

BMJ Open Subjective discomfort in children receiving 3 T MRI and experienced adults' perspective on children's tolerability of 7 T: a cross-sectional questionnaire survey

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To cite: Chou I-J, Tench CR, Gowland P, *et al.* Subjective discomfort in children receiving 3 T MRI and experienced adults' perspective on children's tolerability of 7 T: a cross-sectional questionnaire survey. *BMJ Open* 2014;**4**:e006094. doi:10.1136/bmjopen-2014-006094

► Prepublication history and additional material is available. To view please visit the journal (<http://dx.doi.org/10.1136/bmjopen-2014-006094>).

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Received 11 July 2014
Revised 1 September 2014
Accepted 5 September 2014



CrossMark

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ABSTRACT

Objectives: To explore the possible discomfort perceived by children participating in 7 T MRI research, and the age range in which children are most likely to tolerate it well.

Design: A cross-sectional survey using age-appropriate questionnaires containing six measures of subjective discomfort (general discomfort, dizziness, noisiness, claustrophobia and feeling of cold or warm).

Setting: For children, 3 T clinical scanner in a tertiary referral teaching hospital; for adults, 3 and 7 T scanner in a university research building.

Participants: Non-sedated children and young people under 18 years of age who underwent 3 T clinical MRI for brain or musculoskeletal scans and adult volunteers attending 7 T with or without 3 T for brain scans.

Results: 83% (89/107) of involved individuals returned questionnaires. The most common discomfort among 31 children receiving 3 T MRI was noisiness (39%), followed by cold (19%), general discomfort (16%), dizziness (13%) and claustrophobia (10%). The noise was reported more frequently in children younger than 12 years than those older ($p=0.021$). The most common discomfort for 58 adults receiving 7 T MRI was noisiness (43%). In adults, there was a higher frequency of general discomfort during 7 than 3 T scans ($p=0.031$). More than 85% of adult respondents thought children aged 12–17 years would tolerate 7 T scans well, but only 35% and 15% thought children aged 10–11 and 8–9 years, respectively, would.

Conclusions: Noisiness was the most common discomfort across all ages in 3 and 7 T scanners. Although general discomfort was more common during 7 than 3 T scans in adults, most adults thought children aged 12 years or more would tolerate 7 T MRI well. Cautious enrolment of children in 7 T MRI study is warranted, but until there is more evidence of how well those aged 12 years or more tolerate 7 T MRI, we would caution against enrolling younger children.

Strengths and limitations of this study

- This is the first study to record children's discomfort during 3 T clinical MRI and to consider at what age they might tolerate 7 T MRI.
- The study findings inform clinicians and professionals of the potential sources of discomfort that may arise during high-field MRI and facilitate development of strategies to minimise discomfort.
- This report also provides useful data for Research Ethics Committees who are evaluating protocols for high-field MRI research involving children.
- The limitations are that the sample size was small, and the adult research volunteers may have been biased in favour of 7 T MRI tolerability.

INTRODUCTION

MRI depends on a static magnetic field to generate detectable and decipherable signals. Higher field strength potentially improves signal-to-noise and contrast-to-noise ratio, leading to images with a better spectral and spatial resolution. Currently 1.5 T MRI is the routine for clinical use and 3 T MRI in a clinical context is becoming more common. With clear depiction of submillimeter anatomical details and better imaging contrast, 7 T MRI may become an ancillary diagnostic tool for brain and musculoskeletal imaging in the near future.

Despite many technical improvements, obtaining optimal images relies on how well an individual tolerates lying in the MRI scanner, the surrounding environment and attendant procedures. Factors which may reduce the participants' tolerance for all types of MRI regardless of field strength

include prolonged scanning time, environmental temperature, noisiness, uncomfortable position or padding, and the individual's level of anxiety.¹⁻³ Discomfort that is more commonly experienced in MRI systems operating at 3 T or higher magnetic field strengths than that at 1.5 T includes dizziness, vertigo, nausea, peripheral nerve stimulation and the perception of a metallic taste.⁴⁻¹⁰ These subjective perceptions have been described in adults. No study has been conducted to survey tolerability of 3 or 7 T MRI in children despite increasing use of 3 T MRI and a small number of children involved in 7 T clinical functional MRI.¹¹ In addition, ethical considerations in involving children in 7 T MRI research have not been tackled.

To explore the possible discomfort perceived by children participating in 7 T MRI research, and the age range in which children are most likely to tolerate it well, we launched this preprotocol public and patient involvement survey. To do this we (1) documented the sources of discomfort reported by children (stratified by age group) undergoing clinical 3 T MRI studies; (2) documented the sources of discomfort reported by adults undergoing 7 T MRI studies; (3) compared the reported rates of discomfort in a cohort of adults who underwent both 7 and 3 T MRI and (4) asked the adult participants who underwent 7 and 3 T MRIs to predict how well children (stratified by age group) would tolerate each system.

MATERIALS AND METHODS

This public and patient involvement, which is in line with current guidance regarding service evaluation in the UK,^{12 13} was part of the successful research ethics committee application (13/EM/0080). Anonymised data from children undergoing clinical 3 T MRIs came from an ongoing service evaluation exercise performed in the MRI Department at the Nottingham University Hospitals NHS Trust, which the ethics committee approved as a preprotocol exercise.

Patient and public engagement

We invited a convenience sample of non-sedated children and young people under 18 years of age who underwent 3 T clinical MRI for brain or musculoskeletal scans, and their parents/carers to complete an anonymised questionnaire on the day of the scan. Adult volunteers attending our 7 T MRI research facility were also asked to help by completing an anonymised questionnaire. Some of the adults had undergone both 3 and 7 T scans; they completed identical questionnaires for each scanner.

MRI

The characteristics of MRIs are shown in [table 1](#); the sequences and duration of scans are shown in [table 2](#). Adult participants underwent the MRIs at a university MRI research facility using a 3 T Philips Achieva (Philips Medical Systems, Best, Netherlands) with a bore diameter of 60 cm and a 7 T Philips Achieva (Philips Medical Systems, Best, Netherlands) with a bore diameter of 58 cm. Children undergoing a clinical 3 T scan were imaged using an identical Philips Achieva system in the MRI department of a tertiary referral teaching hospital. Ear plugs and headphones were provided in both 3 T systems, while ear plugs and acoustic foam pads were used in the 7 T system because of the smaller size of the transmit-receive head coil.

Questionnaires

We designed age-appropriate questionnaires to measure the degree of discomfort during MRI, which were designed by a paediatric neurologist (WPW) and an adult neurologist (CSC); both have many years' experience of designing and using questionnaires in service evaluation, clinical audit and clinical trials. Six subjective measures were surveyed for all ages: general discomfort, dizziness, noisiness, claustrophobia and feelings of cold or warm. These were chosen because they were the most common symptoms of discomfort reported in the high-

Table 1 A comparison between the 7 and 3 T MRIs for brain imaging

	7 T MRI	3 T MRI
Scanner	Philips, Achieva, Best, the Netherlands	Philips, Achieva, Best, the Netherlands
Gradient system	Whole body	Whole body
Radiofrequency transmitter coils	Head-only	Whole body
Radiofrequency receiver coils	Head-only, 16 or 32 channel parallel imaging SENSE (sensitivity encoding) receive coil	Head-only, 8-channel parallel imaging SENSE receive coil
Dimensions of the bore (diameter, length)	58 cm, 340 cm	60 cm, 180 cm
Height of the bed	106 cm; fixed	54 cm (lowest level); automatically adjustable table
Room temperature	Centrally controlled	Centrally controlled
Humidity setting	Centrally controlled	Centrally controlled
Noise protection	Acoustic foam pads plus ear plugs	Headphones plus ear plugs

Table 2 Characteristics of respondents to questionnaires on high-field MRI

	Adults (n=58)		Children (n=31)
	7 T (n=58)	7 and 3 T (n=26)	3 T
Age (years; mean, range)	41.5 (19–60)	39.7 (27–58)	12.7 (7–17)
Female	37 (65%)	15 (58%)	14 (45%)
Diagnosis			
Healthy (n, %)	10 (17%)	5 (19%)	0
MS/CIS (n, %)	48 (83%)	21 (81%)	0
Other (n, %)	0	0	31 (100%)
Body part scanned			
Brain (n, %)	58 (100%)	26 (100%)	70%*
Musculoskeletal (n, %)	0	0	30%*
Sequences	7T: 3D MPRAGE (\pm Gd), FLAIR, T2-star, B1 map, T1 map, MT imaging, LLTFE	3 T: FLAIR, T2, DTI	T1 (\pm Gd), T2, FLAIR, ADC map, DWI
Duration of scan (min)	55–75	7 T: 55–75 3 T: 20	20–60

*Value estimated.

ADC, apparent diffusion coefficient; CIS, clinically isolated syndrome; 3D MPRAGE, three-dimensional Magnetisation-Prepared Rapid Acquisition and multiple Gradient Echoes imaging; DTI, diffusion tensor imaging; DWI, diffusion-weighted imaging; FLAIR, fluid attenuated inversion recovery; Gd, gadolinium contrast agent; LLTFE, Look-Locker Turbo Field-Echo; MS, multiple sclerosis; MT, magnetization transfer.

field MRI literature.^{7–10} The less frequently occurring perception of metallic taste or sensation of twitches that could be related to peripheral nerve stimulation was also included in the questionnaires for children aged 8–11 and 12–17 years, but not for children aged 5–7 years, considering their ability to understand these concepts and read lengthy text. We also asked participants aged 12–17 years whether having a blood test or being given contrast agents would affect their decision to be involved in future MRI research.

Separate questionnaires were designed for children aged 5–7, 8–11, 12–17 years and adults. The questions for patients aged 5–7 years were illustrated with pictures and asked for 'yes' or 'no' answers. Patients aged 8–11, 12–17 years and adults were given a five-point modified Likert scale: 'yes very' (score 5), 'yes a little' (score 4), 'so-so/not sure' (score 3), 'no not really' (score 2), 'no not at all' (score 1). Children and adolescents were also asked if they would mind having the MRI again in 1 year's time.

To understand public opinion on the suitability of involving children and young people in high-field MRI research, we designed questionnaires for adults who had experienced 7 T, and some of them also 3 T, MRI and asked their opinion on how they thought children and young people of different ages (8–9, 10–11, 12–15 or 16–17 years) would tolerate 7 and 3 T MRI. We also used the five-point modified Likert scale as 'yes definitely' (score 5), 'yes probably' (score 4), 'not sure' (score 3), 'no probably not' (score 2), 'no definitely not' (score 1).

A separate questionnaire was designed and given to parents or carers of involved children, which contained open questions to collect their views on the tolerability of 3 T clinical MRI for their children. The questionnaires used are included in the 'online supplementary file 1'.

Image quality assessment

To test the possible relationship between the tolerability measured by the questionnaire and the quality of acquired images, the 7 T research brain images of adult patients were evaluated by I-JC, who was blinded to the results of the questionnaire. The image quality was classified as excellent, good or blurred. The aspects of image quality such as lesion detection, motion artefacts and sharpness were all considered.

Statistical analyses

Likert scale data were analysed as ordinal variables. We also dichotomised the data into 'agree' (score 4 or 5) and 'disagree' (score 1–3). Summary statistics were expressed as percentages for categorical data and mean \pm SD for approximately normally distributed continuous variables. Differences in the baseline characteristics and response of each question between the subgroups were tested using the Fisher's exact test for dichotomised data. Differences in the Likert scaled data were tested using the Mann-Whitney U test. Differences among the paired groups were tested using the McNemar's χ^2 test for dichotomised data. Two-tailed tests were used and a p value less than 0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics, V.21 (SPSS Inc, IBM Corp, Chicago, Illinois, USA).

RESULTS

Eighty-three per cent (89/107) of involved individuals returned questionnaires (response rate of children: 78%; of adults: 87%). Questionnaires from three children (aged 9, 14 and 16 years) were partially completed. Twenty-six out of 58 adult respondents (45%) experienced both 3 and 7 T research MRI. Children were aged

7–17 (mean 12.7, SD 3.0) years and adults 19–60 (mean 41.5, SD 9.9) years (table 2).

Questionnaires

The most common discomfort in children and young people undergoing 3 T MRI was ‘noisiness’, as reported by 39% (12/31) of them. Discomfort was reported by 19% (6/31) for ‘cold’, 16% (5/31) for ‘general discomfort’, 13% (4/31) for ‘dizziness’ and 10% (3/31) for claustrophobia (‘being closed-in’). Only one of 31 children (3%) rated the experience as very uncomfortable. Additionally, 1 of 26 children (4%) reported a metallic taste (‘funny’ or ‘strange’ taste), while 6 of them (23%) had a feeling consistent with possible peripheral nerve stimulation (‘funny’ or ‘strange’ movements, or ‘twitches’). There was neither an age trend nor significant gender difference in their answers. Seventy-nine per cent (22 out of 28) children were willing to have another MRI in a year’s time. Figure 1 compares the proportion of subjective discomfort between children and young people older than 12 years and those younger. Only noisiness was reported more frequently in younger than in older children ($p=0.021$). Twenty-seven per cent (7 out of 26) parents/carers reported that their children’s discomfort was related to the hard mattress and lying too still for too long.

Of 58 adult respondents who underwent 7 T MRIs, noisiness was the most frequent discomfort 25/58 (43%), followed by cold 20/58 (34%), general discomfort 18/58 (31%), claustrophobia 18/58 (31%) and dizziness 17/58 (29%). Women reported higher ‘general discomfort’ Likert scale scores than men ($p=0.042$).

In 26 adults who underwent both 3 and 7 T MRIs, there was a higher frequency of general discomfort during 7 than 3 T scans (McNemar test, $p=0.031$; figure 2). There was a higher frequency of noisiness, dizziness or claustrophobia during 7 T MRIs than during 3 T MRIs, although it did not reach statistical significance.

More than 85% of adults thought children aged 12–17 years would tolerate both 3 and 7 T scans well, but only 35% and 15% thought children aged 10–11 and 8–9 years would (figure 3). The sum of scores for the six discomfort domains was negatively correlated with the sum of the scores of the adult’s opinion of the children’s probable ability to tolerate 7 T MRI (Spearman’s correlation= -0.330 , $p=0.011$).

Among adolescents aged 12–17 years, 8/19 (42%) of them agreed that having a blood test would ‘put them and other young people off’ volunteering for a MRI research examination, while only 12/58 (21%) adults did ($p=0.077$). Further, 8/19 (42%) adolescents agreed that having a contrast agent injection during a scan would ‘put them and other young people off’ volunteering for a research scan.

Image quality

In total, linked anonymised brain images of 29 adult patients were available to be examined retrospectively. Nineteen of 29 (65%) images were classified as excellent, 8/29 (28%) good and 2/29 (7%) blurred. Both of the patients with blurred MRIs did not find 7 T MRI uncomfortable. There was no statistical difference in the image quality between patients who reported discomfort and those who did not ($p=1.000$).

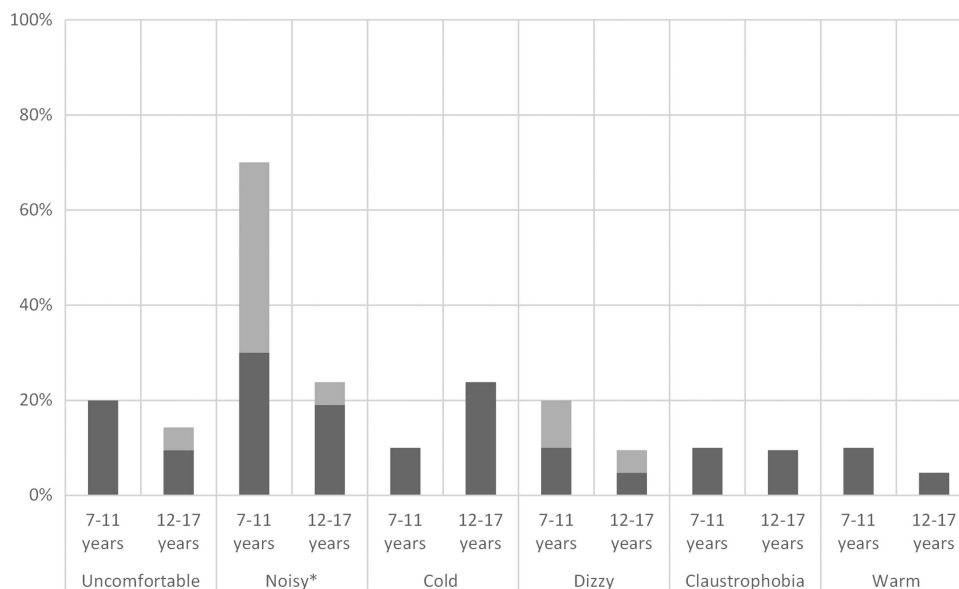


Figure 1 The subjective discomforts reported by children aged 7–11 years ($n=10$) and 12–17 years ($n=21$) undergoing 3 T clinical MRI. Thirty-one children reported discomfort in six domains using a five-point Likert scale: ‘yes very’; ‘yes a little’; ‘so-so’; ‘no not really’; ‘no not at all’. Histograms show % reporting discomfort as ‘yes very’ (light grey) and ‘yes a little’ (dark grey). *Younger children reported noise discomfort significantly more often than older children, $p=0.021$.

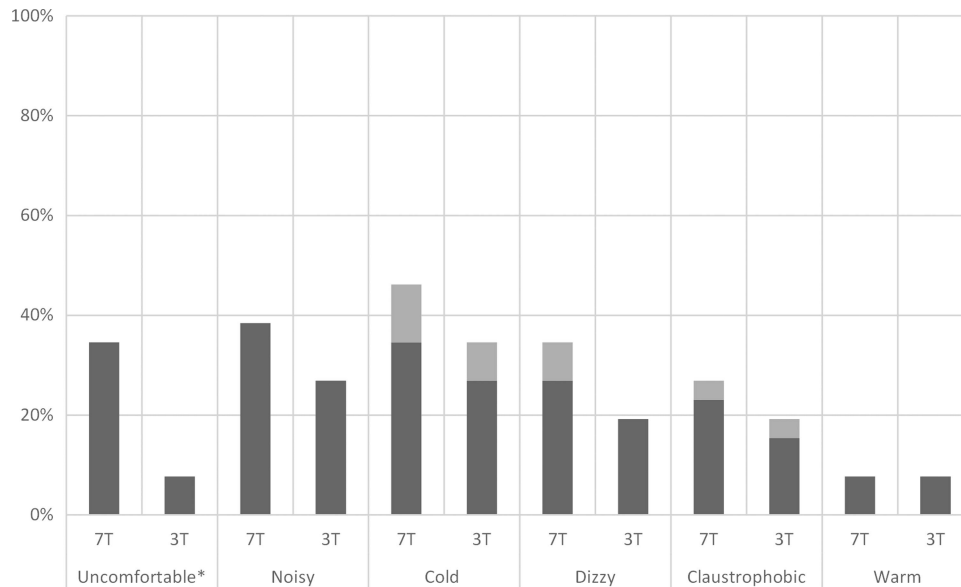


Figure 2 The subjective discomforts reported by adults who underwent both 3 and 7 T research MRI. Twenty-six adults reported discomfort in six domains using a five-point Likert scale: 'yes very'; 'yes a little'; 'not sure'; 'no not really'; 'no not at all'. Histograms show % reporting discomfort as 'yes very' (light grey) and 'yes a little' (dark grey). *Adults found the 7 T MRI generally more uncomfortable than the 3 T MRI, $p=0.031$.

DISCUSSION

This preprotocol public and patient involvement found that only a small proportion (3%) of child respondents reported a 'very uncomfortable' experience of 3 T MRI and three-quarters were willing to participate again in 1 year. It seems that these subjective discomforts irritate but do not preclude their willingness to undergo a clinical MRI again. Noise is the most common discomfort reported by children and young people undergoing 3 T MRI; in particular, 70% of children younger than 12 years indicated noise as a cause of discomfort during the procedure. In contrast, only 25% of adults and older children found the 3 T scanner noise uncomfortable. Adults found the 7 T MRI more uncomfortable than the 3 T MRI in general and noise was still the most common discomfort during 7 T MRI, as reported by 40% of adult respondents. As for involvement of children and young people in 7 T MRI research, a higher percentage of adults reported subjective discomfort indicating the possibility of even greater risk for subjective discomfort in children undergoing 7 T MRI, particularly younger children who are more vulnerable to 3 T discomfort. This view echoed the finding that most adult participants, based on their personal experiences, did not think children younger than 12 years would tolerate 7 T MRI well. This survey supports the case for cautious enrolment of children and young people of 12 years or more in 7 T MRI studies. However, we would caution against involving children under 12 years in 7 T MRI studies, until more experience with the older children is accrued, or new techniques to further mitigate the discomfort are developed.

Our study collated the subjective discomfort of 3 and 7 T MRI scanning in adults who had experienced both

procedures. Their experiences may serve as a proxy for potential discomfort that would occur in child participants. A higher proportion of adult respondents found the noise uncomfortable in the 7 T MRI than during 3 T MRI. We would expect an even higher proportion of child participants will find the noise at 7 T MRI uncomfortable, particularly those younger than 12 years old. These subjective perceptions reflect objective evidence that MRI-related acoustic noise is field strength dependent. The peak sound pressure levels among the loudest sequences at 1.5 T MRI system were measured at a range of 101–117 A-weighted decibels (dB(A)),^{14–16} and at 3 T MRI system were as high as 122–131 dB(A).^{17 18} The audiometry measurement at 7 T system has not been reported because of the difficulty of locating the metallic apparatus directly within its bore, where the magnetic field is intense. Note that the threshold for instantaneously acquired acoustic trauma is 140 dB(A), and for discomfort for normal individuals is 120 dB(A). Therefore, our current policy is to use double hearing protection¹⁸ in 3 and 7 T MRI systems. Sound attenuation of 36 dB(A) is offered by earplugs (3M, E-A-R soft Yellow Neon Ear Plugs); along with headphones or acoustic foam pads, the subjective sound pressure is expected to be decreased further to below the level 99 dB(A) as regulated by the International Electrotechnical Commission (IEC).¹⁹ This sound pressure level is equivalent to listening to a single trumpet at a 25 cm distance.²⁰ Despite hearing protective devices being used, there was still a high percentage of respondents who found both 3 and 7 T scans uncomfortably noisy.

Our finding was consistent with previous studies in that the noise was a common discomfort perceived by

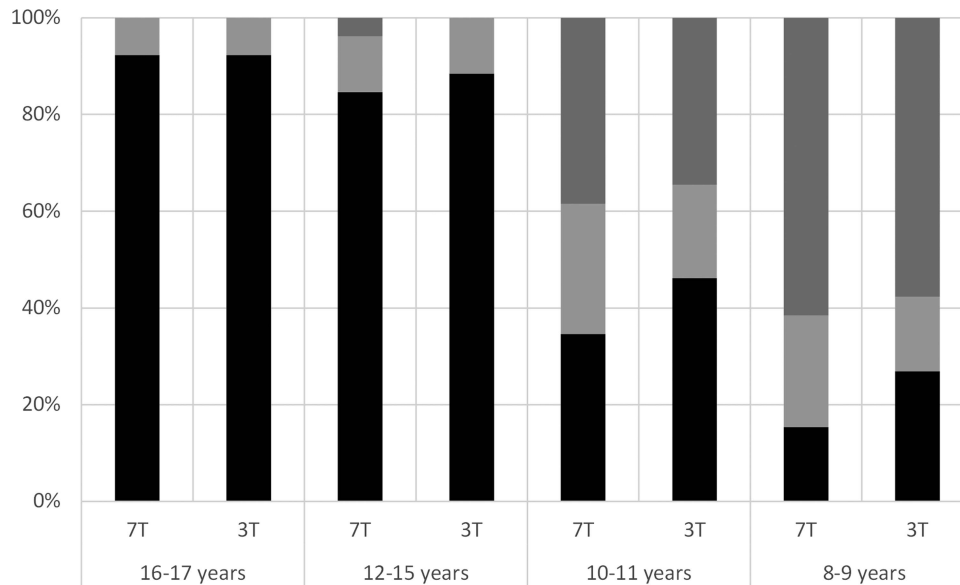


Figure 3 The opinions of experienced adults on whether children 'would feel ok' undergoing 7 T MRI. Twenty-six adults who had undergone both 3 and 7 T research MRI reported how, in their opinion, children aged 16–17, 12–15, 10–11 and 8–9 years would feel undergoing 7 T research MRI. Histograms show % reporting the views as 'yes definitely' or 'yes probably' (black), 'not sure' (light grey), and 'no probably not' or 'no definitely not' (dark grey).

children undergoing MRI. Marshall *et al*² reported that 16% of 80 children aged 10–18 years rated the noise as the most annoying part of scans. Tyc *et al*³ asked 55 paediatric oncology patients aged 8–22 years, and their parents, to select which bothered the patient most about the MRI from among eight choices: size of machine, noise, darkness, small space, IV insertion, lying still, head restraint and other. Noise was rated the fourth most distressful in 22% of patients, following IV injection (33%), confined space (25%) and lying still (24%). However, these two studies did not mention the magnetic field of the scanners. Since both studies were conducted in 1995, the magnetic field of the scanner was more likely to be at 1.5 T or less. In our study, a higher proportion of children (39%) found the noise of a 3 T scanner uncomfortable. MRI-related acoustic noise has been linked to a temporary shift in hearing thresholds, brief hearing loss²¹ and a decrease in otoacoustic emissions even with ear plugs.²² Therefore, for children who are involved in 3 or 7 T MRI examinations, it is very important to take all steps to reduce potential harm from noise-related hearing impairment. To better protect children and young people, age-appropriate hearing protection is essential to reduce the risk of discomfort as well as noise-induced hearing impairment and procedural discomfort. Furthermore, careful fitting of ear plugs is essential as research showed that training in earplug insertion and visual evaluation of the earplug fit were important to achieve good attenuation.²³

Other discomfort during MRI was reported less often in our survey. Only less than 20% of children undergoing 3 T MRI complained of general discomfort, feeling of cold, claustrophobia or dizziness. Uncomfortable

padding and long duration of scan were reported as sources of discomfort by their parents or carers. MRI-related discomfort or anxiety in children will not only come from the MRI itself but also from related factors such as the site of scanning, waiting time and cannulation. Tyc *et al*³ showed that intravenous cannulation performed prior to MRI to allow contrast agent injections can arouse anxiety in one-third of children. Our study revealed MRIs that involved contrast agent administration or blood tests may impair recruitment of adolescents to research. A further study is needed to understand the contribution of these other factors to children's overall experience of different MRIs.

Our study of user experiences of 7 and 3 T MRI showed that the 7 T was generally more uncomfortable as scanning time of 7 T research scans was double or triple that of 3 T research scans. The difference of subjective perceptions of the two systems has rarely been reported. Heilmaier *et al*⁷ found more people complained about noisiness and dizziness in the 7 T MRI than in the 1.5 T MRI with the perception being more pronounced when participants were positioned head-first into the bore compared with feet-first. Weintraub *et al*¹⁰ showed that postscan vertigo was more commonly encountered in patients undergoing 3 T (5.6%) MRI than 1.5 (1.9%) or 0.6 T (0%) MRI. Other less frequent field strength-related adverse feelings in both systems include metallic taste, peripheral nerve stimulation and a feeling of warmth.^{4,9} It is therefore particularly important to consider these factors when enrolling young children in 7 T MRI research since they may be more sensitive and susceptible to discomfort related to high field strength.

Other subjective discomforts during scanning at 3 and 7 T MRI are manageable. Experience of coldness will depend on the ambient temperature in the scanner room, which is often deliberately made low to assist the participant in dissipating the heat deposited in their body by the radiofrequency (RF) electromagnetic fields. Specific Absorption Rate (SAR) limits on RF power assumes temperatures in the MR examination room of less than 25°C, good bore air flow and the patient being lightly clothed. However, in practice, coldness is a common discomfort after a long duration of scan. A blanket may be needed to prevent the participant getting cold if heat loss mechanisms are not compromised. A leg support can decrease the discomfort caused by lying flat for too long and also reduce the risk of RF burns arising from crossing the legs. Slow movements inside the scanner hall, including slow bed movement can reduce the perception of dizziness and metallic taste. Claustrophobia, the most common cause of premature termination of scans, can be prevented by increasing lighting and air flow through the bore and using a mirror or prism glasses to allow the participant to see out of the bore. Finally, good verbal communication with the participant over the intercom is especially important in this vulnerable population.

A number of caveats regarding this work merit discussion. First, the sample size was small and the adult research volunteers may have relatively positive views about MRI, making generalisation to a younger population possibly biased. Second, there have been no validated questionnaires across all ages to evaluate subjective perceptions on MRI environment. Third, adult respondents with or without children may have different viewpoints on the tolerability of MRI in children and young people. However, we did not collect information on parenthood. Furthermore, a small proportion of children were positioned differently, not the head at the centre of the magnet bore and without a head coil. Therefore, these children may not perceive dizziness or claustrophobia which might be more frequently perceived by those receiving a brain scan that requires a head coil. However, this was not a controlled experiment, but rather a way of giving a voice to parents and children who had experienced routine clinical MRIs and to volunteers who had experienced research MRIs: to explore previously hidden experiences of children and adults undergoing 3 or 7 T MRI.

To the best of our knowledge, this is the first account of children's tolerability during 3 T clinical MRI and of adults' views on enrolment of children in 7 T MRI research. Our findings can inform clinicians and professionals on the potential sources of discomfort that may arise during high-field MRI and facilitate development of strategies to minimise discomfort. This report also provides useful data for Research Ethics Committees who are evaluating protocols for 7 T MRI research involving children.

CONCLUSIONS

In general, 3 T MRI is well tolerated by children aged 7–17 years. Noisiness was the most common discomfort across all ages in 3 and 7 T scanners. Although general discomfort was more common during 7 than 3 T scans in adults, most adults thought children aged 12 years or more would tolerate 7 T MRI well. Further work to assess how children actually tolerate 7 T MRI will be undertaken.

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Contributors WPW, CSC, CRT and I-JC conceived the study idea and designed the study. I-JC, CSC, TJ, RAD, NE and RA-F collected the data. I-JC analysed the data with help from CRT, WPW and CSC. All authors interpreted the findings. I-JC reviewed the literature together with PG and CSC. I-JC wrote the first draft, and all authors critically reviewed and edited the manuscript and approved the final version.

Funding The study was supported by the University of Nottingham (Sponsor reference 13009) and Chang Gung Memorial Hospital (funding project CMRPG4A0122).

Competing interests None.

Ethics approval Data from the adult participants came from research studies approved by the local Research Ethics Committee (07/H0408/115, 05/Q2404/44).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement No additional data are available.

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