looked for in the title and/or abstract depending on the database configuration, and the inclusion criteria used were papers written in English and available in full text. Supplementary to the database searches, various combinations of the search terms were also used to search the world wide web using Google and Google Scholar for any additional resources to complement the lack of peer-reviewed papers identified.

Table 1: Databases and search terms

• Medline OVID (which included Ovid Medline, EMBASE and APA Psycinfo) • CINAHL • Medline PubMed				• Google • Google Scholar
VR *Virtual Reality* *360*	**AND**	*Claustrophobi** *Anxiety* *Experience*	**AND**	*MRI* *Magnetic Resonance Imaging* *MRI Scan*

Suitability of papers were first screened from their abstract contents to ensure their relevance, followed by the removal of any duplicate papers - Figure 1. Full text copies of all papers were then obtained and reviewed with key aspects recorded - Table 2. These data were then reviewed under 3 overarching themes with further coding underneath each allowing easy identification of relevant aspects of each study - Table 3.

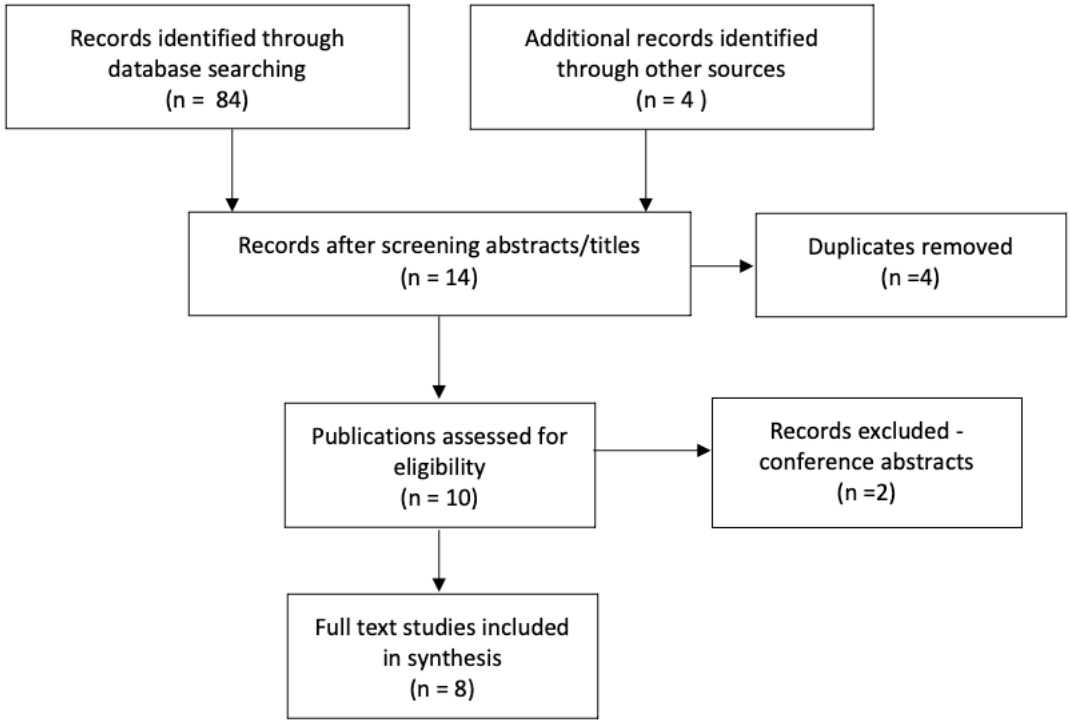

Figure 1: PRISMA flow chart

Table 2: Paper summaries

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Table 3: Thematic Overview

Themes	VR Design							VR Intended Use					Outcomes	
Authors	Non scanner Sim	3D scanner modelling	360 scanner Video	Gamification	Providing Pt Info	Scanner and scan Room only	Other rooms/areas	Explorable	Exposure/ desensitisation Rx	Inform & prepare	Distraction during scan	Paediatrics	Reduction in anxiety	Positive feedback
Botella et al (1998)	✓							✓	✓				✓	
Garcia-Palacios et al (2007)	✓			✓							✓		✓	
Liszio & Masuch (2017)		✓		✓	✓		✓	✓	✓	✓		✓	✓	✓
Brown et al (2018)		✓			✓		✓	✓	✓	✓			No measures	
Rahani et al (2018)	✓	✓	✓	✓		✓			✓				✓	✓
Ashmore et al (2019)			✓		✓		✓			✓		✓		✓
Nakarada-Kordic et al (2020)		✓			✓	✓		✓	✓					✓
Liszio et al (2020)	✓			✓							✓	✓		✓

Due to the scarcity of papers available none were excluded based on critical appraisal or content as it was felt that they all contributed in terms of relevance to the aim of the review. The papers found were variable in nature and design with a lack of empirical evidence overall whilst still providing useful insights into the potential role of VR. The aims and limitations of each paper will be addressed in the results.

Results

The majority of studies (6 out of 8) found were from within the last 4 years and from western based countries, which likely reflects the increasing use of VR as a tool as it becomes more affordable, accessible and applicable in practice.

VR as Therapy

The earliest study from 1998 [31] sets the scene on how VR could be used to support treatment of claustrophobia in preparation for a scan. Whilst their case report was aimed at a patient undergoing a computerised tomography scan, the effects and implications may also have some application to MRI although the case study design means it is not generalisable. The design was based around exposure therapy where the patient was placed in a virtual environment (VE) that could be explored as they became acclimatised, increasing in severity as they progressed through the simulated rooms, whilst under their control always.

Numerous psychologically validated measures were used to assess the response to fear, avoidance and discomfort which all reduced during the treatment and at one month. Ultimately success was evidenced in this case with completion of the required scan procedure.

Twenty years on, a similar VE approach was used where participants were exposed to a lift scenario [32]. Whilst the approach ended with the participant being exposed to an MRI

scanner, this was achieved through a video which limited the immersiveness of the design. Physiological measures were undertaken at the start of the simulation, but not throughout or afterwards, so it is not possible to evaluate the physiological response as the VE progressed. The main measure used for assessment of the participant anxiety was a modified version of the State-Trait Anxiety Inventory (STAI), as well as a questionnaire looking at playability of the platform. Overall, the results suggest a reduction in the mean anxiety scores pre- and post-simulation, with a larger spread of results post intervention.

Around the same time, Brown et al., [33] describe their VR tool for the simulation of the MRI experience which used 3-dimensional (3D) modelling to replicate the scan room environment and scanner itself. Participants were able to explore the scan environment as well as be placed within the bore of the magnet. To further enhance the realism, sounds of the scanner were added. Whilst only a developmental study, it does highlight some useful points regarding design and suggests that interaction over many times could aid desensitisation as well as fully informing patients what to expect prior to a scan.

Most recently, Nakarada-Kordic et al., [34] compared their 3D simulation of a virtual scan room and scanner with that of undergoing a mock MRI. This was a small-scale study, the measures used may not have been validated, and there was a low occurrence of claustrophobia experienced by the participants. However, despite this limited transferability, this study does provide useful data. Twenty participants underwent both a 20-minute mock head scan and one replicated in the VE.

A mix of subjective questions about the experience and rating scales of how anxious, comfortable, or relaxed they were, were obtained throughout. Whilst results showed a similar downwards trend between the two approaches, due to the small study numbers there was no statistically significant differences noted. The only notable finding was on the

mock scanner where participants felt less comfortable towards the end, although this was felt to be more realistic than VR. That said, the majority still found VR helpful and would choose it over a mock scan, mainly because it could be accessed at home and at a time that suited, as well as having that control over the VE and being able to immediately withdraw from the simulation if needed. The study therefore suggests that VR is a suitable replication of a real scan experience.

Paediatric Preparation

A common theme for almost half of the papers reviewed was the focus on paediatric patients varying in age between 4-15 years old. Application of VR in this patient group was more around preparation to achieve compliance as opposed to necessarily claustrophobia.

Liszio & Masuch, [35] combined exposure therapy along with information, gamification and play therapy to reduce anxiety. Following a classic play therapy approach, this provided information related to having a scan, observation of the environment, modelling what happens and then actual experience of a scan. This brings together anxiety reducing methods using gaming and VR. They used different participants at different stages of the design and testing process to develop the tool.

Their results showed that those using the VR simulation showed a small degree of reduction in self-reported anxiety immediately afterwards, but this was not maintained during the real scan. No significance was found and a wide variation in scores from the experimental group suggest response was likely influenced by other factors, such as the nature of prior scanning. That said, the overall experience of VR was positive, and with repeated exposure and addition of coping strategies the effect could be more replicable and sustained.

A cross-sectional evaluation by Ashmore et al., [36] took a different approach to the VE with the use of 360º captured video footage for immersion into the virtual world. This comes with limitations around full explorability and simply being a bystander observing the experience. Others have suggested that video footage can be distorted and limits the realness of the experience compared to modelling [33], plus consideration is needed over practicalities to acquire footage within the magnetic field. That said, they accomplished a series of 360º videos which takes the patient along their journey within the department and is accompanied with a book to aid preparation.

Non-validated experience measures were used, although feedback was positive from all parties, including the parents. 4 out of 5 patients planned for general anaesthesia were able to tolerate a scan without, and with no image degradation caused by movement.

Distraction Technique

The final two papers reported on the use of VR whilst undergoing a scan to see if this helped as a distraction technique as opposed to preparation or exposure therapy.

The first was a case series with two patients who both prematurely terminated a mock MRI scan [37]. One was then scanned with music and the other using VR. The former was unable to complete the scan again, whilst the patient with VR was able to complete with lower anxiety, suggesting that as a distraction technique this could be more effective. Both participants had confirmed levels of claustrophobia, and self-reported levels of anxiety were recorded every 3 minutes during the mock scan. The participant using music had heightened anxiety on their second attempt and the scan was abandoned sooner, potentially raising the contributing factor of failing a previous scan, as well as audio distraction alone not being enough.

Most recently, Liszio, Basu, & Masuch, [38] developed an in-bore VR game to reduce stress and anxiety in children undergoing MRI. The study design followed a participatory model throughout to ensure the developed tool met children's needs, was age relevant, and accepted. Whilst not a formal study, the feedback was positive and it has the potential to avoid need for sedation to achieve a diagnostic scan with minimal distress and time.

Discussion

Whilst only a limited number of papers were identified as part of the literature review, findings show that VR can be used in several ways to support patient anxiety and experience when undergoing MRI. Whilst the published data are from small scale studies, they do highlight real potential for reducing anxiety and improving compliance through its use. Perhaps just as importantly there is also evidence that the use of VR seems to be well-accepted by those subjects involved. The main themes considered have been the design of the VR intervention itself, its intended use, and how effectiveness has been assessed. There is less information on the underlying mechanisms behind how VR may be working and of most benefit.

Half of the papers reviewed used 3D modelling to create the VE of a scan room, a quarter as a distraction technique and another quarter utilised some other claustrophobia inducing VE. Useful development points highlighted were around being in control and able to explore the VE as they would in the real world. Immersiveness and the feeling of reality is important, with consideration over making the view from within the scanner and the table feel realistic. Along with placement of receiver coils used to acquire images and positioning into the scanner, entry into the scan room has been acknowledged as a point of heightened anxiety [4,15,39] and so being able to experience all of these aspects adds to the realness.

The main approach behind the use of VR was to inform and prepare patients for a scan. Anxiety associated with MRI can be reduced with the provision of information about what is involved in advance and effective communication [23,24]. These approaches focus on reducing the perceived harm associated with the unknown or anticipated experience of a scan [35]. The use of VR as an intervention is in this ability to replicate and immerse the individual into a world that represents reality, allowing participation rather than simply observing.

Previous studies have shown how written materials or verbal description are lacking due to their misinterpretation and limited representation [23]. Compared with more traditional approaches using information leaflets or video, VR can provide a more realistic example of what to expect. Use of sensory information has been shown to help patients better understand and manage demands placed on them [40]. Furthermore, use of video and animation have shown more realism and representation to a point, and support accessibility and acceptability at home [14,41,42], concepts which have potential to be enhanced with VR.

With the nature of the equipment being the main source of fear, use of mock scanners has been suggested, but not widely available [3,43]. Studies have shown that patients want to practice entry and exit into the scanner to become accustomed to it [6,15]. Munn, Jordan, Pearson, Murphy, & Pilkington, (2014) found that being able to spend time with patients to coach them into the scanner was difficult due to operational pressures and lack of time. Again, these may be where the use of VR could provide a safe space for patient coaching and exposure in advance of a scan procedure, without taking time away from much needed scanners.

Conclusion

Whilst a limitation with the review was the scarcity of literature available, plus a lack of larger scale, controlled research, this does show that the use of VR in supporting patients undergoing MRI is a growing field. All papers either showed positive feedback from participants or suggest a reduction in anxiety. However, there is a lack of understanding as to how VR may be having a positive effect and how best to target its use. Is it time spent in the VE that truly prepares patients or does it come down to the additional time afforded to them with its use?

Further work, therefore, is needed in terms of the design of the VE to ensure its realism, but also clarity over its purpose to ensure its impact beyond just novelty. Studies to date have focused on development of the VEs and initial feasibility. The limitations overall are in the variability of measures used and small numbers assessed. Moving forwards, use of standardised, validated psychometric measures to evidence clinical efficacy is recommended. Although that said, the papers highlight early thinking around the uses and benefits of VR within MRI. The review was very much focused on the specific use of VR in the specialised clinical context of MRI. Exploring the wider VR literature and its use in managing claustrophobia and other anxiety disorders may also be transferrable to help inform future developments and use.

Findings from this review support the case for further developing VR as a potential tool. Compared to other interventions, VR comes with improved accessibility, lowering resource costs, and allows patients to be able to practice and experience the procedure as many times as they like to become accustomed to it and build on any taught coping strategies without the need to take up actual scanner time.

Using technological approaches like VR has the potential to provide real opportunity to harness its immersive benefits and realism to support patient experience. At the same time its use provides scope for enhanced emotional support from imaging staff away from the constraints of a busy department, thereby helping to bring the importance of human connection and patient centred approaches back into the clinical setting to support patients' emotional needs prior to MRI.

This scoping review has shown that VR is gaining traction as an intervention with continued research needed to evidence its effectiveness but also practical application in the clinical setting. It has been shown to reasonably replicate the real-life scenario and have a positive impact on patient satisfaction and reduce anxiety. However, there is little evidence around the theoretical basis on which it works. Further understanding of this would better inform further development as a tool for optimal implementation and effectiveness.

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Author(s)	Year	Country	Design	Aims/Purpose	VR Design	Measures Used	Methodology	Participants	Results	Outcomes	Limitations
Botella et al	1998	Spain	Case report	Exposure treatment prior to CT scan	VR modelling of 3 environments controlled by patient	6 measures: Fear & avoidance scale (FAS) Fear of closed space measure (FCSM) Problem related impairment questionnaire (PRIQ) Subjective units of discomfort scales (SUDS) Self-efficacy towards the target behaviour measure (SETBM) The attitude towards CT measure (TAM)	exposure only with no anxiety management techniques. 8 sessions (35-45mins) over 3 weeks = interaction long enough for anxiety to reduce. Measures conducted at beginning, post treatment and one month follow-up. SUDS assessed every 5mins throughout exposure.	1 (43F)	All measures reduced and were maintained at follow-up. Fear and avoidance measures dramatically decreased. Session SUDS were highest when exposed to greater threat but reduced in following sessions.	Patient rated contribution of VR to her success as 8/10. Successfully underwent CT scan after session 6.	Single case No statistical testing of measure changes. VR tool did not replicate scan but focused on phenomena of claustrophobia.

Garcia-Palacios et al	2007	Spain/USA	Case series	Use of VR to reduce claustrophobia during mock MRI scan	SnowWorld - 3D virtual canyon with games	Claustrophobia questionnaire (CLQ) Anxiety Disorder interview schedule (ADIS-IV) Behavioural avoidance test	Both patients exposed to mock scan and abandoned before 10mins. On second attempt, one received music and one received VR - randomly assigned	2 (29F & 49F)	Patient 1 scored lower on CLQ but rated higher anxiety in scanner, abandoning after 6 mins but with VR managing the full 10mins with reduction in anxiety scores. Patient 2 scored higher on CLQ but rated lower anxiety in scanner, with anxiety increasing before abandoning at 6mins. She abandoned sooner at 3mins with higher anxiety with music.	Potential of VR during MRI to temporarily reduce claustrophobia symptoms. Highlights visual tools as being more distractive than audio.	Single case with one comparator.

Liszio & Masuch	2017	Germany	Developmental and Pilot study	To develop a tool to reduce children's anxiety prior to MRI	Combines patient information; play therapy; gamification; exposure to desensitize and habituate to scanner beforehand. Focuses on preparation and primary assessment of stress - based on experience, information and games. Built on 4 steps in play therapy - information, observation, modelling, exposure.	Structured interview questions State-Trait Anxiety Inventory for Children (STAIC) subscale before, after and during. T-scale STAIC for overall anxiousness.	Child-centred co-design process - feedback from explorative/unstructured interviews Focus group with children with and without MR experience, and staff. Used with sample in clinical practice with those needing a scan. Control group (CG) with no intervention; Exposure group (EG)received VR app ion waiting room.	Paeds (8-15) Design = 5 Development study = 7 + 4 staff Pilot study = 13	Overall positive feedback - informed further development. Differences in mean STAIC-S scores across EG were not significant - MANOVA, neither did means of CG with paired t-test. No difference between groups on MANOVA either. No differences with prior experience, or correlations of scores with presence, immersion or age.	Drop in mean scores post use, although these return to pre levels. Suggests potential for reducing anxiety. Stats were not significant. VR offers a potential alternative to conventional methods for patient prep.	Only used VR once - repeated usage would strengthen effects. Small cohort size. Potential external factors influencing patients. Limited emersion due to VR hardware used.

								Positive user experience feedback and scoring.			
Brown et al	2018	USA	Developmental	VR tool to simulate MRI Experience	Educates patients about MRI and to virtually experience having a scan.	None used	Design process outlined. Plan to offer to those who may consider need for sedation.	No feedback obtained General patient focus	None to report	Clinical trial being planned to assess effectiveness of the VR app in decreasing anxiety, claustrophobic cancellations, and need for conscious sedation.	Developmental study and so no outcome measures reported
Rahani et al	2018	Iran	Developmental and Pilot study	VR tool to treat claustrophobia as exposure therapy	Following game development process; preproduction, design, implementation, evaluation Video on fear of	HR, BP and resp rate recorded at start STAI-Y questionnaire before and after game Playability questionnai	Participants underwent game and completed measures	33 total 14 patients with claustrophobia 19 volunteers without	Obvious anxiety after the game was less than before Significant difference in mean scores pre and post for	Could help reduce anxiety due to closed spaces Playable resource	No between group comparison of patient's vs participants. Only significance testing of

					closed spaces Lift experience in 10 storey building with access to relaxation room MRI Scan room with video of inside once close up Uses 360 video footage to acclimatise to MRI journey. For use with play therapists, at home, in waiting areas, and as part of pre assessment process for GA. Developed by play specialists and	re after game			the patients with claustrophobia Good playability factors		patient group.
Ashmore et al	2019	UK	Cross-sectional evaluation	Development of VR platform to prepare paediatric patients for MRI		NICE Standards Framework for Digital Health Technologies (2018) Questionnaires used 10- or 5-point Likert scales for feedback on their experience.	Resource provided to patients before having MRI scan; either at home or on site. Following use feedback was obtained to inform further development and implementation	Paeds (4-12) = 23 10 staff Across 3 locations	Positive response as a prep resource. Helped parents understand what their child was undergoing, reducing their own concerns and meaning they were more prepared to help. Positive response	Enjoyable experience for children.	Fixed video scenes limiting free exploration through environment. No formal measures of reduced anxiety - perceived or physiological. Feedback based and not comparative with a

					radiographers to capture entire journey. Accompanying prep book. Freely downloadable app with Google cardboard.				from staff seeing this as a useful tool. 4/5 booked GA cases were able to undertake study awake with no degradation from movement.		control group so limited application of results.
Nakarada-Kordic et al	2020	NZ	Feasibility study	VR tool to simulate MRI Experience Feasibility of using VR MR Sim as cost-effective and accessible alternative to mock MR for scan prep.	VR model replicates mock exam room. Can walk around scan room and move in and out once lying down.	Self-reported anxiety, level of comfort and relaxation Assessed at beginning of study, 5 touch points during each sim, at the end of each sim, at end of study. Subjective	Head and neck scan as most challenging exam Participants underwent VR and Mock in different orders; randomised to approach. 20min mock or VR sim	Staff and students Excluded if prior MRI or any hx of mental health n=20	No significant differences between ratings and the 2 interventions. Comfort on the mock exam reduced during the exam. No significant differences in post sim experiences.	No difference between the 2 experiences, although feedback suggests they were more nervous in the mock scanner, suggesting this still feels more realistic. VR has the potential to	Small sample size. Non patient group - no assessment of those with and without claustrophobia, and their levels of anxiety. non-validated survey tools.

	questionnaire modelled on prior studies pre. Verbal 5-point rating on how anxious, comfortable and relaxed they were throughout - modelled on STAI Subjective questionnaire on overall experience and comparing the two.	Having claustrophobia felt less comfortable etc throughout but subjective comments aligned with those without claustrophobia. Mock scan felt more real than VR in 65% of cases, although 86% found VR helpful as a prep tool. 75% would choose VR because they could undergo at home. During VR more participants felt more comfortable and relaxed	be a viable, more accessible alternative with some modifications.

										(55%/60% vs 25%/15%)		
	Liszio et al	2020	Germany	Developmental	Participatory design of in-bore VR tool	Pengunauts: Star Journey story and game for in-bore immersion	Worksheets, facilitated workshops, semi-structured interviews	Participatory design process in 3 phases from ideation to prototype	Paeds - 15 (5-15), 14 (9-11), 6 (5-11)	Positive response from participants on final prototype.	Developed in-bore VR environment is child relevant and supports emersion and distraction during an MRI scan	No formal assessment of improved scan outcome - tolerance, movement etc

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