ZonMw

20 jaar onderzoek naar de beroepsmatige risico's van MRI

Hans Kromhout

Institute for Risk Assessment Sciences (IRAS) Utrecht University, Utrecht, NL

Universiteit Utrecht

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History of IRAS and MRI goes back a long time

Early 1996 e-mail message from Occupational Hygienist from Arbodienst Philips: talking about system testers reporting dizziness when working on 1.5 T MRI scanners; worries about their safety in traffic

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PHILIPS

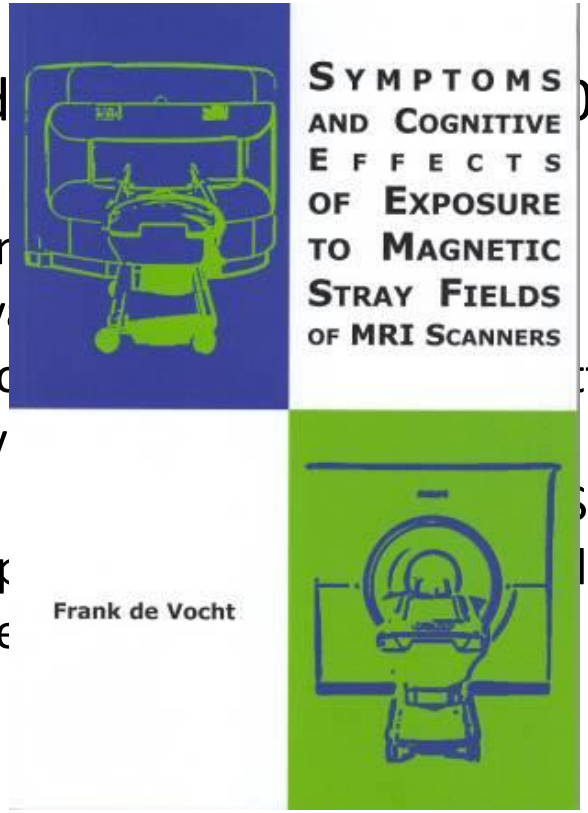
Healthcare

Institute for Risk Assessment Sciences

History of IRAS and MRI goes back a long time

Several stud)08):

- Nelleke Kar
- Hinkelien v
- Frank de Vo ttingham)
- Tobias Stev
- Anneke de GF Nottingham)
- Kirsten Klap lata)
- Floris Mulle



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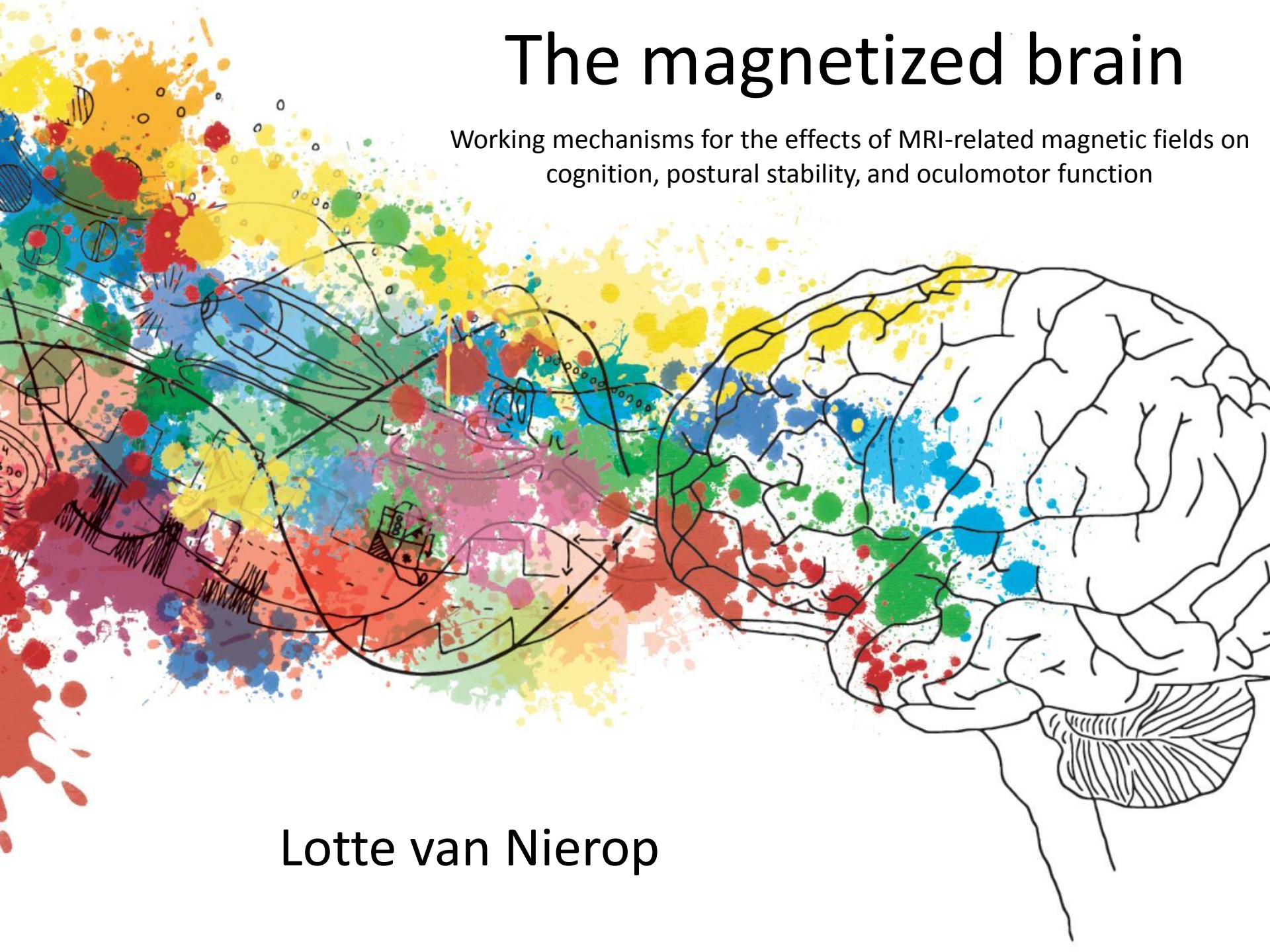
Healthcare

Symptoms, acute and chronic health effects of exposure to MRI-related electromagnetic fields 2007 – 2019

- Experimental studies to unravel underlying mechanisms by Lotte van Nierop
- Cross sectional studies on exposed populations: exposure and symptoms by Kristel Schaap
- Retrospective cohort study among workers from an MRI manufacturing plant by Suzan Bongers

The magnetized brain

Working mechanisms for the effects of MRI-related magnetic fields on cognition, postural stability, and oculomotor function



Lotte van Nierop

Background

Employees report sensory symptoms when in the vicinity of the MRI scanner, e.g. nausea, dizziness and metallic taste (de Vocht et al. 2006; Wilén and de Vocht 2010, Schaap et al. 2014)

Stray SMF in combination with movement induced `time-varying magnetic fields (TvMF) induced decreased speed and precision of eye-hand coordination, contrast sensitivity, visual tracking speed, visual and auditive working memory (de Vocht et al. 2003; 2006; 2007)

Objectives of the study

1. Explore behavioral domains and functions affected by exposure to stray magnetic fields

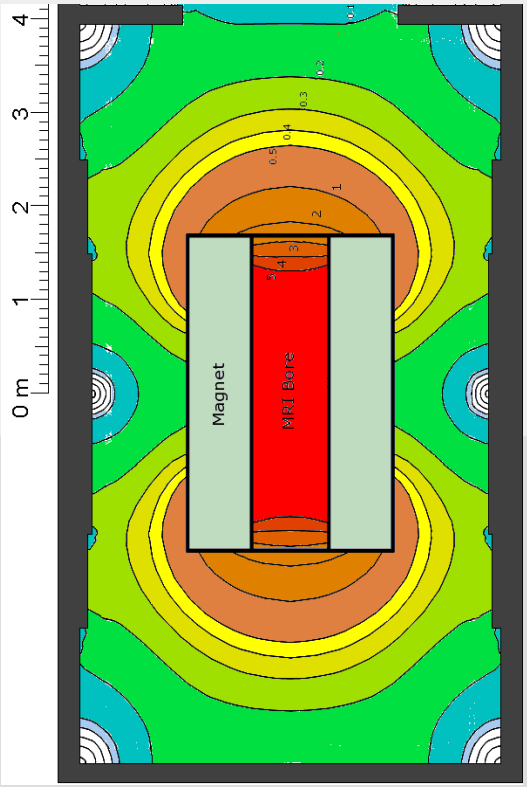
2. Disentangle the behavioral changes induced by static magnetic fields versus in time-varying magnetic fields

3. Indications for a working mechanism; involvement of the vestibular system

1. Domains and functions affected by stray magnetic fields

Study Design

- In two studies healthy subjects were exposed to the stray SMF of a 7 Tesla MRI system using a double blind randomized cross-over design
- Exposure to 1.0 T SMF and low-frequency movement-induced TvMF 2.4 T/s by head movement before every task



Test Battery

- Broad range of cognitive and vestibular related functions
- Functions relevant for medical professions working within the stray fields
- Earlier identified cognitive functions

Memory	Long term memory story recall(RBMT)
	Long term memory picture recall (MCG)
	Letter-number sequencing task (WAISIII)
Attention	Symbol cancellation task
	Reaction time task simple, complex, and inhibition level
Spatial- orientation	Roadmap task
	Judgment of Line Orientation task (JULO)
	Line bisection task
Haptic perception	Kappers task
Visual perception	Visual tracking task
	Contrast sensitivity (F.A.C.T.)
Visuomotor coordination	Pursuit Aiming task
Postural stability	Romberg task; feet parallel or in tandem
Oculomotor functions	Smooth pursuit
	Saccades
Vestibular-ocular reflex	Nystagmus

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Of all cognitive tasks assessed we demonstrated:

decreased verbal memory
(van Nierop et al. 2014)
attention and concentration, eye-hand coordination, spatial orientation, and visual perception
(van Nierop et al. 2012)

Memory	Long term memory story recall(RBMT)
	Long term memory picture recall (MCG)
	Letter-number sequencing task (WAISIII)
Attention	Symbol cancellation task
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	Saccades
Vestibular-ocular reflex	Nystagmus

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Vestibular related functions affected were:

postural stability and
increased saccadic eye velocity
(van Nierop et al. 2013)

Memory	Long term memory story recall(RBMT)
	Long term memory picture recall (MCG)
	Letter-number sequencing task (WAISIII)
Attention	Symbol cancellation task
	Reaction time task simple, complex, and inhibition level
Spatial- orientation	Roadmap task
	Judgment of Line Orientation task (JULO)
	Line bisection task
Haptic perception	Kappers task
Visual perception	Visual tracking task
	Contrast sensitivity (F.A.C.T.)
Visuomotor coordination	Pursuit Aiming task
Postural stability	Romberg task; feet parallel or in tandem
Oculomotor functions	Smooth pursuit
	Saccades
Vestibular-ocular reflex	Nystagmus

Conclusions

Exposure to a 1.0 T stray SMF of an MRI scanner in stand-by modus modulates oculomotor function, while performance of head movements inducing an additional TVMF of 2.4 T/s resulted in postural instability and decreased cognitive functions of visuo(motor) function, visuoperception, verbal memory, and attention and concentration

Indications for a working mechanism via the vestibular system explaining the magnetic field induced behavioral changes could not be confirmed with certainty but could also not be ruled out

Several other mechanisms are proposed like sensory conflict theory and information processing capacity

WORKING WITH MRI

An investigation of occupational exposure to strong static magnetic fields and associated symptoms

- Kristel Schaap -

Universiteit Utrecht

BACKGROUND

Focus on

- occupational exposure to MRI-related **EMF** in healthcare and research sectors
- **SMF** and low-frequency motion-induced **TvMF**

  - ➢ main source of exposure for MRI staff
  - ➢ (potentially) associated with reporting of acute, short-lasting symptoms:

- ✓ Dizziness/vertigo
- ✓ Nausea
- ✓ Tinnitus/head ringing
- ✓ Phosphenes/light flashes
- ✓ Metallic taste
- ✓ Tiredness/sleepiness
- ✓ Concentration problems
- ✓ …

BACKGROUND

Symptoms

Not clear…

…which symptoms occur among MRI workers

…how often these symptoms occur

…how (if) they are associated with exposure to MRI-related EMF

Exposure

Relevance of exposure assessment:

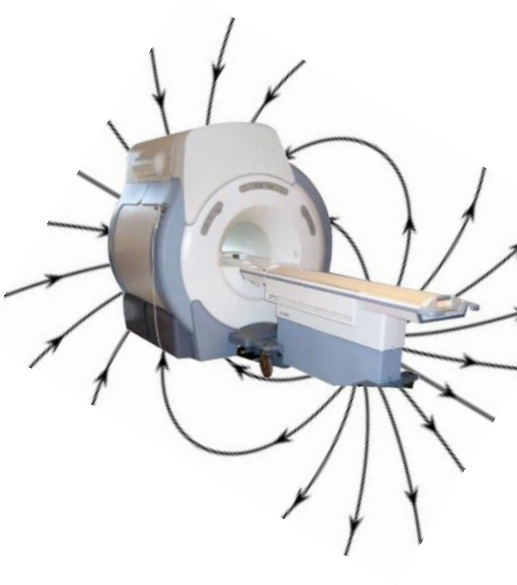
- Exposure must be known in order to limit and monitor health effects
- Important aspect of epidemiological research

Most of the existing studies on exposure to SMF & TvMF did not provide estimates of exposure levels in normal work:

- Hypothetical exposures (computer models, spot measurements, simulations)
- These do not take into account natural exposure variability
- This can be assessed by performing personal measurements during real work situations (i.e. ‘observational study’ instead of ‘experimental setup’)

AIMS

Exposure



I. Characterization of the occupationally exposed population

II. Assessment of SMF and motion-induced TVMF exposure levels, variability and determinants

III. Characterization of MRI-related symptoms and how often these occur

IV. Determine associations between exposure and symptoms

Symptoms

PERFORMED STUDIES

1. MRI inventory

On department level

2. Cross-sectional survey of (symptoms related to) occupational exposure to SMF and motion-induced TVMF

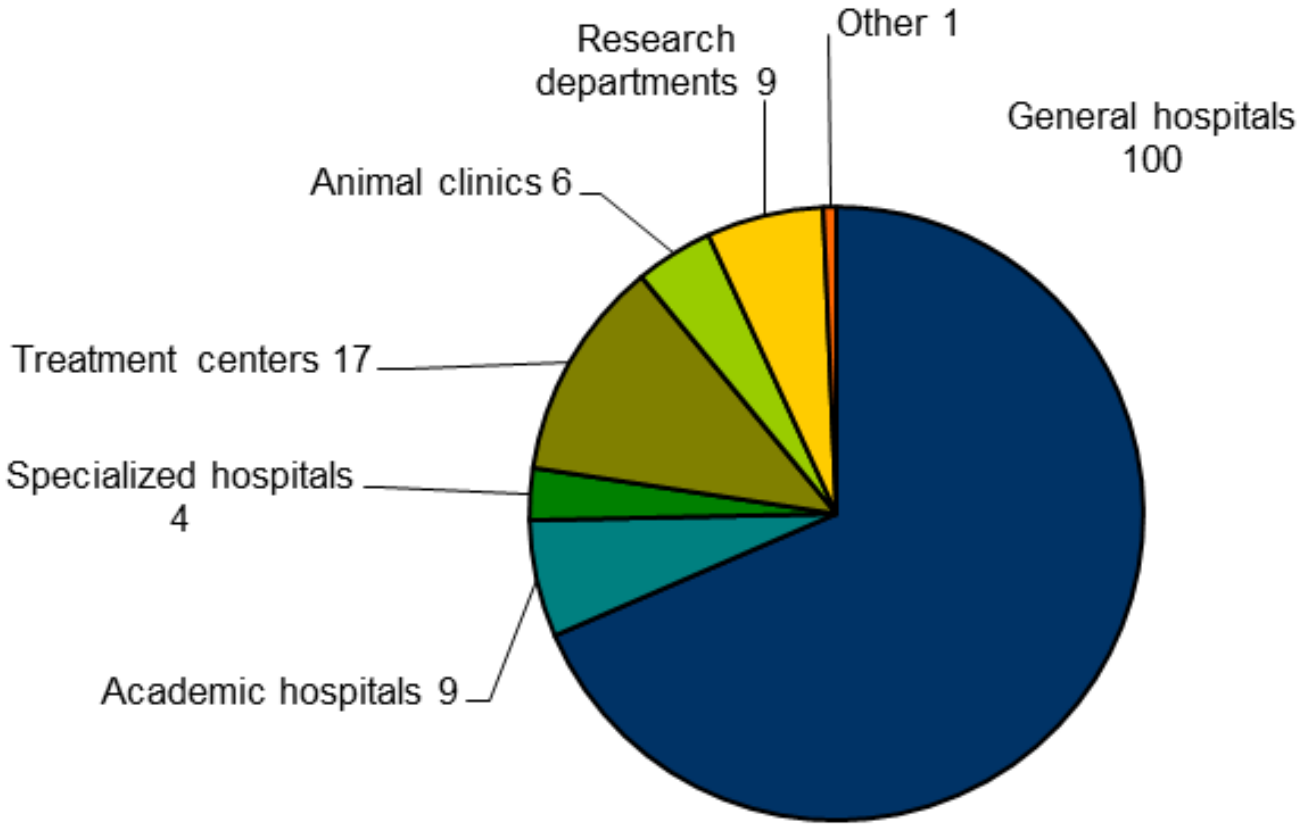
On personal level

3. Pooled analysis of exposure measurements

4. MRI radiographers questionnaire on symptoms

STUDY 1: MRI INVENTORY

- Paper questionnaire to all (n=152) MRI facilities in the Netherlands
- Response = 95%



STUDY 1: MRI INVENTORY

Assessment of the working population exposed to MRI-related EMF:

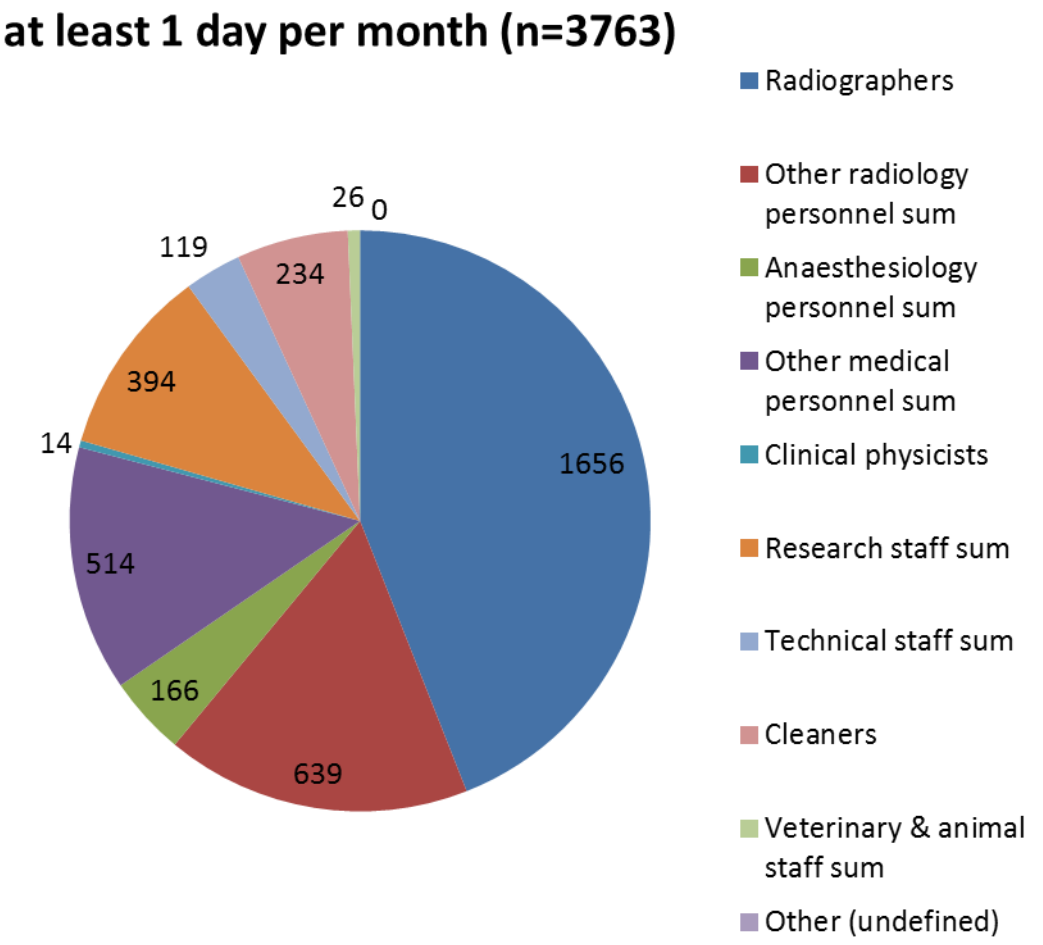
- Who are exposed? (number and jobs)
- How often are they exposed?
- To which EMF types are they exposed?
- Where can specific exposures be expected?
  (i.e. type of workplace)

Provide a background to select relevant target groups for extensive exposure measurement survey

STUDY 1: MRI INVENTORY

- **6,981** workers work in an MRI scanner room and are thus exposed to SMF.
  54% of these workers (n=**3,763**) are exposed at least one day per month.

- 9% of these workers (n=**614**) is present in a scanner room during image acquisition at least once per month.



STUDY 2: MEASUREMENT SURVEY

Study design

15 MRI facilities

- Scanning human subjects or animals
- Scanners of 0.2-11.7 Tesla

MRI facilities included in the study

Type of MRI facility	**Number of facilities**
General hospital MRI facilities	4
Academic hospital MRI facilities	4
Academic children's hospital	1
Human research MRI facilities	1
Animal research MRI facilities	4
Academic veterinary clinic	1
TOTAL	**15**

STUDY 2: MEASUREMENT SURVEY

Workplace visits of 1-2 weeks per MRI facility

A. Personal exposure measurements SMF [B] & TVMF [dB/dt]

Shift-based measurements

Part-shift measurements

Repeats where possible

B. Work

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Sub

C. Gener **e,**

Populati

- MRI os
- Additional SMF unexposed control gr

Repeated measurements:

- 1-6 measurement days per person

STUDY 2: MEASUREMENT SURVEY

Exposure levels and variability

Schaap et al. 2014. Ann Occup Hyg; 58:1094-1110

Shift-based exposure measurements

Personal exposure measurements

N = 271 subjects
N = 413 shifts

Self-reported data on shift level from logbook

Scanner type and strength

Other work: tasks, procedures

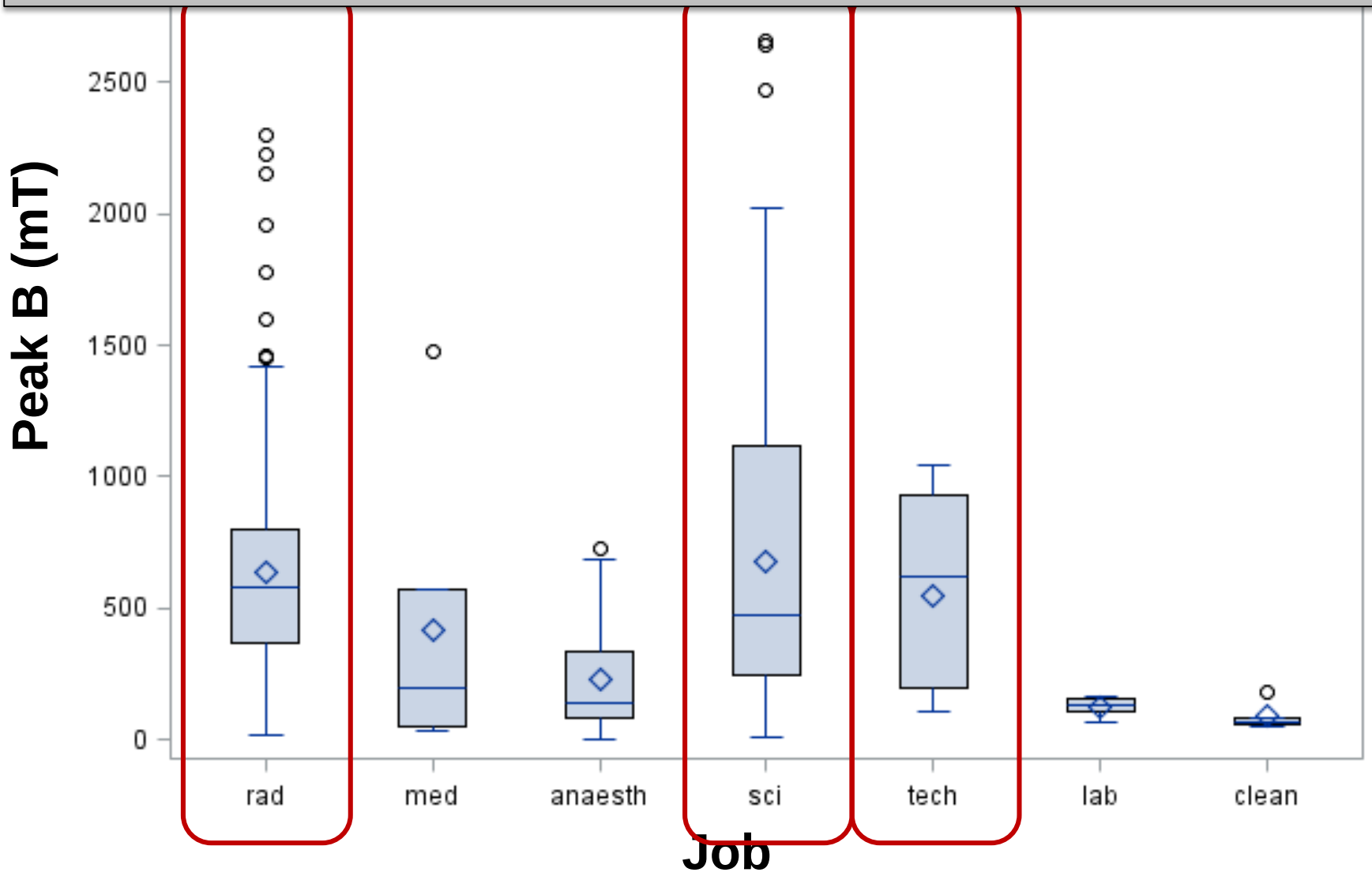
Symptoms

Self-reported data from general questionnaire

Demographic data

Peak SMF exposure per job (mT)

For peak dB/dt patterns very similar (very high correlation)



Determinants of exposure

Schaap et al. 2015. Magn Reson Med; 75:2141-55

Exposure variability explained by fixed effects

Depending on exposure metric, 27-76% of the exposure variability could be explained by self-reported information about scanners, scan procedures and tasks.

- better able to explain TWA exposure than peak exposure
- better able to explain SMF exposure than TVMF exposure
- More difficult to explain exposures due to scanning animals

STUDY 2: MEASUREMENT SURVEY

Scanner type and field strength were important determinants of <u>all</u> exposure metrics

- A 1 Tesla increase in closed-bore scanner strength was associated with a 30-76% increase in exposure, depending on metric

In comparison to 1.5 T clos

- working with extremity ed with 73-97% lower exposure levels
- upright scanners c mes higher exposure levels

Also **body height of t** levels at the chest and head

Specific tasks and pro f one or more specific exposure metrics include:

- ✓ total number of s ce of test scans
- ✓ the number of fM administration
- ✓ preparation of th high-care patients

STUDY 2: MEASUREMENT SURVEY

Symptom occurrence in relation to scanner type & strength

Schaap et al. 2014. Occup Environ Med; 71:423-429

Shift-based exposure measurements

Personal exposure measurements

N = 331 subjects
N = 633 shifts

Self-reported data on shift level from logbook

Scanner type and strength

Other work: tasks, procedures

Symptoms

Self-reported data from general questionnaire

Demographic data

Symptoms

Target symptoms
Vertigo
Nausea
Head ringing
Magnetophosphenes
Metallic taste
Headache
Tiredness
Concentration problems
Vomiting
Instability
Light-headedness
Blurred vision
Strange smell

A priori unrelated symptoms
Black spots
Irritated eyes
Irritated skin
Hot flashes
Earache
Palpitation

Core symptoms

STUDY 2: MEASUREMENT SURVEY

Scanner category	N_{obs}	% of shifts with symptoms	OR (95% CI)
Unexposed	134	19%	1
1.5T closed bore	259	28%	**1.88** (1.07-3.31)
3T closed bore	131	35%	**2.14** (1.13-4.03)
~~**7T closed bore**~~	~~31~~	~~39%~~	~~**4.17** (1.30-13.35)~~
<1.5T various types	49	27%	1.47 (0.59-3.64)
>4.7T small bore	57	16%	0.72(0.27-1.94)
Overall	619	26%	

STUDY 2: MEASUREMENT SURVEY

- Individual target symptoms were reported in 0 – 12% of shifts
- Similar trends observed for vertigo & metallic taste:

Scanner category	Vertigo	Metallic taste
Unexposed	0.0%	0.0%
1.5T closed bore	3.5%	0.4%
3T closed bore	7.6%	0.8%
7T closed bore	22.6%	19.4%
<1.5T various types	2.0%	2.0%
>4.7T small bore	0.0%	0.0%

  - transient (duration <1 minute to <15 minutes)

STUDY 2: MEASUREMENT SURVEY

Associations between symptoms and exposure levels

Schaap et al. 2016. Occup Environ Med; 73:161-166

Shift-based exposure measurements

Personal exposure measurements

N = 234 subjects
N = 358 shifts

Self-reported data on shift level from logbook

Scanner type and strength

Other work: tasks, procedures

Symptoms

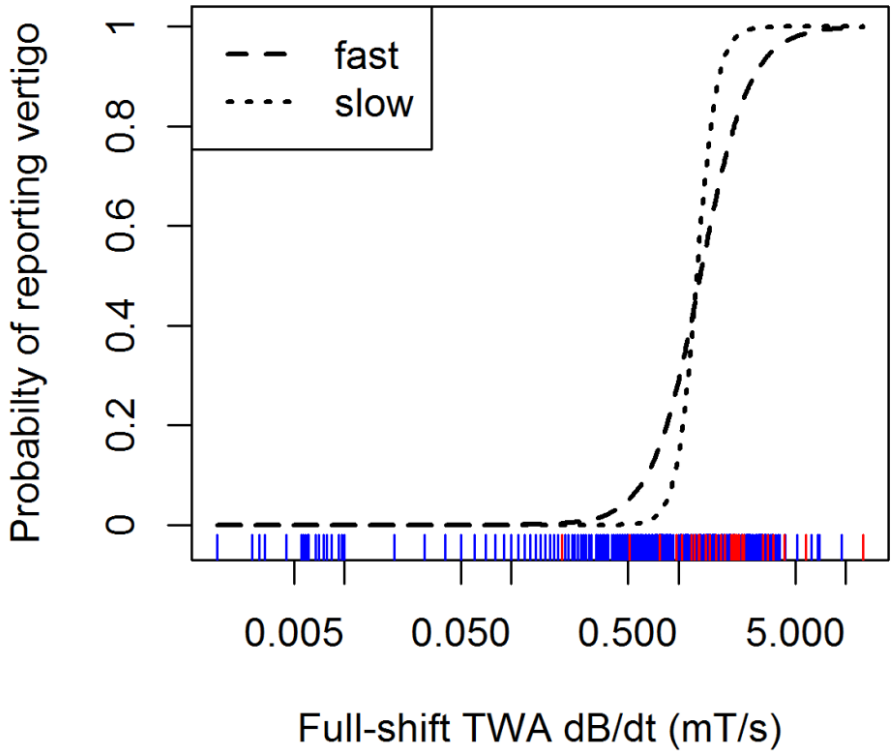
Self-reported data from general questionnaire

Demographic data

STUDY 2: MEASUREMENT SURVEY

Exposure levels where probability of vertigo in 'symptom-reporting' class is estimated to be 5%

Exposure type	Exposure Metric	5% level
SMF (B; mT)	peak B	409 mT
	SMF-exposed TWA B	48 mT
	full-shift TWA B	3 mT
TVMF (dB/dt; mT/s)	peak dB/dt	477 mT/s
	SMF-exposed TWA dB/dt	6 mT/s
	full-shift TWA dB/dt	0.6 mT/s



Vertigo significantly associated with all 6 exposure metrics

STUDY 4: MRI radiographers questionnaire on symptoms

- **Online questionnaire**
  - Members of the Dutch Society of Radiographers
  - Lifestyle, health, and work practices
- **Analyses so far:**
  - IUD use among radiographers and abnormal uterine bleeding (Huss et al. 2017)
  - MRI-related magnetic field exposures and risk of commuting accidents – A cross-sectional survey among Dutch imaging technicians (Huss et al. 2017)
  - Occupational exposure to MRI-related magnetic stray fields and sleep quality among radiographers - A cross-sectional study in the Netherlands (Özdemir et al. 2018 in preparation)

STUDY 4: MRI radiographers questionnaire on symptoms

Abnormal uterine bleeding

	N_t	N_c	OR (95% CI)
Unexposed	186	28	1.00
Working with MRI never present during image acquisition	102	23	1.44 (0.74-2.78)
Working with MRI present during image acquisition	93	21	1.43 (0.74-2.76
Unexposed no IUD	157	24	1.00
Unexposed with IUD	29	4	0.76 (0.34-2.40)
Working with MRI never present during image acquisition, no IUD	85	20	1.54 (0.76-3.13)
Working with MRI present during image acquisition no IUD	17	3	0.94 (0.24-3.71
Working with MRI never present during image acquisition, with IUD	71	11	0.91 (0.41-2.02)
Working with MRI present during image acquisition, with IUD	**22**	**10**	**3.43 (1.26-9.34)**

Adjusted for age and age^2, work stress, emotional stress, and physical strain at work

STUDY 4: MRI radiographers questionnaire on symptoms

Commuting accidents from home to work

	N_t	N_c	OR (95% CI)
Unexposed	227	21	1.00
In MRI room at least once during pas year	**244**	**36**	**2.00 (1.08-3.70)**
Sometimes working with MRI (1-66 days)	121	14	1.67 (0.67-3.61)
Often working with MRI (67-230 days)	**122**	**22**	**2.27 (1.14-4.52)**
Exposed to MRI but not during image acquisition	**125**	**19**	**2.41 (1.16-5.00)**
Present during image acquisition (1-3 days)	58	6	1.32 (0.49-3.59)
Present during image aquisation (4-140 days)	61	11	2.02 (0.86-4.72)
Low/medium scanner strength	159	21	1.87 (0.93-3.74)
High scanner strength	79	13	1.97 (0.88-4.40)

STUDY 4: MRI radiographers questionnaire on symptoms

Commuting accidents from work to home

	N_t	N_c	OR (95% CI)
Unexposed	221	15	1.00
In MRI room at least once during pas year	**237**	**29**	**2.32 (1.15-4.70)**
Sometimes working with MRI (1-66 days)	121	13	2.19 (0.94-5.11)
Often working with MRI (67-230 days)	**116**	**16**	**2.43 (1.10-5.38)**
Exposed to MRI but not during image acquisition	**121**	**15**	**2.88 (1.24-6.70)**
Present during image acquisition (1-3 days)	58	6	1.73 (0.61-4.92)
Present during image aquisation (4-140 days)	58	8	2.16 (0.82-5.68)
Low/medium scanner strength	155	17	2.06 (0.94-4.51)
High scanner strength	**77**	**11**	**2.68 (1.08-6.65)**

Sleep

- Overall, no clear evidence for an association between MRI-related EMF exposure and sleep quality
- However:
  - Presence during image acquisition in the past 4 weeks and sleep disturbance **(adj OR 1.93; 95% CI 1.00-3.70)**
  - Entering an MRI room more often (≥7 days) in the past 4 weeks and non-optimal sleep quantity **(adj OR 1.95; 95% CI 1.11-3.44)**

Self-reported symptoms and accidents

- Increased incidence of specific transient symptoms among people working with closed-bore MRI scanners of 1.5-7.0 Tesla
- Positive association with scanner strength; in agreement with previous studies among MRI staff (*Wilen & De Vocht, 2011; De Vocht et al., 2006; Schenck et al., 1992)*
- Effects most clearly seen for vertigo and metallic taste
  - reported during 6% and 2% of the MRI shifts, respectively
- Future perspective: stronger magnets → more workers with symptoms
  - At 7 T vertigo reported during 23% of the shifts.
- Vertigo estimated to emerge around 400 mT (peak exposure)
  - Far below the 2 T limit to prevent sensory effects as proposed by ICNIRP (2009)

Self-reported symptoms and accidents

- Exposed imaging technicians using IUDs, in particular those present inside the scanner room during image acquisition report abnormal uterine bleeding more often than their co-workers without an IUD, or non-exposed co-workers with an IUD.
- Imaging technicians working with MRI scanners may be at an increased risk of commuting (near) accidents.
- No clear evidence for an association between MRI-related EMF exposure and sleep quality, except for being more often in an MRI room and non-optimal sleep duration and presence during image acquisition and sleep disturbance

Promotie UU op 14 mei a.s.

MRI Cohort Study

Health effects from long-term exposure to MRI-related fields

Suzan Bongers

IRAS, Utrecht University

The Netherlands

Yvette Christopher-de Vries, Pauline Slottje,

Lützen Portengen, Hans Kromhout

Study aims

To study (health) effects of occupational exposure during MRI production

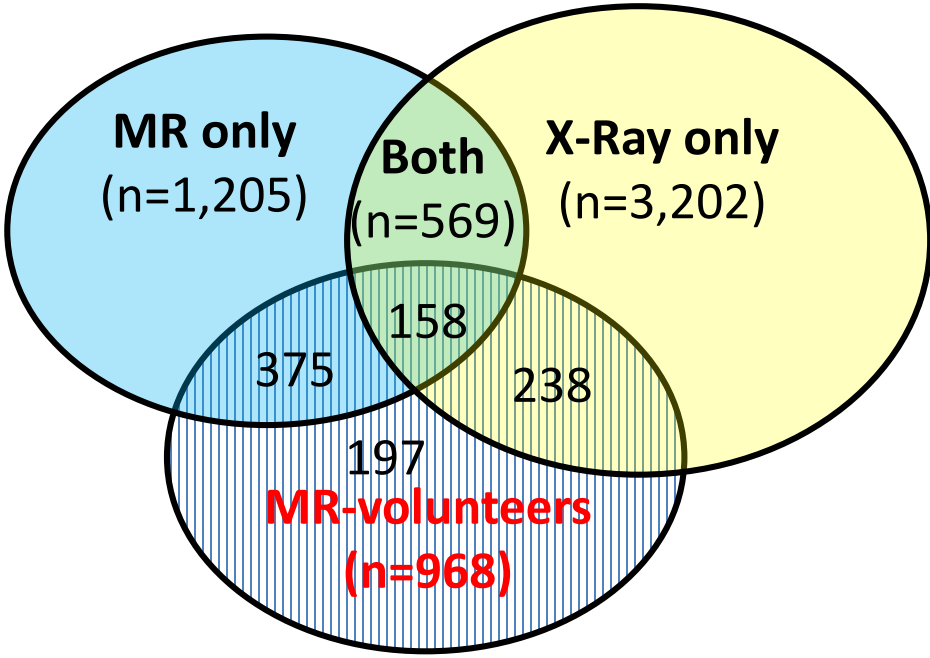
- Accident risk
- Change in absolute threshold of hearing
- Development of hypertension
- Neurological symptoms (memory, early symptoms of possible Parkinson's disease, headache), fatigue, quality of sleep, quality of life.

Retrospective occupational cohort

Retrospective occupational cohort study in medical imaging device production facility (1984-2011)

<u>Base cohort (n=5,173):</u>

- Employees of PHC from business units MR and X-Ray with ≥1 year employment (n=4,976) among them MR-volunteers (n=771)
- MR-volunteers from other business units with ≥1 year employment (n=197)



Occupational exposure to MRI-related magnetic fields and noise

Exposure	Type	Worker	MR-volunteer
Static magnetic fields (SMF)	Continuous	+	+
Time-varying magnetic fields (TvMF)	Motion-induced	+	minimal
Switched gradient fields (SGF)	During scan	minimal	+
Radio-frequency fields (RF)	During scan	minimal	+
Scanning noise	During scan	minimal	+

Available and collected data

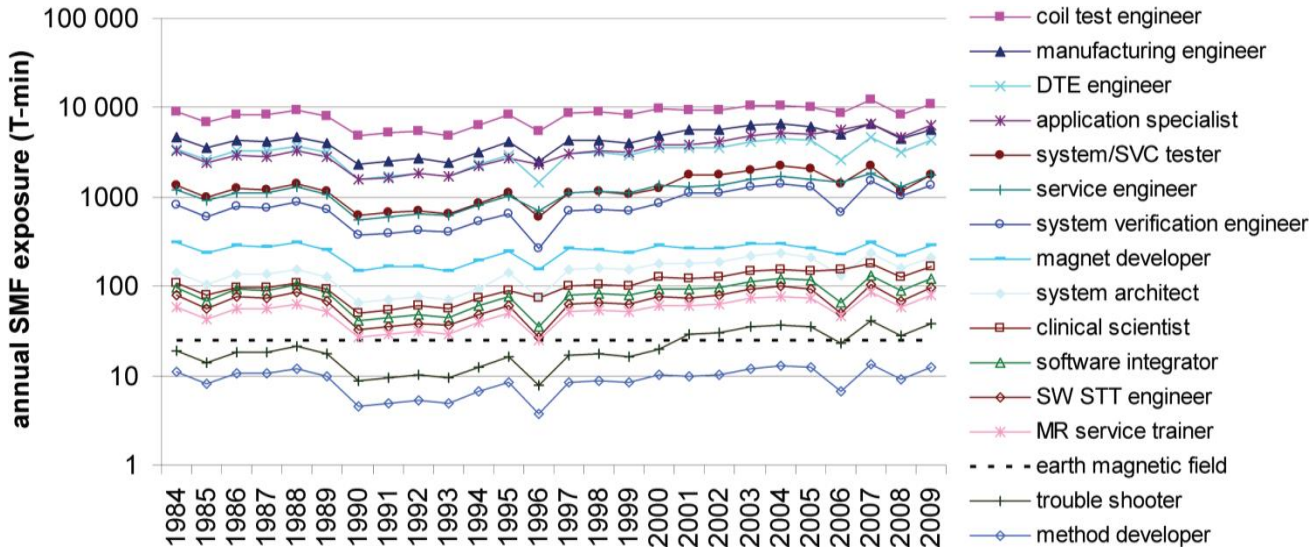
- Study population:
  - Employees at MRI manufacturing and X-ray business units of medical devices manufacturing company
- EMF exposure sources:
  - work during MRI manufacturing (salary administration)
  - voluntary scans
- Audiometry and Blood Pressure (BP) measurements
  - periodical health examinations for MR employees
  - health examinations for older employees
  - entry and exit examination for X-ray employees

Available and collected data

- MR-volunteer exposure
  - Company records detailing
    - Per volunteer: number of scans
    - Per scan: date, duration, MRI system

Historical JEM

We elaborated an algorithm to create a historical JEM for estimating MRI-related occupational exposure to SMF. The algorithm and JEM were validated with historical measurement data



Estimated annual cumulative exposure to B_0 for each job title during the period 1984–2009

Bongers S, Christopher Y, Engels H, Slottje P, Kromhout H. Retrospective Assessment of Exposure to Static Magnetic Fields During Production and Development of Magnetic Resonance Imaging Systems. *Ann Occup Hyg* 2014 **58:** 85-102

Risk of accident leading to injury

≥1 Accident with injury in the past 12 months	Odds ratio	95% CI
Recent SMF Exposure		
Non-exposed (no occupational SMF exposure)	1	
Past exposure, but no recent exposure	1.49	0.70 – 3.32
Recent SMF exposure low [>0 - < 1796 T-min]	0.76	0.10 – 5.80
Recent SMF exposure high [≥1796 - <11053 T-min]	**4.16**	**1.14 – 15.25***
Career SMF Exposure		
Non-exposed (no occupational SMF exposure)	1	
Career SMF exposure low [>0 - <24,597 T-min]	1.32	0.57 – 3.03
Career SMF exposure high [≥24,597 - <179,911 T-min]	2.20	0.89 – 5.48

Adjusted for age, gender, recent excessive alcohol consumption, and MR-volunteer exposure

Risk of accident leading to injury

Injury of most recent accident in past 12 months treated by a doctor	Odds ratio	95% CI
Recent SMF exposure		
Non-exposed (no occupational SMF exposure)	1.00	
Past exposure, but no recent exposure	1.47	0.63 – 3.42
Recent SMF exposure low [>0 - < 1796 T-min]	1.00	0.13 – 7.69
Recent SMF exposure high [≥1796 - <11053 T-min]	**5.78**	**1.57 – 21.32***
Career SMF exposure		
No career exposure (no occupational SMF exposure)	1.00	
Career SMF exposure low [>0 - <24,597 T-min]	1.22	0.46 – 3.23
Career SMF exposure high [≥24,597 - <179,911 T-min]	**2.79**	**1.11 – 7.04***

Adjusted for age, gender, recent excessive alcohol consumption, and MR-volunteer exposure

Risk of commute-related (near) accidents home to work

Commuting from home to work	Hazard Ratio	95% CI
Recent SMF exposure in year of event		
Non-exposed	1.00	
Past SMF exposure, no SMF exposure in year event	1.08	0.59 – 1.97
recent SMF exposure low	1.02	0.47 – 2.22
recent SMF exposure high	**2.49**	**1.14 – 5.43**
Career SMF exposure		
Non-exposed	1.00	
Career SMF exposure low	0.85	0.48 – 1.50
Career SMF exposure high	**2.45**	**1.40 – 4.30**

Adjusted for age, sex and alcohol use (categorical units per week per age group), and ever MR-volunteer exposure (Y/N)

Conclusions
Accidents

- We found an association between MRI-related occupational SMF exposure and:
  - increased risk of accidents leading to injury
  - commute-related (near) accidents during the commute from home to work, but not from work to home/elsewhere
- Unclear if association is causal or indirect through an unknown pathway
- Further research into health effects of (long-term) SMF exposure is warranted to corroborate our findings

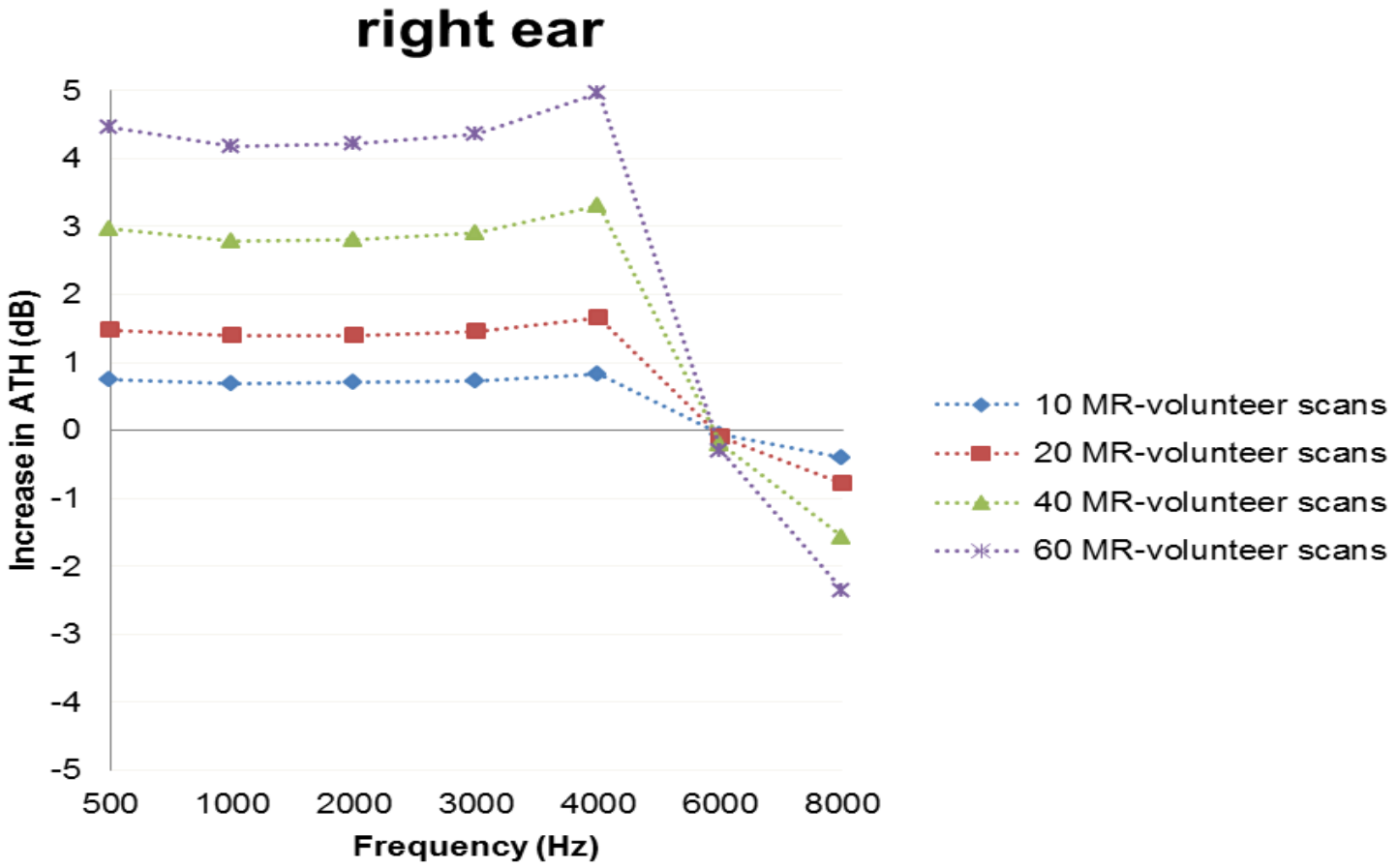
Bongers S, Slottje P, Portengen L, Kromhout H.
Magn Reson Med. 2016;75:2165-74.

Conclusions
Noise exposure and hearing

- Number of MR-volunteer scans is associated with a significant increase in ATH over time for the right ear at lower frequency range (0.5 to 4 kHz)
- A smaller but not significant increase is seen for the left ear
- Modelled noise exposure (dB) did not show a dose response relationship
- No association found between modelled SMF exposure and increase in ATH over time
- MR-volunteers have a somewhat better hearing at baseline, which may have influenced results

Bongers S, Slottje P, Kromhout H.
Occup Environ Med. 2017;74:776-784

Number of volunteer scans and increase in hearing threshold



Multivariate logistic regression of association cumulative SMF exposure and hypertension

Medical surveillance database (N=463)		
Exposure between first and last examination	**Odds Ratio**	**95% Wald CI**
Non-exposed	1	
SMF Low (<7,413 T-min)	0.71	0.33-1.51
SMF High (≥7,413 T-min)	**2.32**	**1.27-4.25**
Scans Low (1-21 scans)	**0.54**	**0.30-0.97**
Scans High (>21 scans)	0.62	0.35-1.09
Age (years)	**1.04**	**1.01-1.07**
Systolic BP baseline	**1.06**	**1.03-1.09**
Diastolic BP baseline	1.02	0.98-1.05
BMI ≥ 25	**1.77**	**1.09-2.84**

Multivariate logistic regression of association cumulative SMF exposure and hypertension

Medical surveillance database (N=463)		
Exposure between first and last examination	**< 10 years Odds Ratio (95% ci)**	**≥ 10 years Odds Ratio (95% ci)**
Non-exposed	1	1
SMF Low (<7,413 T-min)	1.28 (0.48-3.40)	0.33 (0.09-1.25)
SMF High (≥7,413 T-min)	**3.96 (1.62-9.69)**	1.16 (0.49-2.76)
Scans Low (1-21 scans)	**0.42 (0.19-0.96)**	0.89 (0.36-2.17)
Scans High (>21 scans)	0.80 (0.35-1.84)	0.58 90.26-1.31)
Age (years)	1.03 (0.99-1.07)	1.04 (0.99-1.09)
Systolic BP baseline	**1.09 (1.05-1.13)**	1.02 (0.98-107)
Diastolic BP baseline	1.01 (0.96-1.06)	1.04 (0.99-1.09)
BMI ≥ 25	1.37 (0.70-2.65)	**2.63 (1.21-5.71)**

Conclusions
SMF exposure and blood pressure

- Workers with high cumulative exposure to SMF had a twofold increased risk for developing hypertension

- A “healthy volunteer” selection effect is clearly apparent in our prospective cohort study (as expected)

- Intensity of SMF exposure seems to be more important than duration of SMF exposure; workers who accrued high cumulative exposure in a shorter time period showed a fourfold increased risk for developing hypertension

Conclusions
SMF exposure and blood pressure

- Age, BMI and systolic blood pressure at first examination (known risk factors for hypertension) were clearly related to development of hypertension, but did not confound the association with cumulative exposure to SMF
- Additionally adjusting for smoking and alcohol intake did not materially change the association with SMF exposure
- Replication of our findings is clearly needed; but will be hard to achieve given the limited number MRI producers
- Prospective studies of MRI-technicians working with MRI-systems might be a good alternative since their exposure (at present) is not that different

Conclusions
SMF exposure and blood pressure

Potential mechanisms

- Hemodynamic compensatory mechanism to counteract magnetohydrodynamic slowing of blood flow resulting in an increase systolic blood pressure

- Generation of free radicals after exposure to SMF resulting in oxidative stress, which may lead to hypertension via rapidly ageing of cells of the vascular lining

Bongers S, Slottje P, Kromhout H.
Environ Res. 2018;164:565-573.

Future work (needed)

- MRI is a very valuable imaging technique that has less health effects than imaging techniques with ionizing radiation, but less harmful is not harmless.
- Focus should not only be on patient safety, but also on MRI technicians
- Health surveillance and prospective (European-wide) cohort studies are needed
- **Development of 14-T metabolism scanner in NL, health and safety onboard from the start**

ZonMw

Thank you for your attention

h.kromhout@uu.nl

Universiteit Utrecht

Institute for Risk Assessment Sciences