FULL PAPER

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MRI-Related Static Magnetic Stray Fields and Postural Body Sway: A Double-Blind Randomized Crossover Study

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We assessed postural body sway performance after exposure to movement induced time-varying magnetic fields in the static magnetic stray field in front of a 7 Tesla (T) magnetic resonance imaging scanner. Using a double blind randomized crossover design, 30 healthy volunteers performed two balance tasks (i.e., standing with eyes closed and feet in parallel and then in tandem position) after standardized head movements in a sham, low exposure (on average 0.24 T static magnetic stray field and 0.49 $T{\cdot}s^{-1}$ time-varying magnetic field) and high exposure condition (0.37 T and 0.70 $T{\cdot}s^{-1}$). Personal exposure to static magnetic stray fields and time-varying magnetic fields was measured with a personal dosimeter. Postural body sway was expressed in sway path, area, and velocity. Mixed-effects model regression analysis showed that postural body sway in the parallel task was negatively affected ($P < 0.05$) by exposure on all three measures. The tandem task revealed the same trend, but did not reach statistical significance. Further studies are needed to investigate the possibility of independent or synergetic effects of static magnetic stray field and time-varying magnetic field exposure. In addition, practical safety implications of these findings, e.g., for surgeons and others working near magnetic resonance imaging scanners need to be investigated. Magn Reson Med 000:000–000, 2012. © 2012 Wiley Periodicals, Inc.

Key words: static magnetic field; static magnetic stray field; time-varying magnetic field; balance; vestibular organ

INTRODUCTION

In the last 30 years, magnetic resonance imaging (MRI) has become an important diagnostic modality within clinical settings because of its broad range of applications and noninvasive advantages compared to other diagnostic methods like X-ray, PET, and CT. These advances have been enabled by the introduction of stronger magnetic field (MF) strengths of the machines up till the recently clinical available 14 Tesla (T) systems (1). These ultrahigh-field scanners are never switched off since changing the MF strength of the machine is a very time demanding and expensive procedure. Therefore, the static magnetic field (SMF) is always present, which necessitates strict safety rules about ferromagnetic materials that can become projectiles in the MRI room (2,3). In addition, exposure of patients and personnel to these increasingly strong MFs raises concerns regarding their well-being and health.

Employees working near MRI-systems and patients exposed to MRI-related magnetic stray fields have been previously shown to report (transient) symptoms such as dizziness, vertigo, nausea, and metallic taste (4–6). Besides these reported sensory symptoms there is also experimental evidence for acute effects of exposure to strong MRI-related MFs on several neurocognitive functions like visual (spatial) perception, attention, and concentration (7–10).

Given the above, exposure to MRI-related MFs could lead to acute symptoms and cognitive disturbances in professionals working near MRI systems. This is especially important when high levels of precision and performance are required, e.g., surgeons performing MRI-guided operations (11–14). Most surgeons and personnel stand upright during (part of) their work in the MRI room. Hence, it is of special interest to investigate whether standing balance in terms of postural sway is affected by exposure to a static magnetic stray field (SMF) and whether or not in combination with movement induced time-varying magnetic fields (TVMFs) of an MRI magnet.

In a double-blind randomized crossover study, we aimed to characterize acute effects of movement-induced TVMFs within the SMF around a 7.0 T MRI-magnet on postural body sway.

METHODS

Subjects

Healthy volunteers were recruited by flyers and advertisements on bulletin boards at Utrecht University. Exclusion criteria were: self-reported presence of MRI incompatible elements in the body, medical history pointing to a possible neurological or neuro-otological disease, serious vision deficiencies, use of medication (except for birth control pills), use of soft or hard drugs, excessive alcohol (>2 glasses per day), or coffee (>5 cups per day) consumption and sensitivity to motion sickness in adulthood.

Sensitivity to motion sickness in adulthood was defined as a score higher than 2 on a four-point rating scale (Likert scale) ranging from 1 (not at all) to 4 (very often) on at least one of three types of motion sickness symptoms, i.e., car sickness, see sickness, and air sickness. These questions were derived from the revised

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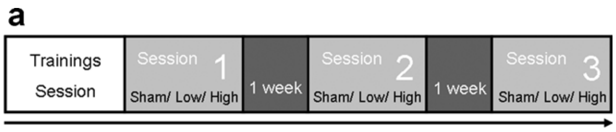

b

Time in min:sec	Activity
0:00	Practice parallel task
1:00	Head movements
1:16	Parallel task
1:46	Break
4:00	Practice tandem task
5:00	Head movements
5:16	Tandem task
5:46	End of experiment

FIG. 1. Setup of the experiment (**a**) and specifications of the experimental session (**b**). (a) Each subject first underwent a training session followed by the first experimental session out of three. The experimental sessions were at the same time of the day with 1 week in between. Sham, low, and high exposure conditions were randomized and balanced over the subjects. (b) Setup of the time scheme for a single experimental session. After practicing the balance task with feet in parallel position, standardized head movements were made (in about 16 s 10 movements in vertical and 10 in horizontal directions), immediately followed by the recorded parallel task (30 s). After a small break of 2 min, the same procedure was followed for the task with feet in tandem position. One experimental session took around 6 min to complete.

Motion Sickness Susceptibility Questionnaire (15). Subjects reporting mild sensitivity to motion sickness in adulthood (i.e., scores <3) were included. This factor was taken into account in the analysis (see data analysis).

Thirty healthy volunteers who signed an informed consent participated in the experiment. Of all volunteers, nine were male and 21 were female with an average age of 23.8 (SD 6.5) years. All participants were asked to abstain from consumption of alcohol and caffeine (24 and 6 h resp.) prior to the start of the experiment since these can substantially affect standing balance (16). A modest incentive gift voucher was provided for every completed test session. The study was approved by the local medical ethics committee of the University Medical Center Utrecht, the Netherlands.

Experimental Design

A double-blind randomized crossover design was used to examine postural body sway when in a sham, low and high SMF of a passively shielded 7.0 T MRI system (Philips Achieva research system located at University Medical Center Utrecht in the Netherlands).

The sequence of the three exposure conditions was balanced and assigned prior to the start of the experiment using a randomization protocol. Each subject was tested on three occasions conducted at the same time of day ±52 min (SD 48), with 1 week between each session (see Fig. 1a). A single session took on average 6 min in which two different balance tasks were assessed in standing position with eyes closed (see Fig. 1b). To reduce a possible practice effect on test performance, the subjects practiced both tasks once in a training session and also in every single experimental session right before the recorded task (17).

In the low and high exposure conditions, subjects were tested in front of the MRI bore at two designated distances (see Fig. 2). Average SMF exposure were 0.24 and 0.37 T in the low and high exposure conditions, respectively. Immediately before each task TVMFs were induced by standardized head movements of on average 0.49 and 0.70 $T{\cdot}s^{-1}$ in the low and high exposure conditions, respectively. The head movements took about 16 s and consisted of 10 movements in the vertical and 10 in the horizontal direction between two visual markers (covering an angle of 180° in 0.8 s). The start of each head movement was indicated by an auditory cue.

Prior to the balance task subjects sat for an hour on a chair with fixed position in a corresponding low (0.5 T) or high (1.0 T) exposure condition and performed several neurocognitive tasks reported elsewhere (10). Each of these neurocognitive tasks was preceded by the same standardized head movements, which in this case induced TVMFs of 1.20 and 2.40 $T{\cdot}s^{-1}$.

Exposure Assessment

Personal exposure to MFs was registered in real-time by use of a dosimeter [Magnetic Field Dosimeter, University of Queensland, Australia (18)] which was attached to the inside of a plastic helmet worn by the subject. The dosimeter registered exposure to SMF and TVMF in three directions, where

$$\text{total static field } \|\boldsymbol{B}\| = \sqrt{B_x{}^2 + B_y{}^2 + B_z{}^2}$$

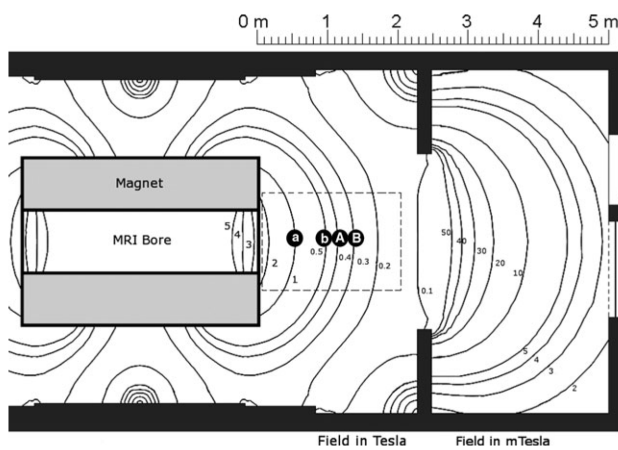

FIG. 2. Top view map of the 7 T MRI with calculated field lines of the SMF as provided by Magnex Scientific Inc. Dots represent the positions of the subject in the exposure conditions within the tent (interrupted line). Circle A in front of the bore represents the test position (on average 0.37 T) after staying an hour in the high exposure position of 1.0 T (circle a). Circle B represents the test position (on average 0.24 T) after staying an hour in the low exposure position of 0.5 T (circle b). The tent was shifted when subject was in the low exposure position. Distance to the bore was around 90 (A) and 130 (B) centimeter. The sham condition was in a room opposite to the scanner room.

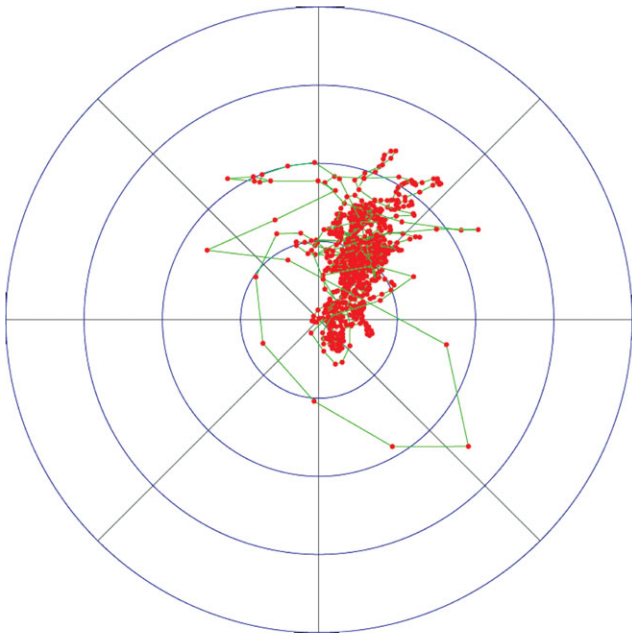

FIG. 3. Example of a postural sway recording of a subject in the high exposure condition as viewed from above. Subject stood with feet in tandem position (heel to toe) with eyes closed. Measurement started after the head movements were completed, in the center of the web and postural position was sampled at 100 Hz (represented by the dots) during 30 seconds. Sway path (cm), area (cm^2), and velocity (cm/s) were computed as outcome measures. In this case, the depicted subject had a sway path of 31 cm, sway area of 494 cm^2 and sway velocity of 47 cm/s.

and

$$\text{total time-varying field } \|\mathbf{d}\boldsymbol{B}/\mathbf{d}\boldsymbol{t}\| = \sqrt{(\mathrm{d}B_x/\mathrm{d}t)^2 + (\mathrm{d}B_y + \mathrm{d}t)^2 + (\mathrm{d}B_z/\mathrm{d}t)^2}.$$

Average exposure to the SMF and TVMF during head movements before each balance task was used as an estimate of exposure in the main analysis.

Blinding

Several measures were taken to develop a double blind setup: subjects were tested inside a standardized tent ($210 \times 140 \times 190$ cm^3) to hide the exposure condition. The subject and trained experimenter were blindly guided into and out of one of the tents by the experiment coordinator (LEvN). In addition, in the sham condition an audiotape played the acoustic noise of an MRI system in stand-by mode. Eight subjects reported to have undergone an MRI but none of the subjects or experimenters had ever worked with MRI or had seen the test room before. Prior to each session, subjects were checked for metallic components and after each session a questionnaire on perception of the actual exposure condition was completed.

Assessment of Postural Sway

For measuring postural sway a balance task was selected which could be safely used in an MRI environment. The balance task [better known as the Romberg test (19)] had two levels of difficulty: the simple test, in which postural body sway was measured with feet next to each other in parallel position (0 cm apart), and an advanced test, with feet in tandem position, heel to toe (0 cm apart). Subjects had to stand upright barefoot with their arms alongside their body. After performing the standardized head movements, postural body sway with closed eyes was recorded real-time during 30 s by use of a balance belt around the waist, containing a shielded 2D accelerometer from Sensabalance Therapy Cushion 1.0 (Sensamove, Utrecht). The recording frequency of the device was 100 Hz.

Three sway endpoints were derived from the data record: postural sway path, sway velocity, and sway area (see Table 2 and Fig. 3). Sway path was defined as the total length of the swayed path in centimeter. Sway velocity was calculated as the average speed of movement over the sway path length in centimeter per second (cm/s). The correlation of this metric with sway path length will therefore be rather high. Sway area was defined as the total area within the outer bounds of a subject's sway path expressed in centimeter squared (cm^2). Higher test scores indicated poorer postural sway performance.

Data Analysis

Statistical analyses of interindividual and intraindividual differences in test performance in association with exposure were performed using mixed-effects models (20) in Statistical Package for Social Science version 16.0 (SPSS Inc., Chicago, IL). Four exposure metrics were entered as continuous variables in separate models assuming a log-linear exposure-effect association: (a) SMF exposure and (b) TVMF exposure, both measured during head movements before the parallel task; (c) SMF exposure and (d) TVMF exposure, both measured during head movements before the tandem task. Before modeling postural sway, endpoints were log(10)-transformed to improve the fit of the statistical models. All analyses were adjusted for order of the sessions, gender, and reported "mild sensitivity to motion sickness in adulthood" (see paragraph "subjects"). Random effects were modeled using heterogeneous compound symmetry which assumes a similar correlation between residuals of the same subject but no correlation between different subjects. Statistical significance level was defined as $P \leq 0.05$.

Before the balance tasks, subjects performed a neurocognitive test battery [reported elsewhere (10)] for about an hour in the same three conditions (sham, low, and high exposure, with standardized head movements). Therefore, a sensitivity analysis was run using the average personal exposure to SMFs and TVMFs during the hour prior to the balance tasks in similar mixed-effects models.

RESULTS

Of the 30 eligible subjects, 28 subjects completed all three experimental sessions; two subjects completed only two sessions. Eventually a total of 69 sessions of 28 subjects were included in the analysis, and 25 sessions

Table 1
Average Personal Exposure Levels (in Tesla) in the Assigned Sham. Low and high exposure conditions as measured in the hour prior to the balance tasks, during the head movements (about 16 s) before the parallel task, and head movements (about 16 s) before the tandem task ($N = 28$)

		Sham (28)			Low (20)			High (21)		
Time period	Field	Mean	GM	GSD	Mean	GM	GSD	Mean	GM	GSD
Hour before balance task	B_0	0.01	0.01	2.26	0.46	0.46	1.14	0.78	0.77	1.14
	dB/dt	0.02	0.02	2.49	0.21	0.20	1.21	0.37	0.37	1.17
Head movements before parallel task	B_0	0.01	0.01	1.24	0.24	0.24	1.14	0.37	0.37	1.15
	dB/dt	0.02	0.02	1.34	0.50	0.48	1.36	0.71	0.70	1.22
Head movements before tandem task	B_0	0.01	0.01	1.24	0.24	0.24	1.15	0.36	0.36	1.12
	dB/dt	0.02	0.02	1.34	0.47	0.45	1.35	0.68	0.67	1.19

Abbreviations: Geometric mean, GM and Geometric standard deviation, GSD.
(28/20/21): number of subjects in calculation.
Note: All data represent raw, untransformed data.

were excluded because of missing exposure or postural sway data.

Average personal exposure as measured during the hour of neurocognitive testing and during head movements before both balance tasks in the sham, low and high exposure conditions are shown in Table 1. The mean scores for postural body sway path, area and velocity for the parallel and tandem task in the three conditions are presented in Table 2.

Figures 4 and 5 depict the unadjusted results for postural body sway path, area, and velocity in the parallel and tandem tasks according to personal exposure to the SMF and TVMF. In addition, Table 3 presents the adjusted mixed model results of the relationship between personal exposure to SMFs, TVMFs, and postural body sway. Increasing SMF exposure in the balance task with feet in parallel position showed an increase in sway path ($P = 0.008$), sway area ($P = 0.008$), and sway velocity ($P = 0.013$) (Table 3). Similarly, TVMF exposure was associated with reduced performance on the parallel task, i.e., increased sway path ($P = 0.015$), area ($P = 0.018$), and velocity ($P = 0.025$).

When feet were in tandem position a similar increase in sway was seen, which appeared to be only statistically significant association for exposure to the SMF and sway area ($P = 0.023$) (Table 3). For sway path ($P = 0.095$) and sway velocity ($P = 0.090$), the association reached only borderline significance. TVMF exposure was not statistically significantly associated with postural sway (path $P = 0.232$, area $P = 0.063$, or velocity $P = 0.200$), although balance performance was reduced with increasing exposure.

A sensitivity analysis was performed using the average personal SMF and TVMF exposure levels during the hour of cognitive testing prior to the balance tasks in the sham, low, and high exposure conditions. These average hourly exposure measures were strongly correlated with the individual exposure levels during the head movements before the balance tasks ($r = 0.969$ and $r = 0.992$ for SMF of the parallel and tandem task respectively, and $r = 0.930$ and $r = 0.985$ for TVMF of the parallel and tandem task, respectively). There was comparable variation across the sham, low, and high exposure conditions. In line with these observations, these sensitivity analyses resulted in similar trends compared to the main analysis (see on-line Supplemental Information Table S1).

DISCUSSION

In this study, we aimed to characterize acute effects on postural body sway of exposure to head movement-induced TVMFs in the SMF of a 7.0 T MRI magnet. Results indicated a reduced postural stability with increasing levels of exposure in healthy volunteers. The assessed balance task showed an increased sway path, area, and velocity after exposure to SMFs in combination

Table 2
Average Test Performance on Postural Sway for the Balance Task in Parallel and Tandem Position in the Sham, Low and High Exposure Conditions ($N = 28$)

		Sham (28)			Low (20)			High (21)		
Test	Sway	Mean	GM	GSD	Mean	GM	GSD	Mean	GS	GSD
Parallel	Path	10.7	9.72	1.49	23.0	13.6	2.54	18.6	13.0	2.12
	Area	125	107	1.66	203	136	2.34	236	149	2.39
	Velocity	16.3	14.8	1.48	29.6	19.3	2.36	27.5	19.3	2.13
Tandem	Path	50.5	34.3	2.45	66.9	41.7	2.80	81.1	56.0	2.47
	Area	368	244	2.56	514	324	2.83	683	439	2.67
	Velocity	84.4	59.5	2.38	115	67.3	3.06	143	101	2.37

Abbreviations: Geometric mean, GM and Geometric standard deviation, GSD.
Note. All data represent untransformed data; statistical analyses were done on log-transformed data.
(28/20/21): number of subjects in calculation.
Sway path in cm, Sway area in cm^2, Sway velocity in cm/s.

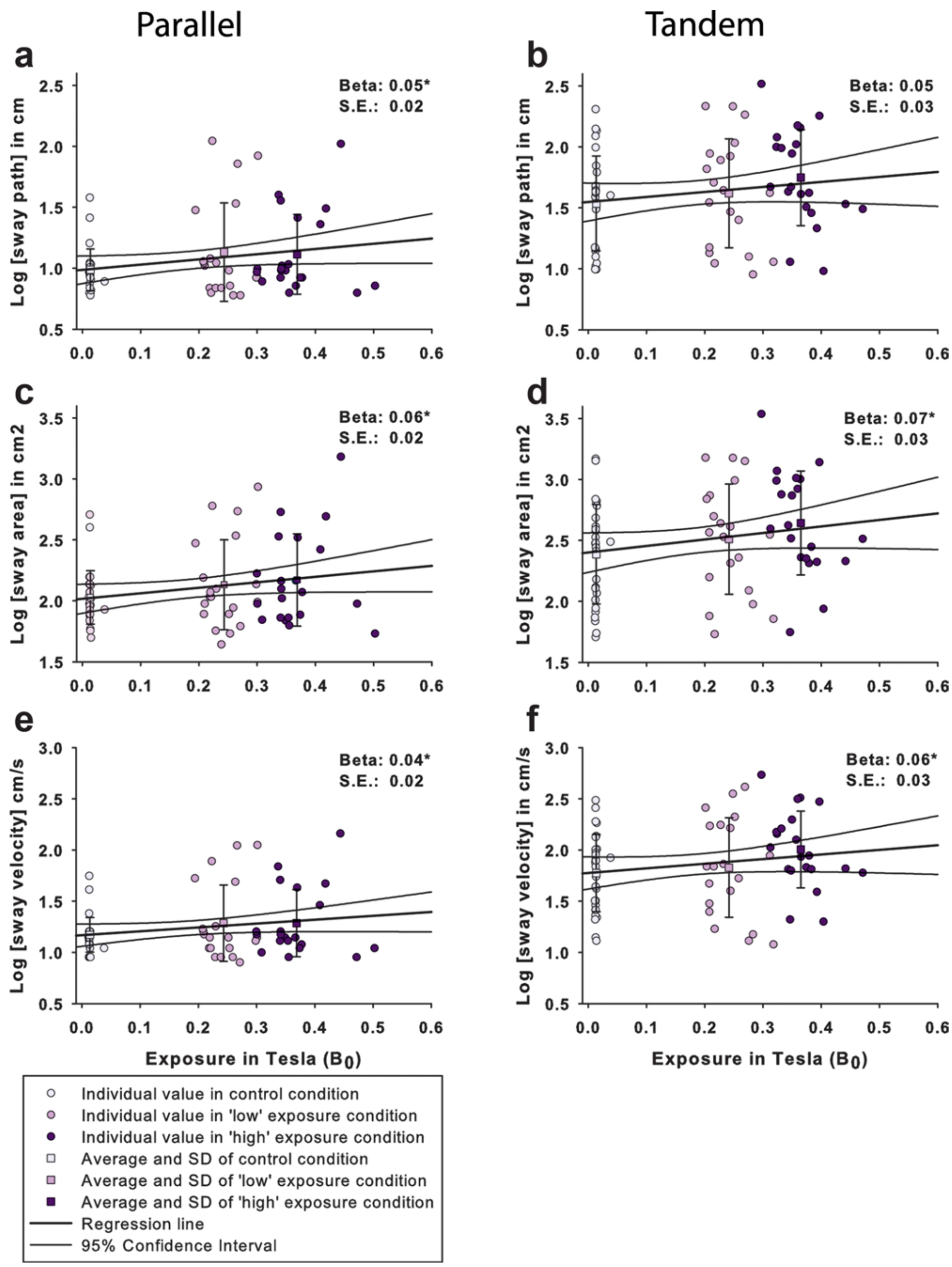

FIG. 4. Postural body sway path (**a**), area (**c**) and velocity (**e**) in the parallel task and sway path (**b**), area (**d**), and velocity (**f**) in the tandem task in relation to static magnetic field exposure (SMF). Each dot represents a single subject ($N = 28$, with 69 subject observations) in one of the three exposure conditions (sham white, low exposure light gray, high exposure black). Unadjusted regression lines with corresponding 95% confidence intervals are based on all data points. The regression coefficient (beta) of the unadjusted model is calculated per 100 mT with corresponding standard error. Group averages in the control, low, and high exposure conditions are depicted by the squares with corresponding standard error bars.

with TVMFs when feet in parallel position and eyes closed. With feet in tandem position and eyes closed similar effects were seen, but only sway area was statistically significantly associated with SMF exposure. These findings support the hypothesis that (movement in) a spatially heterogeneous SMF negatively affects postural body sway.

We assessed two relatively difficult versions of the balance task (better known as the Romberg test) as we aimed to pick up subtle changes in performance in a young and healthy subject population. The balance task with feet in parallel position and eyes closed is relatively easier to perform than the version with feet in tandem position and eyes closed. As expected, the parallel version proved to be easier to finish successfully and showed less random variability in our study, hence making it easier to assess effects of exposure. The postural body sway endpoints used—path, area and velocity—are highly correlated. However, these measures can differ from each other. For example, in our study subjects accomplished a comparable path and velocity, but tended to have a higher area in the tandem task when exposed to the MFs.

It remains unclear whether exposure to SMFs, motion-induced TVMFs, or the combination of both, is responsible for the observed effects on postural body sway. Analyses in the current experiment were performed with exposure to either SMFs or TVMFs as exposure variables. However, exposure occurred simultaneously so the effects of SMFs and TVMFs could not be disentangled. Though, efforts should be made to address this in future studies, as should be the effects of timing, duration, and

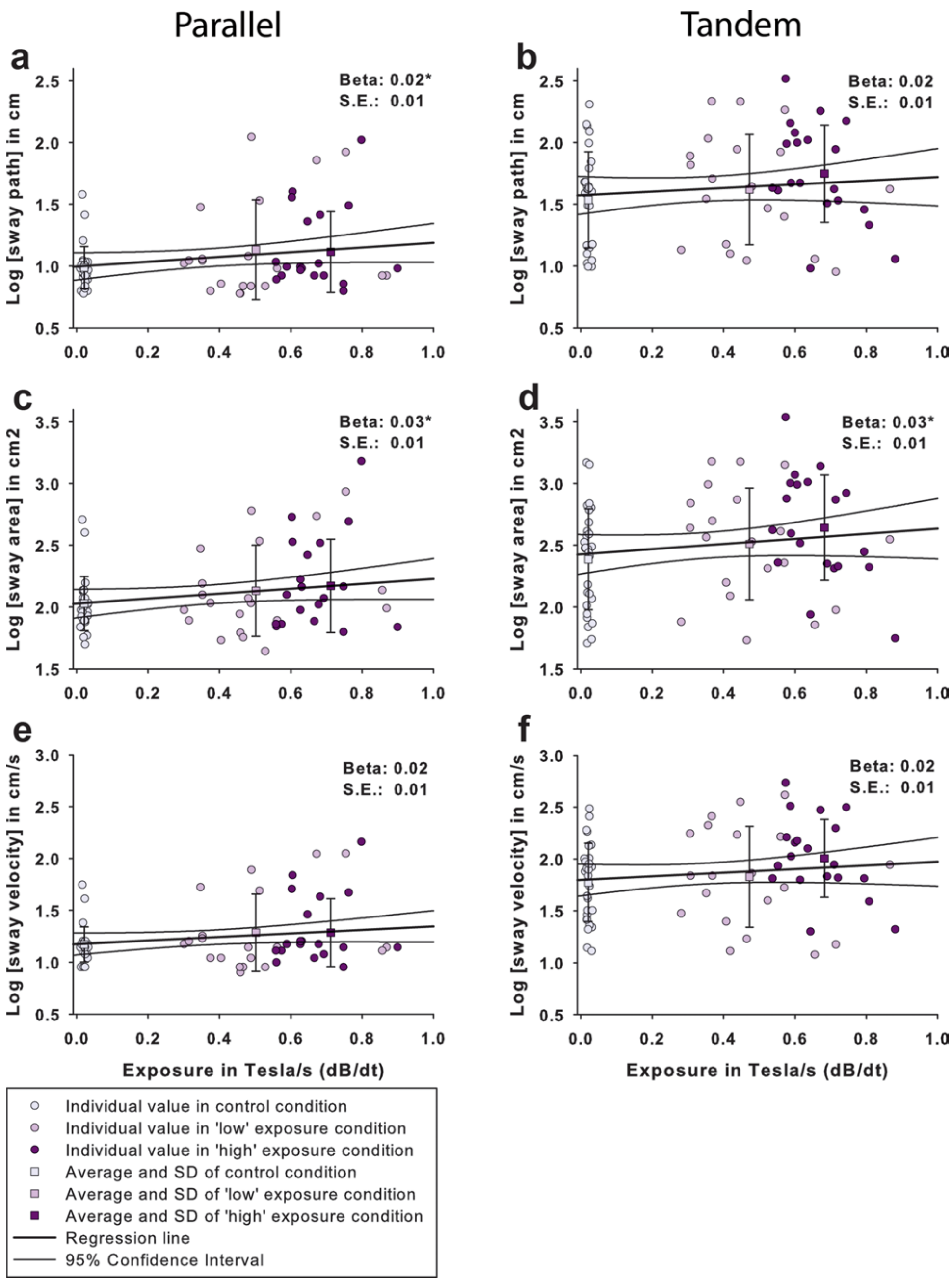

FIG. 5. Postural body sway path (**a**), area (**c**), and velocity (**e**) in the parallel task and sway path (**b**), area (**d**), and velocity (**f**) in the tandem task in relation to TVMF exposure. Each dot represents a single subject (N = 28, with 69 subject observations) in one of the three exposure conditions (sham white, low exposure light gray, high exposure black). Unadjusted regression lines with corresponding 95% confidence intervals are based on all data points. The regression coefficient (beta) of the unadjusted model is calculated per 100 mT with corresponding standard error. Group averages in the control, low and high exposure condition are depicted by the squares with corresponding standard error bars.

direction (orientation relative to the field lines) of exposure on postural stability.

Several lines of research address a possible explanation for acute effects on standing balance. It has previously been postulated that strong MFs of MRI scanners interact with the vestibular apparatus of the human inner ear (9,21–23). Behavioral studies in rodents have demonstrated a role of the vestibular organ in the perception of MFs. For example, normal rats avoided entering a 2 T SMF while labyrinthectomized rats simply entered a 14.1 T SMF (24,25). Furthermore, above 7.0 T exposure conditioned taste aversion (26,27) and circling locomotor activity was induced in normal rats compared to the labyrinthectomized rats (26–29), where the direction of circling was dependent on the spatial position of the rat within the MF. Recently is has been demonstrated that normal rats within a 14.1 T MRI tilt their heads depending on the orientation of the MF (30). In addition, normal rats had an increased c-Fos expression (indicating neuronal activity) after MF exposure in nuclei associated with the vestibular system (29,31). Based on these animal results, it seems likely that the vestibular organ is affected by strong MFs. However, the exact working mechanism and which part of the vestibular organ is involved is not clear since both the semicircular canals and otolith organs are destroyed by chemical labyrinthectomy (31).

Few human studies have been conducted and they showed less clear evidence of vestibular disturbance when exposed to SMFs. Performance on the caloric reflex test was not affected after exposure to SMFs of 2–7 mT (32) nor after exposure to a stronger MF of 9.4 T for

Table 3
Estimated Trends of Test Performance Per 100 mTesla for the SMF and Per 100 mTesla·s^{-1} for the TVMF Using Personal Exposure Data Measured During Head Movements Before the Parallel Task and Tandem Balance Task ($N = 28$, with 69 Subject Observations)

		Intercept			Exposure			
Field	Sway	Estimate	5% CI	95% CI	β per 100 mT (·s^{-1})	5% CI	95% CI	*P*
Parallel task								
SMF	Path	0.809	0.618	1.000	0.060	0.016	0.104	**0.008**
	Area	1.860	1.654	2.066	0.066	0.018	0.114	**0.008**
	Velocity	0.998	0.805	1.191	0.056	0.012	0.100	**0.013**
TVMF	Path	0.831	0.642	1.021	0.028	5.60E−3	0.050	**0.015**
	Area	1.890	1.684	2.096	0.029	5.31E−3	0.053	**0.018**
	Velocity	1.022	0.831	1.213	0.025	3.39E−3	0.047	**0.025**
Tandem task								
SMF	Path	1.611	1.273	1.948	0.049	−8.96E−3	0.107	0.095
	Area	2.431	2.084	2.778	0.068	0.010	0.127	**0.023**
	Velocity	1.878	1.538	2.219	0.051	−8.45E−3	0.111	0.090
TVMF	Path	1.649	1.310	1.987	0.018	−0.012	0.048	0.232
	Area	2.461	2.112	2.810	0.029	−1.64E−3	0.059	0.063
	Velocity	1.913	1.572	2.253	0.020	−0.011	0.051	0.200

Abbreviations: Confidence interval, CI, static magnetic field, SMF, and time-varying magnetic field, TVMF.
Note: All data represent back transformed data. Model was adjusted for order of sessions, gender, and motion sickness. "Adjusted for motion sickness" includes subjects with "mild" motion sickness symptoms ($N = 8$), defined as a score of 2 on a 4 point Likert scale ranging from 1 (not at all) to 4 (very often) for at least one of three types of symptoms (see paragraph "subjects").
Bold values; statistical significant at $P \leq 0.05$. Sway path in log(cm), Sway area in log(cm^2), Sway velocity in log(cm/s).

30 min in a small pilot study with healthy volunteers (33). A recent study by Roberts et al. (34) in healthy volunteers suggested that a strong SMF elicits direction-dependent nystagmus when entering/exiting a 3.0 or 7.0 T MRI. The speed of movement did not increase or enhance the nystagmus suggesting that only the SMF is responsible for inducing nystagmus. Other human experiments in contrast, pointed to acute effects of movement in such SMF. These experiments showed acute effects of movement induced TVMFs in the SMF of an MRI magnet, indicating a decreased cognitive functioning (4,7,9,10) and sensory effects such as nausea, vertigo, metallic taste, and a sensation of movement (4,21). These symptoms are very similar to the symptoms that occur upon galvanic stimulation of the vestibular system (35). In addition, experiments with standing or moving subjects in a SMF demonstrated that only moving subjects in a SMF reported vestibular-related symptoms (21). In practice, such symptoms could be limited by decreasing the rate and frequency of movement within the static magnetic stray field (4).

Taking together previous results and the current effects on postural stability, two possible mechanistic explanations seem plausible, which could also co-exist. On the one hand, it is conceivable that exposure to the MFs elicit a change in cognitive functions, which in turn affects postural stability (36,37), since standing balance (stabilometry) depends on proprioceptive, visual, vestibular, and cognitive information (38). On the other hand, it is also possible that SMFs, TVMFs or the combination of both can interact with (parts of) the vestibular system since a disturbed vestibular system can result in a changed postural stability, changed cognitive functioning (39), and sensory symptoms (40). So far, a few (theoretical) working mechanisms have been proposed, of which direct nerve stimulation by electromagnetic induction (movement in an MF induces an electrical current) seems the most plausible (21).

Alternatively, diamagnetic susceptibility of molecules or magnetohydrodynamic currents in the fluid of the vestibular system could lead to a changed perception and function (21,33). A more recently developed model proposes that Lorentz forces can act as a component of the magnetohydrodynamic condition resulting in a continuous current within the endolymph fluid of the labyrinth (34).

Strengths of our experiment included a balanced double-blind randomized crossover design. As individuals served as their own controls, this design corrects for large interindividual differences in postural sway. Nevertheless, some limitations need to be taken into account. Several measures were taken to develop a double-blind setup, such as an audiotape playing the acoustic noise of an MRI system (in stand-by mode) in the sham condition, and blind-guiding of the subject and experimenter into and out of a standardized tent where they were tested. However, blinding was not perfect since three out of 11 subjects with a splint behind their teeth reported they could feel the MF because their splint was apparently made of a weak paramagnetic material, undetected by the metal detector. A re-analysis of the data without these three subjects resulted in similar conclusions, yet for SMF and TVMF exposure slightly higher effect estimates and smaller *P*-values on postural sway path, area, and velocity in the tandem task were observed (see on-line Supplemental Information, Table 2).

Based on the post-session questionnaires, perceived "exposure" versus "no exposure" reported by the remaining 26 subjects after the sham, low, and high exposure conditions was correct in 68, 36, and 64% of the sessions, respectively. Test leaders were also asked to indicate perceived "sham," "low," or "high" exposure after each session and had 93, 62, and 42% correct predictions, respectively. The test leader rates are more difficult to interpret since they attached the balance belt to the subject and the belt contained a weak paramagnetic material, which could have revealed the exposure condition to the test leaders, but not to the subjects. However, test leaders' knowledge about the exposure condition is not expected to significantly influence a subject's task performance as recording was started by the experiment coordinator and scoring of sway parameters was done automatically by the monitoring device. Nevertheless, blinding in future studies can be improved by refining the setup and specifically enquiring about magnetic splints prior to enrollment.

The potential practical (safety) implications of acute effects of exposure to strong MFs on standing balance, and hence performance of, e.g., surgeons performing MRI-guided operations, need to be investigated. Exposure levels as examined in this experiment occur in practice. Moreover, most surgeons and personnel are in standing position during MRI-guided interventional procedures. Therefore, the present results on standing balance should be taken into account in the safety procedures concerning MRI-guided surgery.

For comparison, the percent increase in postural body sway area due to SMF and TVMF exposure found in this study is of a similar magnitude as the percent increase reported in an experiment with subjects standing on a force plate with a blood alcohol concentration of around 0.09% (41). This concentration is comparable to five alcoholic drinks (one unit of alcohol in UK = 8 g ethanol) for an adult male of 80 kg (42) and is well above the legally allowed maximum blood alcohol concentration for driving.

In conclusion, the results of this study imply that exposure to MRI-related MFs at levels that are experienced in practice, can result in an acute increased postural body sway.

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