The Psychological, Physiological, and Behavioral Responses of Patients to Magnetic Resonance Imaging (MRI): A Systematic Review and Meta-Analysis

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Background: MRI is generally well-tolerated although it may induce physiological stress responses and anxiety in patients.
Purpose: Investigate the psychological, physiological, and behavioral responses of patients to MRI, their evolution over time, and influencing factors.
Study Type: Systematic review with meta-analysis.
Population: 181,371 adult patients from 44 studies undergoing clinical MRI.
Assessment: Pubmed, PsycInfo, Web of Science, and Scopus were systematically searched according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Quality appraisal was conducted with the Joanna Briggs Institute critical appraisal tools. Meta-analysis was conducted via Meta-Essentials workbooks when five studies were available for an outcome. Psychological and behavioral outcomes could be analyzed. Psychological outcomes were anxiety (State–Trait-Anxiety Inventory, STAI-S; 37) and willingness to undergo MRI again. Behavioral outcomes included unexpected behaviors: No shows, sedation, failed scans, and motion artifacts. Year of publication, sex, age, and positioning were examined as moderators.
Statistical Tests: Meta-analysis, Hedge's *g*. A *P* value <0.05 was considered to indicate statistical significance.
Results: Of 12,755 initial studies, 104 studies were included in methodological review and 44 (181,371 patients) in meta-analysis. Anxiety did not significantly reduce from pre- to post-MRI (Hedge's $g = -0.20$, $P = 0.051$). Pooled values of STAI-S (37) were 44.93 (pre-MRI) and 40.36 (post-MRI). Of all patients, 3.9% reported unwillingness to undergo MRI again. Pooled prevalence of unexpected patient behavior was 11.4%; rates for singular behaviors were: Failed scans, 2.1%; no-shows, 11.5%; sedation, 3.3%; motion artifacts, 12.2%. Year of publication was not a significant moderator (all $P > 0.169$); that is, the patients' response was not improved in recent vs. older studies. Meta-analysis of physiological responses was not feasible since preconditions were not met for any outcome.
Data Conclusion: Advancements of MRI technology alone may not be sufficient to eliminate anxiety in patients undergoing MRI and related unexpected behaviors.
Level of Evidence: 1
Technical Efficacy: Stage 5

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MRI is a widespread diagnostic imaging method. In Germany, 145 MRI examinations were performed per 1000 inhabitants in 2018.[1] In general, MRI is well-tolerated by patients although it can induce physiological stress responses and clinically relevant levels of anxiety in a substantial number of patients.[2,3]

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Technological advancements in scanner design like open MRI, or shorter bore length and larger bore diameter, have made MRI more patient-friendly.[4] Some studies have suggested that such technological advancements may have brought about improvements in patient experience.[5–7] Yet, others have still reported high levels of distress, anxiety, and related procedural issues of patients examined in modern MRI scanners, thereby questioning the benefit of new MRI designs.[8–10]

Previous studies have generally found higher levels of anxiety in women than in men.[5,11–14] However, sex differences in MRI-related physiological stress responses have not been reported.[15–17] Age has also been examined as a potentially influencing factor, but with no consensus regarding its role. Some studies do find a relation between age and MRI-related anxiety, others do not.[13,17] Yet, those studies that do report opponent effects: While some observed lower rates of claustrophobia and premature terminations in young (<20 years) and old patients (>80 years),[18] or particularly high risks for claustrophobia in middle-aged patients,[5] others found a higher need for sedation and higher levels of anxiety in younger patients.[14,19] Last, while some studies have shown that prone positioning (Fig. 1) of the patient in the scanner bore is associated with reduced levels of anxiety,[5,20,21] a recent study has questioned this.[22]

Stress and anxiety may not only affect the patient experience of MRI, but may also affect operational efficiency of healthcare providers.[22–24] Anxious patients tend to move more, generating motion artifacts and the need for repeat scans. This in turn prolongs procedural times and reduces the number of patients that can be scheduled.[22,24] In severe cases, scans may be terminated prematurely or only endured under sedation.[22,23] These unexpected patient-related events (UPEs) contribute to lost revenue.

A systematic review that holistically describes patient responses to MRI and their evolution over time is lacking. Existing reviews have either applied an unsystematic approach[2] or have focused on interventions to reduce anxiety.[21,25]

Thus, the aims of this study were to:

1. Provide a holistic overview on patients' psychological, physiological, and behavioral responses to MRI;
2. Assess whether the patients' psychological, physiological, and behavioral responses to MRI have improved over time along with technological advancements; and examine the impact of the following factors: 1) Instruments used for assessment (e.g., the questionnaire used), 2) sex, 3) age, and 4) positioning.

Materials and Methods

This study was conducted following the methods of the Joanna Briggs Institute (JBI).[26] The JBI considers systematic reviews to contribute meaningfully to the evidence on a topic. Moreover, results of systematic reviews can serve as a reliable basis for informed recommendations to guide practitioners as well as policymakers. The methods and scope of this review were preregistered at PROSPERO (CRD42021225489). All studies included had appropriate ethics approval and provision for written informed consent.

Search Strategy

PubMed, Scopus, Web of Science, and PsycInfo were systematically searched. The search strings encompassed the four categories "MRI," "subjective patient-centered outcomes," "physiological patient-centered outcomes," and "behavioral outcomes"; each of them including a broad range of different outcomes (see Table S1 in the Supplemental Material). Additionally, the reference lists of all studies eligible for the review were searched for further studies unidentified by the main data base search. The main search was conducted December 17, 2020 and was updated until May 31, 2021.

Inclusion/Exclusion Criteria

Only articles fulfilling the following criteria were included: 1) original empirical research; 2) peer-reviewed articles; 3) study population ≥18 years; studies including minors were only included if minors were not overrepresented compared to the general age distribution; 4) patients received standard care; for studies on interventions to improve the patient experience, only data of the control group receiving standard care was eligible; 5) clinically requested MRI examinations (i.e., MRI examinations acquired solely in the context of scientific studies were excluded).

The following exclusion criteria were applied: 1) studies conducted in healthy volunteers; 2) methods other than "standard MRI" (e.g., PET-MRI); 3) editorials, letters, case reports, conference proceedings, review articles; the latter were searched for suitable original studies; 4) articles written in languages other than English, German, or Spanish.

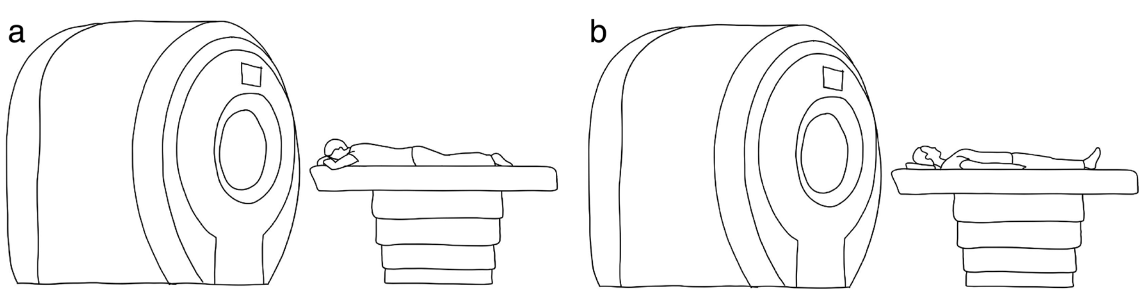

FIGURE 1: Patient positioning. (a) Prone; (b) supine.

TABLE 1. Characteristics of Included Studies

Study Characteristics		Patient Characteristics				
Authors (year)	Country	*N*	Age (years)	Women (%)	Prone Position (%)	CLQ[a]
Ahlander et al. (2016)[29]	Sweden	247	54.7	59.1	0.0	–
Ahlander et al. (2018)[30]	Sweden	48	49.4	54.2	0.0	–
Ajam et al. (2017)[31]	USA	11,950	–	–	–	–
AlRowaili et al. (2016)[32]	Saudi Arabia	904	40.1	55	–	–
Andre et al. (2015)[24]	USA	192	56	50.5	0.0	–
Bangard et al. (2007)[33]	Germany	72	49.3	60	27.0	55
Calabrese et al. (2009)[34]	Italy	18	48	100	11.1	–
Dantendorfer et al. (1997)[11]	Austria	297	45.0	56.9	–	–
Dewey et al. (2007)[5]	Germany	55,734	47.9	52.1	–	–
Enders et al. (2011)[6]	Germany	172	53.1	79.9	0.0	62.4
Eshed et al. (2007)[18]	Germany	5798	49.9	54	6.8	–
Evans et al. (2020)[35]	UK	114	65.3	42.1	0.0	–
Fiaschetti et al. (2013)[36]	Italy	630	57.5	100	100.0	–
Harris et al. (1999)[37]	Australia	78	47.4	70.5	0.0	30.9
Harris et al. (2001)[38]	Australia	137	44.6	59.9	–	29.3
Harris et al. (2004)[39]	Australia	118	44.2	67.8	–	30.6
Hobbs et al. (2015)[40]	Australia	49	55	100	100.0	–
Hutton et al. (2011)[41]	UK	616	40	100	100.0	–
Jaite et al. (2019)[9]	Germany	28	43.7	67.9	0.0	–
Katz et al. (1994)[12]	USA	40	53.4	70	–	–
Katznelson et al. (2008)[42]	Canada	276	59.6	10.9	0.0	–
Kilborn & Labbé (1990)[43]	USA	108	42.7	47.2	–	–
Kurian et al. (2005)[44]	USA	43	41	100	100.0	–
Ladapo et al. (2018)[45]	USA	4050	–	–	–	–
Leithner et al. (2008)[46]	Austria	62	30.2	100	0.0	–
Mackenzie et al. (1995)[13]	UK	500	43.5	52.4	0.0	–
McCauley et al. (1992)[47]	USA	61	39.9	100	54.2	–
McIsaac et al. (1998)[20]	Canada	80	40	46.3	–	26.3
Michel et al. (2002)[7]	Switzerland	30	29	100	0.0	–
Miles et al. (2018)[48]	UK	159	38	59.1	0.0	–
Murphy & Brunberg (1997)[14]	USA	939	66.37	53.6	0.0	–
Napp et al. (2017)[49]	Germany	6520	51.65	57.9	18.0	17.6
Napp et al. (2021)[50]	Germany	89	51.2	56.9	0.0	39.3
Nielsen et al. (2010)[51]	Denmark	78	67	35.4	0.0	–

TABLE 1. Continued

Study Characteristics		Patient Characteristics				
Authors (year)	Country	N	Age (years)	Women (%)	Prone Position (%)	CLQ[a]
Norbash. et al. (2016)[52]	Netherlands	49,733	–	–	–	–
Redd et al. (1994)[53]	USA	37	43.5	54.4	7.0	–
Sadigh et al. (2017)[8]	USA	34,587	–	–	–	–
Santarém Semedo et al. (2020)[54]	Portugal	85	54.8	69.4	–	–
Selim (2001)[55]	Egypt	30	44.5	–	–	–
Thu et al. (2015)[10]	USA	200	52.5	63	0.0	–
Tugwell et al. (2018)[56]	UK	58	51.1	45.8	0.0	–
U-King-Im et al. (2004)[57]	UK	167	70	27.0	0.0	–
van Minde et al. (2014)[3]	Netherlands	67	54	62.7	0.0	–
Youssefzadeh et al. (1997)[58]	Austria	6170	–	–	3.1	–

Only data of patients receiving standard care are displayed.
[a]CLQ = Claustrophobia Questionnaire[59] sum score; values reported as mean values were transferred to the sum score.

Quality Assessment and Data Extraction

The screening process was performed using Rayyan.[27] Two independent reviewers (JM, IN/SN) screened titles and abstracts of all identified records. The authors are experienced in scientific working: JM, 4 years; IN, 9 years; SN, 3 years; OA: 19; NR: 20; LB, 15 years. Full-texts were retrieved when studies were deemed to be eligible or when eligibility could not be determined based on title and abstract only. Then, two independent authors (JM, IN) screened full-text versions and assessed the methodological quality via the appropriate JBI critical appraisal tool[28] for eligible studies. The JBI critical appraisal tools are available for different study types (e.g., case control studies, randomized controlled trials, qualitative research). Each tool consists of 8–13 criteria that help assess the methodological quality of a study (e.g., criterion "Was true randomization used for assignment of participants to treatment groups?" for randomized controlled trials). The two reviewers coded for every study and every criterion whether it was met. Studies of insufficient methodological quality were excluded from further analyses. In cases of disagreement, a third reviewer (LB) independently assessed eligibility and methodological quality and consensus was then reached through discussion. This was the case for 12 studies. For each study to be included, a standardized extraction sheet was used to collect information on general aspects of the study, sample descriptors, characteristics of the MRI scanner used, details on the examinations, and the reported outcome measures (see Tables 1 and S3 in the Supplemental Material). If not reported explicitly, information on patient positioning was inferred from the types of examinations conducted. Depending on the type of outcome, mean and SD or prevalence data were extracted. Due to the extent of results, we decided to review and analyze findings of qualitative studies separately (Nieto Alvarez et al., in preparation).

Statistical Analyses

Our search strategy aimed at retrieving all studies reporting potentially relevant outcomes to generate the most holistic picture possible. We conducted meta-analyses whenever five or more studies reported outcomes that were sufficiently comparable based on the authors' assessment. For meta-analyses, Meta-Essentials workbooks were used.[60] We applied the appropriate workbook for each level of data and chose a random-effects model. We calculated the pooled prevalence for all binary outcomes. For continuous data, pooled estimates were calculated when a sufficient number of studies had applied the same measurement. Changes of outcomes were analyzed via standardized mean differences between dependent groups (Hedge's g). To assess the effect of influencing factors, we performed direct comparisons between independent groups when data allowed (i.e., odds ratios (OR) for binary data and Hedge's g for continuous data); else, meta-regressions were used to examine their influence as moderator effects. Table 2 provides an overview of the outcomes analyzed.

Some studies[13,39,41,46,54] examined anxiety and its change from pre- to post-MRI via different questionnaires. It these cases, pooled effect sizes were calculated for the change from pre- to post-MRI anxiety and included in the meta-analysis. Studies with extreme effect sizes ($M \pm 3$ SD) were excluded from the analyses; we report results after exclusion of extreme values.

Heterogeneity was assessed using the Higgins inconsistency index (I^2) test.[61] Publication bias was assessed via funnel plots and Egger's regression.[62]

As for our main analysis, we conducted subgroup or moderator analyses whenever five or more studies reported the same outcomes. Comparisons between different assessment instruments (e.g., the questionnaire employed) via subgroup-analysis was only

TABLE 2. Overview of Outcomes and Analysis Methods.

Outcome	k (n)	Data Level	Moderator Analysis: k (n)				
			Year	Age	Sex	Position	Claustrophobia
Anxiety: Change pre-post MRI	11 (1755)	Continuous	11 (1755)	11 (1755)	11 (1755)	–	–
Anxiety (Pre-MRI): Sex differences	6 (1184)	Continuous	–	–	–	–	–
STAI-S pre-MRI levels	12 (1903)	Continuous	12 (1903)	12 (1903)	11 (1873)	–	–
STAI-S post-MRI levels	9 (1556)	Continuous	9 (1556)	9 (1556)	9 (1556)	–	–
No willingness further MRI[a]	10 (1925)	Binary	10 (1925)	10 (1925)	10 (1925)	–	–
Failed scans	21 (157,436)	Binary	21 (157,436)	19 (63,710)	19 (63,710)	14 (13,359)	7 (7090)
No-shows	5 (66,809)	Binary	–	–	–	–	–
Sedation/general anesthesia	13 (101,997)	Binary	13 (101,997)	11 (63,718)	11 (63,718)	–	–
Motion artifacts	8 (35,925)	Binary	8 (35,925)	7 (1338)	7 (1338)	–	–
UPEs overall	38 (181,151)	Binary	38 (181,151)	33 (75,166)	33 (75,166)	28 (24,815)	7 (7093)
UPEs overall: Sex differences	8 (68,826)	Binary	–	–	–	–	–

Moderators were operationalized through year of study publication (year), mean age of study population (age), % of women in the sample (sex), % of patients in prone position (position), and mean claustrophobia score (Claustrophobia Questionnaire, 36).
k = number of studies; n = number of patients; STAI-S: State–Trait-Anxiety-Inventory state portion; UPEs = unexpected patient-related events.
[a]Lacking willingness to undergo MRI again was only coded for those patients not at all willing to undergo MRI again.

possible for change of anxiety; moderator analyses were performed applying random effects models for age, sex, position, and claustrophobia. We originally had planned to assess claustrophobia as an outcome; however, as it had mostly been assessed via the Claustrophobia Questionnaire,[59] a trait instrument, we used it as an exploratory moderator variable instead. In addition to the moderator analysis, direct comparisons of women and men were possible for change of anxiety and UPEs (see Table 2).

Results

Included Studies

The search resulted in 14,503 articles (1942 duplicates). During initial screening, 12,439 articles were excluded. Full-texts were retrieved for 294 studies of which 104 were included in quality assessment. Methodological quality was sufficient for 56 studies. Of these, seven studies reported qualitative data exclusively, four studies did not report an outcome that could be included in meta-analysis (i.e., <5 studies reported comparable outcomes), and one study which was originally included in meta-analyses had to be excluded from all analyses as all values exceeded the respective thresholds for outliers. Therefore, 44 studies were included in the quantitative review ($N = 181{,}371$ patients; Fig. 2).

Psychological Outcomes

While there was a broad variety of subjective patient-centered outcomes (see Table S2 in the Supplemental Material), we were only able to conduct meta-analysis for anxiety and willingness to undergo further MRI examinations. Heterogeneous definitions and assessment methods prevented meta-analyses for other outcomes. Table 2 provides an overview of the analyses that were conducted.

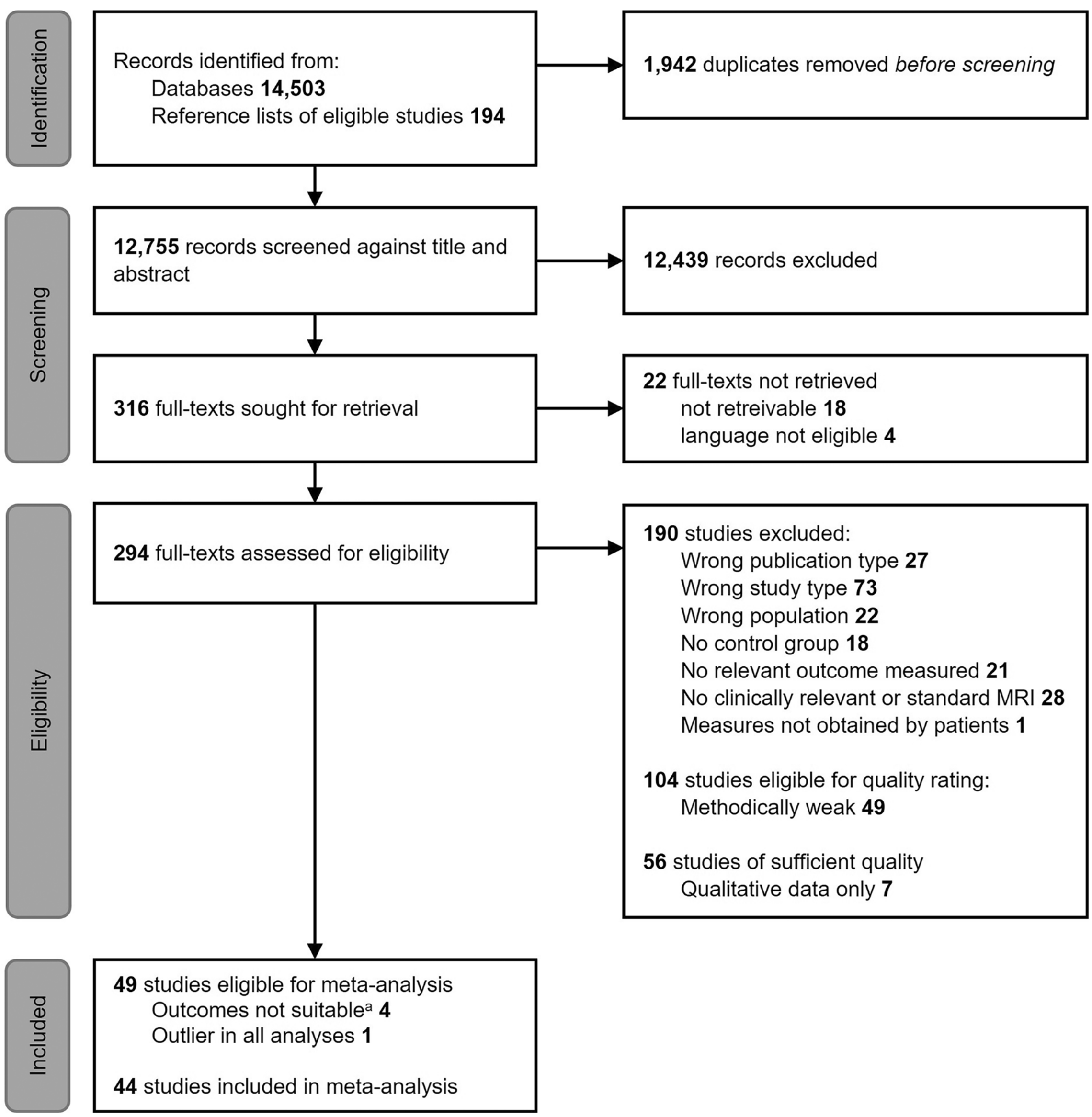

FIGURE 2: PRISMA study flow.

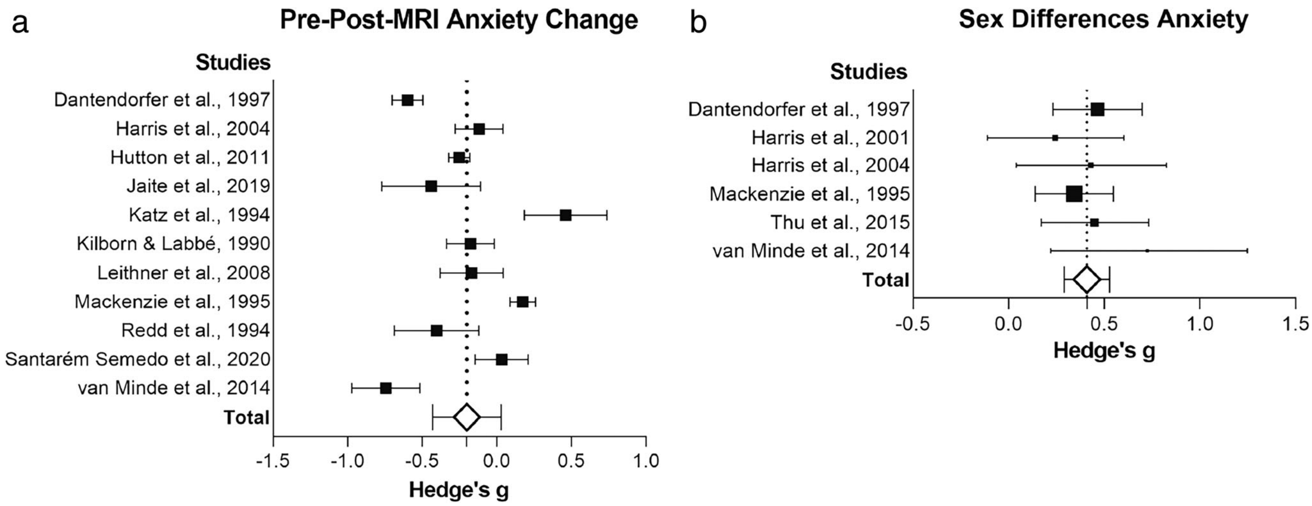

FIGURE 3: Anxiety. (a) Change of anxiety from pre- to post-MRI; (b) Sex differences of pre-MRI anxiety.

ANXIETY. Patient anxiety was examined in 17 studies of which 11 studies measured pre- and post-MRI anxiety and were sufficiently comparable to be included in meta-analyses. The decrease of anxiety from pre- to post MRI did not reach significance (Hedge's $g = -0.20$ [−0.42, 0.03], $P = 0.051$; Fig. 3a). The I^2-test indicated heterogeneity ($I^2 = 94.78\%$). There was no significant difference between subgroups that used the state position of the State–Trait-Anxiety Inventory (STAI-S)[63] vs. a different assessment instrument ($Q_{between} = 0.05$, $P = 0.816$; $Q_{within} = 9.25$, $P = 0.415$; $Q_{total} = 9.30$, $P = 0.503$). The funnel plot and Egger's regression showed a low likelihood of publication bias ($P = 0.857$).

The STAI-S[63] was used in 12 studies, and we were able to compute pooled values for pre- (12 studies) and post-MRI (9 studies) values. There was heterogeneity in both analyses (pre: $I^2 = 96.30\%$; post: $I^2 = 97.03\%$). The funnel plots and Egger's test indicated significant publication bias (Fig. S1 in the Supplemental Material). The pooled STAI-S values were 44.93 for pre- and 40.36 for post-MRI anxiety.

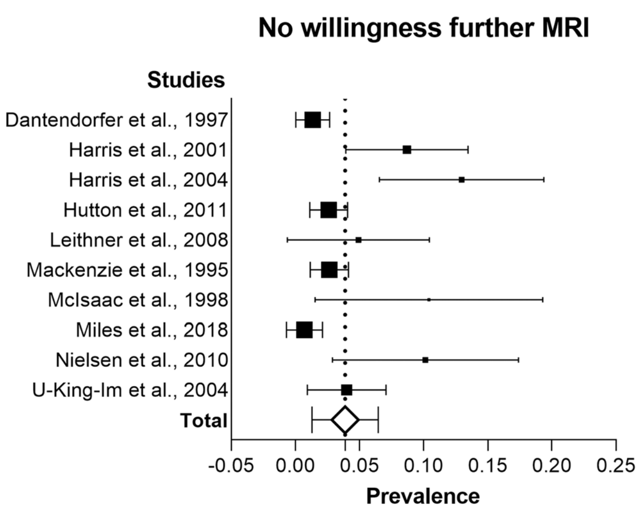

FIGURE 4: Unwillingness to undergo further MRI examinations.

WILLINGNESS TO UNDERGO FURTHER MRI EXAMINATIONS. Twelve studies analyzed the patients' willingness to undergo further MRI examinations of which 10 were included in meta-analysis. The I^2-test showed heterogeneity ($I^2 = 74.62\%$); the funnel plot and Egger's regression suggested significant publication bias (Fig. S2 in the Supplemental Material). The analysis showed that 3.9% of all patients were not willing to undergo MRI again (Fig. 4).

Physiological Patient-Centered Outcomes

Few studies analyzed the physiological response of patients to MRI. Two studies examined blood-pressure,[9,53] four studies heart rate,[3,9,12,53] and one study heart rate variability.[3] These small numbers prevented meta-analyses for physiological outcomes.

Behavioral Outcomes

Meta-analysis was possible for failed scans, no-shows, need for sedation, and motion artifacts (see Table 2). Additionally, a combined analysis summarizing all behavioral outcomes was conducted: UPEs.

FAILED SCANS. The number of scans that had to be terminated prematurely was reported in 26 studies of which 21 were meta-analytically combined. The analysis revealed a pooled share of 2.1% failed scans (Fig. 5a). The studies were heterogeneous ($I^2 = 97.56\%$) and the funnel plot and Egger's regression suggested a low likelihood of publication bias ($P = 0.224$).

NO-SHOWS. Five studies analyzing the prevalence of no-shows were combined in meta-analysis. Across these studies, 11.5% of patients did not attend for their appointments (Fig. 5b). The I^2 test indicated heterogeneity ($I^2 = 99.25\%$) and there was no evidence for publication bias in the funnel plot or Egger's test ($P = 0.933$). Only one study

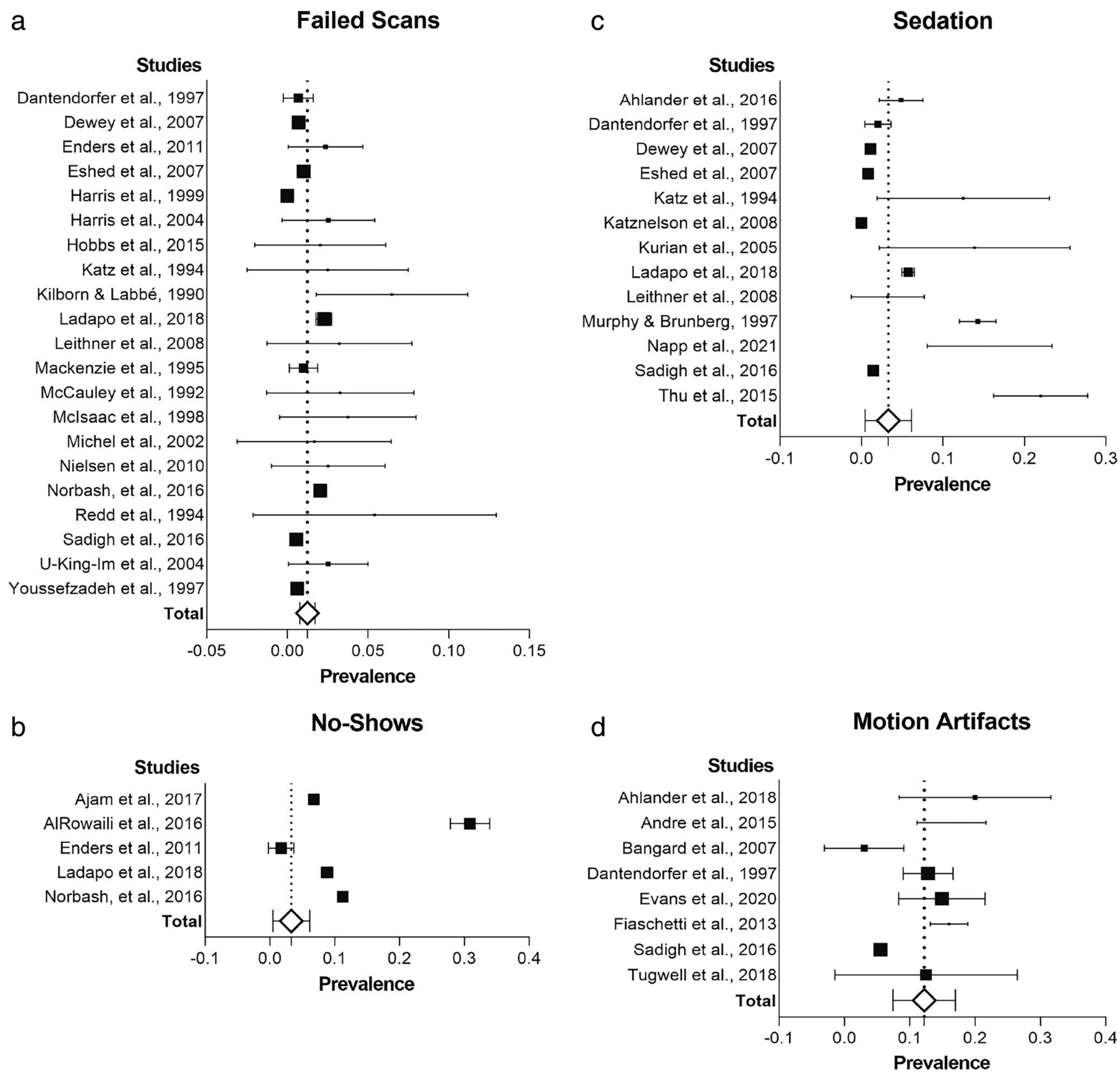

FIGURE 5: Prevalence of singular unexpected patient behaviors. (a) Failed scans; (b) no-shows; (c) sedation; (d) motion artifacts.

systematically investigated the reasons for no-shows,[32] which is why no systematic analysis thereof could be conducted.

SEDATION. Fourteen studies analyzed the prevalence of sedation or anesthesia and 13 of these could be combined in meta-analysis. The studies were heterogeneous ($I^2 = 99.22\%$); the funnel plot and Egger's regression indicated significant publication bias (Fig. S3 in the Supplemental Material). The analysis showed that 3.3% of patients required sedation or anesthesia to undergo MRI (Fig. 5c).

MOTION ARTIFACTS. Nine studies reported the frequency of moderate to severe motion artifacts; of these, eight could be combined in meta-analysis. The studies were heterogeneous ($I^2 = 92.78\%$) and the funnel plot and Egger's regression indicated significant publication bias (Fig. S4 in the Supplemental Material). The analysis showed that 12.2% of patient scans had moderate to severe motion artifacts (Fig. 5d).

UNEXPECTED PATIENT-RELATED EVENTS (UPES). Thirty-eight of the 39 studies reporting any type of unexpected patient-related behavior could be combined in meta-analysis. The pooled prevalence was 11.4% (Fig. 6a). The I^2 test indicated heterogeneity of the studies ($I^2 = 99.78\%$). The funnel plot and Egger's test indicated

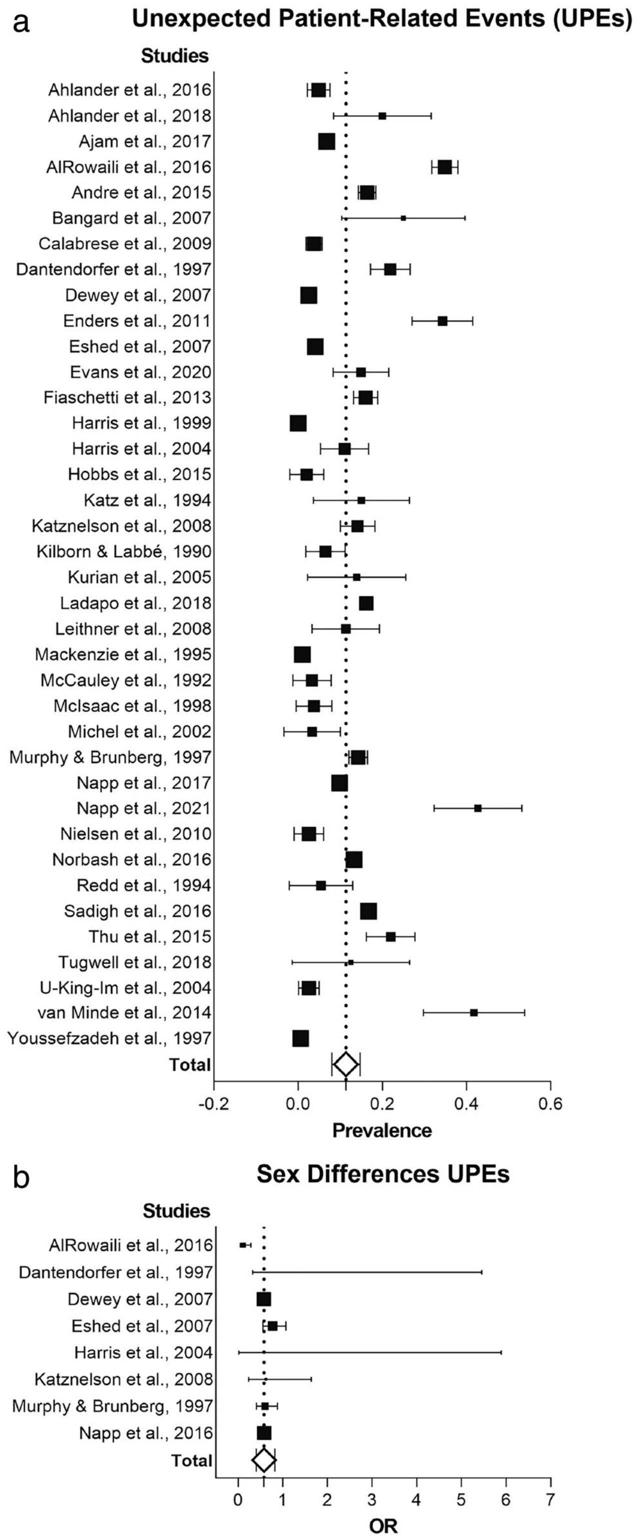

FIGURE 6: Prevalence of unexpected patient-related events. (a) Total prevalence; (b) sex differences.

a high probability for publication bias (Fig. S5 in the Supplemental Material). The number of included UPEs per study was a significant moderator (beta = 0.26): The more behaviors were considered as UPEs, the higher was the overall prevalence.

Analysis of Influencing Factors

For year of publication, sex, and mean age of population, moderator analysis was possible for all outcomes (see Table 2). Variation in year of publication was very low (2011–2018; c.f., Fig. 4d) for no-shows so this outcome has not been reported. For position and claustrophobia, moderator analyses were only possible for UPEs and failed scans.

PUBLICATION YEAR. Year of publication was not a significant moderator for any outcome (pre-MRI anxiety: $P = 0.173$; post-MRI anxiety: $P = 0.402$; willingness to undergo further MRI: $P = 0.547$; failed scans: $P = 0.179$; sedation: $P = 0.560$; no-shows: $P = 0.110$; motion artifacts: $P = 0.616$) except for overall UPEs (beta = 0.41), that is, more recent studies reported higher rates of UPEs than older studies (Fig. S6 in the Supplemental Material).

SEX. Sex significantly moderated sedation rate (beta = 0.38) and failed scans (beta = −0.32), but did not significantly moderate other outcomes (pre-MRI anxiety: $P = 0.928$; post-MRI anxiety: $P = 0.604$; willingness to undergo further MRI: $P = 0.909$; motion artifacts: $P = 0.998$; UPEs: $P = 0.580$). For change of anxiety and UPEs, six and eight studies, respectively, provided data suitable for conducting additional direct comparisons of independent groups. Women reported significantly higher pre-MRI anxiety values than men (Hedge's $g = .41$; Figs. 3b, 6b). These studies were homogeneous ($I^2 < 0.01\%$) and both funnel plot and Egger's regression indicated a low probability of publication bias ($P = 0.397$). Men had significantly lower rates of UPEs (OR = 0.58). I^2 indicated heterogeneity ($I^2 = 54.82\%$) and the funnel plot and Egger's test indicated a low probability of publication bias ($P = 0.695$).

AGE. Age was a significant moderator of sedation, but no other outcome (pre-MRI anxiety: $P = 0.846$; post-MRI anxiety: $P = 0.887$; willingness to undergo further MRI: $P = 0.340$; failed scans: $P = 0.085$; motion artifacts: $P = 0.348$; UPEs: $P = 0.873$). Increasing age was associated with significantly higher rates of patients needing sedation (beta = 0.34).

POSITION. The proportion of patients in prone vs. supine position was not a significant moderator for either overall UPEs or failed scans (failed scans: $P = 0.468$; UPEs: $P = 0.862$).

CLAUSTROPHOBIA. Claustrophobia significantly moderated the overall UPE rate with studies reporting higher levels of claustrophobia also reporting higher levels of UPEs (beta = 0.69). There was no significant moderator effect on failed scans ($P = 0.880$).

Discussion

The aim of this study was to provide a comprehensive picture of patients' psychological, physiological, and behavioral responses to MRI, their changes over time, and the role of moderating factors. Overall, anxiety in MRI patients is common. Contradicting our hypothesis, we did not observe improvements over time regarding either the patients' psychological or behavioral responses to MRI.

Patient anxiety has been found to be highest before MRI examination and to fall afterwards.[11–13,22,33] In our analysis, one of the 11 studies included found a slight, but non-significant increase in anxiety, whereas the other 10 reported a decrease. However, the change of anxiety from pre- to post-MRI did not reach statistical significance. The lack of significance may be due to the changes being small or to issues of statistical power and heterogeneity of studies.

Our analysis of STAI-S scores showed that the average levels of anxiety exceeded the cutoff for clinically relevant levels.[63,64] In addition, almost 4% of patients were not willing to undergo MRI again. Our study also showed that the level of anxiety and unwillingness to repeat MRI did not improve over the years.

Similarly, our analyses did not find a decrease in unexpected behaviors over time, which were prevalent in more than 10% of patients. There was also no moderator effect of year on the separate analyses performed for no-shows, failed scans, sedation, and motion artifacts. We even found an increase of overall UPEs over time, which probably originates from newer studies that defined unexpected behaviors more broadly and thus should not be over-interpreted.

The lack of improvement over time in both patient-related and procedural outcomes suggests that technological advancements that have made MRI quieter, faster, and less confined have not provided measurable relief for patients. This is surprising given that technological advancements have often been reported to improve patient experience and procedural outcomes and studies directly comparing "older" with more patient-friendly technologies have shown positive effects of the latter.[5,21]

Several factors may contribute to this discrepancy. First, our analyses may have been underpowered. Due to missing information on scanner characteristics we were not able to conduct direct comparisons between old vs. new MRI technologies, but could only consider year of publication as a moderator, which may have limited our ability to detect improvements. A more recent publication date does not necessarily imply that the MRI scanners used were more patient-friendly. Medical institutes are not always equipped with the most recent scanner technologies, which compromises the validity of year of publication as a marker for patient-friendliness. However, our finding might as well mirror a true lack of improvements. However, it is also possible that technological advancements until now do not suffice to provide relief for patients. Instead, the patients' needs might have to be addressed more directly and beyond standard care, for example, through additional information about the examination, relaxation, or staff training to improve communication. Interventions directly targeted at patients can be very simple and have demonstrated their value multiple times[17,21,65–67]; yet, their application is not standard. Apart from that, considering insights into the reasons for patients' adverse responses to MRI (Nieto Alvarez et al., in preparation) or including patients when developing new MRI machines, for example, via co-creation sessions, might be approaches to better address patients' needs with MRI technology in the future.[68]

The finding that level of claustrophobia moderated UPE frequency is in line with previous studies[2,11,22,67] and suggests that improving patient experience is important for improving scan quality. Therefore, healthcare providers should have a strong interest in reducing stress and anxiety in patients. Whole-body MRI may pose patients under particular confinement since local coils are placed along the whole body for examination; future research therefore should illuminate whether whole-body MRI examinations are related to more adverse responses of patients than are MRI examinations of singular body regions.

We found that men tolerated MRI better than women which was reflected in significantly lower levels of anxiety and UPEs. When sex was included as moderator, it was only significant for sedation and failed scans. The lack of a significant moderation effect for most outcomes contradicts the results of the direct comparisons analyses. Additionally, we are aware of only one previous study[17] that did not find that women had a higher risk for adverse MRI-related responses. Thus, we suggest that our moderator analysis may have had low power, rather than reflecting truly equivalent risks for women and men.

Imaging in the prone position has been proposed to reduce anxiety in previous studies.[21,33,47,69] However, the positive impact of positioning has been challenged recently[22] and our analyses also did not find a moderation effect for prone position on any outcome. Madl et al.[22] hypothesized that the lack of a positive effect for prone positioning might be due to the fact that most patients examined in the prone position are women receiving breast examinations, who may be a particularly anxious patient group. Taken together with our findings, we suggest that the recommendation to position anxious patients in the prone position[21,33,47,69] should be reassessed. It should be noted, however, that in our study, the proportion of patients imaged in the prone position had to be estimated for many studies, which also might have limited our ability to detect differences.

Several studies have considered whether older patients are at a higher or lower risk for adverse reactions to MRI than younger patients.[5,13,14,17,18,22] In the current study, we found older patients to have a higher need for sedation but no other moderation effect. This implies that age might be of minor importance for the MRI-related response.

Most studies examining physiological outcomes were conducted in healthy volunteers[16,70,71] whose situation differs from that of patients. We were, therefore, not able to conduct meta-analysis regarding the physiological response of MRI patients. As physiological markers have been demonstrated to be promising indicators of scan disruptions[72] and scan duration,[22] the physiological stress response might be an area of interest for future research. Most studies included in this review were conducted in Europe or English-speaking countries; only two studies stemmed from Saudi Arabia[32] or Egypt.[55] It is therefore unclear to what extent our results can be generalized to other regions. Results from AlRowaili et al.[32] and Selim[55] suggest that patient anxiety and unexpected behaviors might be more prevalent in the Middle East, but further studies are needed to address this issue.

Besides, there are further interesting research questions that should be addressed in future research. For example, it is still unclear how claustrophobic fears, for example, in MRI, and fears of other restricted environments compare. Comparing the responses of patients to MRI with negative control groups (e.g., patients with other phobias than claustrophobia) or positive control groups (e.g., entering closed spaces of non-medical nature) might be interesting areas for future research. A further research question should concern the application of contrast medium which may pose patients under additional stress. The question whether contrast agents or their application are related to worse patient responses to MRI should also be addressed in upcoming studies.

Limitations

First, the number of studies that could be included in meta-analysis after inclusion appraisal and methodological quality assessment was small, which indicates room for further research in the field. Our broad inclusion criteria lead to heterogeneity in our analyses, in terms of study population, context, and examination types. The lack of breakdown of contributing study results prevented us from conducting further subgroup analyses and the pooled results presented therefore represent all sexes, ages, types of diseases, and settings. Second, due to unavailable information, moderator analyses often could only be conducted for a small part of the original analysis, thereby limiting statistical power. Further, variability of moderators was mostly low, which may restrict validity of the results. Third, high variability in the reported outcomes, their measurement instruments, and definitions, limited or precluded meta-analyses for many outcomes. Future research in this area would benefit from efforts to standardize outcome measurements. Finally, our study focused on the published literature only and publication bias cannot be excluded.

Conclusion

Although technological advancements in MRI have brought about improvements regarding scanner design, anxiety levels in MRI patients and the prevalence of unexpected patient-related events have not reduced. Increased efforts to improve patient experience beyond current standards are therefore needed and could reduce the rates of unexpected behaviors.

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Conflict of Interest

The authors JM and IN report to be employed by Siemens Healthcare GmbH. They further declare that this affiliation had no impact on study design, data analysis, decision to publish, or preparation of the manuscript. The authors OA, NR, and LB of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Informed Consent

Written informed consent was not required for this study because this systematic review and meta-analysis is no original research.

Ethical Approval

Institutional Review Board approval was not required because this systematic review and meta-analysis is no original research.

Data Availability Statement

Data and material is available on reasonable request.

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