Technical Note

Thresholds for Perceiving Metallic Taste at High Magnetic Field

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Purpose: To perform an initial characterization of the metallic taste effect observed by some workers when moving around an MRI scanner.

Materials and Methods: A total of 21 subjects performed controlled movements in the stray field of a 7-T scanner. Rates of change of magnetic flux were recorded during the study using a custom-built three-axis coil unit connected to a data logger.

Results: Relatively normal movements could generate switched fields of 2 T/second. Of the 21 subjects, 12 detected a metallic taste, but the threshold at which it was perceived varied greatly between subjects, with the minimum dB/dt value at which such a taste was detected being 1.3 T/second. The threshold also depended on the direction of movement.

Conclusion: This study indicates that 50% of subjects will perceive a metallic taste for head shaking with a period of 1.5 seconds (magnetic field in an anterior/posterior direction) causing a dB/dt of 2.3 ± 0.3 T/second. The presence of dental fillings is not a requirement for the sensation of metallic taste.

Key Words: electrogustatory effect; bioeffects; safety of magnetic fields; metallic taste; high magnetic field
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WITH THE PURSUIT OF high-field MRI there is increasing concern about any possible adverse consequences of human exposure to high static magnetic fields. It is clear that MR workers in very high fields experience transient sensory effects such as dizziness, nausea, magnetophosphenes, and metallic taste (1,2), but the thresholds for perception of such effects, and their long-term consequences to health, have not been established (3). Nonetheless, considerable weight has been given to these sensory effects by regulatory bodies, and they have played a large role in discussions around the European Union (EU) Physical Agents Directive (4) that is intended to protect workers from any short term effects of exposure to electromagnetic fields (EMFs).

Discussions about the interactions that cause perceived sensory effects, or indeed whether these effects lead to any adverse health effects, must be informed by basic data describing the situations under which these effects are detected in the population. The vertigo effect has recently been discussed in some detail (5), and magnetophosphenes are not a practical problem for MRI since they are rarely reported for normal MRI exposures even up to 7 T. This study focuses on the metallic taste effect, which is particularly important since it is possible that it can interact with magnetically-induced vertigo to cause a sense of nausea.

This study aims to investigate the threshold for detecting a metallic taste for different types of head movement within the stray magnetic field of a 7-T, whole body MR system; specifically to determine what fraction of people experience this effect, and what sorts of movement and rates of change of magnetic flux (dB/dt) elicit the effect. It also reports subjective experiences of staff and volunteers working around high-field magnets.

MATERIALS AND METHODS

A total of 21 subjects (11 male, mean age 29 ± 6 years with no previous history of vestibular or gustatory dysfunction) were recruited for the study, which was approved by the Nottingham University Medical School Local Ethics Committee. Five of the 21 subjects reported never having any dental fillings. All the subjects were MR workers, although for several of the volunteers this was their first experience of a magnetically-induced metallic taste.

Two experiments were carried out inside the magnet hall, requiring subjects to perform two types of head motion while seated 0.80 m axially from the end of the bore of a 7-T MR scanner in a static magnetic field of approximately 0.5 T. The mean head height above the floor was 1.2 m. Subjects carried out head shakes (horizontal rotation left to right) (experiment 1) followed by

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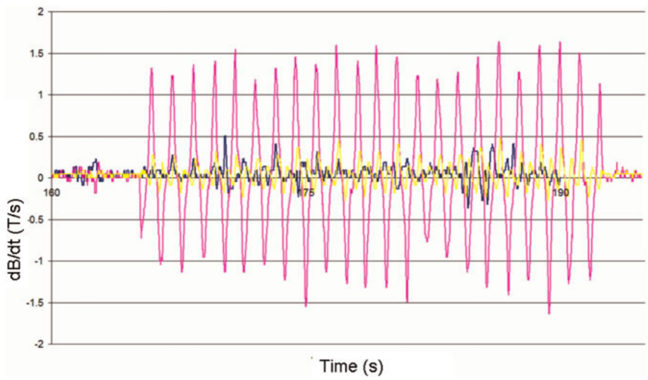

Figure 1. Time course excerpt from dB/dt recording for Subject 3, who reported a metallic taste sensation at a threshold of 80 bpm during head shaking, inducing a mean peak field change dB/dt of 2.8 T/second. Three traces show the record for the three orthogonal coil sensors.

nods (experiment 2) at different rates for a 20-second period. Subjects were asked to synchronize these head movements with the beat of a metronome at four different rates (60, 80, 100, and 120 beats per minute [bpm.] with two beats per cycle of the head), and to rotate the head through 105° in the horizontal plane (experiment 1) or nod in the vertical plane through 85° (experiment 2). It was not possible to randomize the presentation of the different rates of rotation, since once the metallic taste was perceived, an aftertaste was sometimes reported, which may have confounded further experiments. Therefore, the aim was simply to determine the threshold at which the taste was first perceived. Subjects were told to keep their mouths closed during the experiment since there is anecdotal evidence that this increases the perception of metallic taste. After each exposure level for each experiment the subjects were asked whether they could perceive any unusual sensations; they were not asked directly if they had any taste sensations.

dB/dt Meter

To measure the rate of change of field, a dB/dt meter employing three orthogonal search coils (100 turns, of cross-sectional area 284.0 mm^2) was built. This was used to measure the induced EMF as a result of head motion in the B_0 field, from which dB/dt values were calculated. The search coils were calibrated using an 800-turn solenoid coil connected to two Techron amplifiers, which in turn were connected to a waveform generator. The calibration factor was found to be 0.022 VS/T. Category 5e, screened, twisted-pair patch cable was used to connect the output from the search coils into three separate low-noise instrumentation amplifiers (INA 118P). Data from each coil output was logged via a laptop parallel port, using a separate channel of a PicoLog (Pico Technology Limited, St Neots, UK), 11-channel, 10-bit analog to digital converter, at a rate of 100 Hz. Prior to the start of each task the coils were positioned on the right side of each subject's head, in such a way that the same coil sensor was always placed behind the ear over the sphenoid bone of the skull. The coils were oriented so that the cable attached to the coils would not interfere with the head movements during the experiment.

Staff Experiences

A total of 19 staff members who regularly scanned volunteers in our magnets were sent an email questionnaire about their sensory experiences during scanning.

RESULTS

Figure 1 shows typical rate of change of field traces measured on volunteers making the head movements. The mean of the peak rates of change of field in each cycle was calculated for each subject at each frequency and ranged from 1.3 T/second to 4.1 T/second (Fig. 2). Horizontal head shakes induced a metallic taste sensation in 12 of the 21 subjects taking part in the study, and this was not related to whether the subjects had fillings (Table 1). Some subjects reported that the sensation increased with increasing rate of movement. Figure 2 shows the thresholds at which these subjects experienced the taste sensation (which varied from 60 to 120 bpm) and also gives the mean peak dB/dt for all the different movements. Only one subject reported a metallic taste sensation during the head nodding task

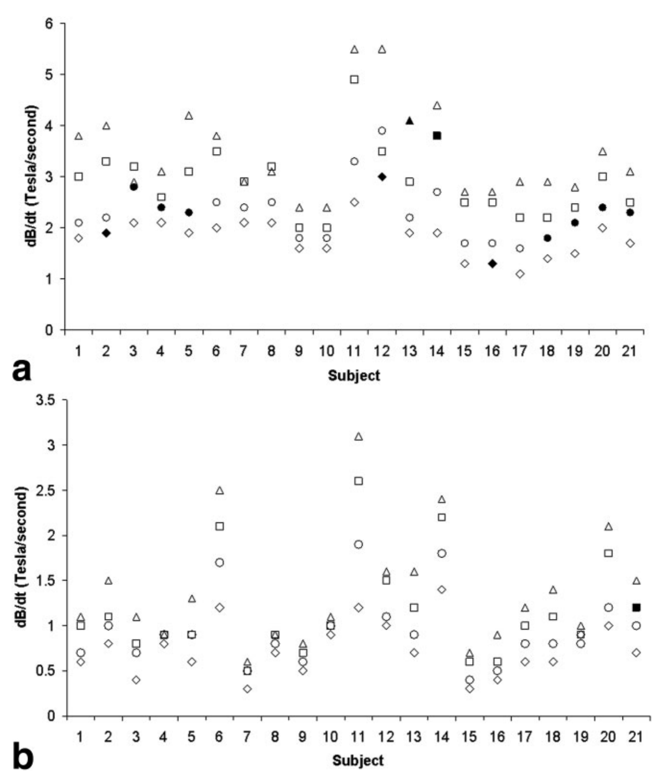

Figure 2. Mean peak dB/dt values recorded for all 21 subjects during head (**a**) shakes and (**b**) nodding task. Markers shapes are used to denote head motion rates: (diamonds) 60 bpm; (circles) 80 bpm; (squares) 100 bpm; and (triangles) 120 bpm. Filled shapes indicate the threshold of metallic taste for that subject. Measurement error bars indicating standard deviations (SDs) in peak amplitudes are not shown for clarity, but representative errors are given in Table 1.

Table 1
Mean Peak dB/dt Magnitudes at the Different Frequencies for All 21 Subjects During the 20 Second Horizontal Head Shaking Task

Subject	Subject reported having fillings	Threshold rate of movement (bpm)	Threshold dB/dt (T/second ± SD)
1	✓	X	X
2	✓	60	1.9 ± 0.2
3	✓	80	2.8 ± 0.4
4	✓	80	2.4 ± 0.4
5	✓	X	X
6	✓	80	2.5 ± 0.2
7	✓	X	X
8	✓	X	X
9	o	X	X
10	o	X	X
11	✓	X	X
12	✓	60	3.0 ± 0.3
13	o	120	4.1 ± 0.2
14	✓	100	3.8 ± 0.5
15	✓	X	X
16	o	60	1.3 ± 0.1
17	✓	X	X
18	o	80	1.8 ± 0.2
19	✓	80	2.1 ± 0.5
20	✓	80	2.4 ± 0.4
21	✓	80	2.3 ± 0.2

✓ = yes, o = none, X = no metallic taste detected.

for movement rates greater than 100 bpm, corresponding to a mean peak rate of change of field of 1.4 T/second. Figure 3 shows the percentage of subjects who first experience a metallic taste at each rate of motion. Many subjects reported some dizziness during this experiment, and two reported problems with their eyes ("problems with focusing," "visual disturbances"), and it varied between subjects as to whether these effects occurred at lower or higher thresholds than the metallic taste. It is not clear to what extent these reported perceptions are due to movement in the magnetic field, as compared to simply the movement, since we did not analyze this data without a control experiment away from the magnet.

A total of 15 staff members responded to the questionnaire. The questionnaire specifically asked staff about any sensory disturbances they experience while positioning subjects in the scanner (as opposed to exposures to the higher fields present in the magnet bore). The questions cover a period of about 16 months. Approximately 40% had experienced a metallic taste; there was no evidence of accommodation to this effect with time, and no one reported having changed their working practices to reduce this effect. Incidentally, 66% had experienced vertigo; there was no clear evidence of accommodation to this effect and 40% of these people claimed to have changed their working practices to reduce the effect. None reported having definitely experienced phosphenes (although one person was not sure). When working around a Philips 3-T scanner, 15% of staff had experienced a metallic taste.

DISCUSSION

This study suggests that the perception of metallic taste in a magnetic field depends on the direction and rate of head motion. It is difficult to investigate an effect that relies on measuring a subjective response, particularly once the stimulus has been removed. Indeed, it has previously been reported that taste responses have been elicited from individuals entering a magnet hall in which the magnet had been deenergized (6), and such an effect was also noted by some workers in our laboratory when our magnet was ramped down. To try to overcome this problem, we did not attempt to determine the amplitude of the sensation perceived by the subjects, but rather the threshold at which they first observed an effect. Nonetheless, some subjects did report that the magnitude of the sensation of metallic taste increased with the rate of head movement. Several subjects reported a lingering metallic taste at the end of the

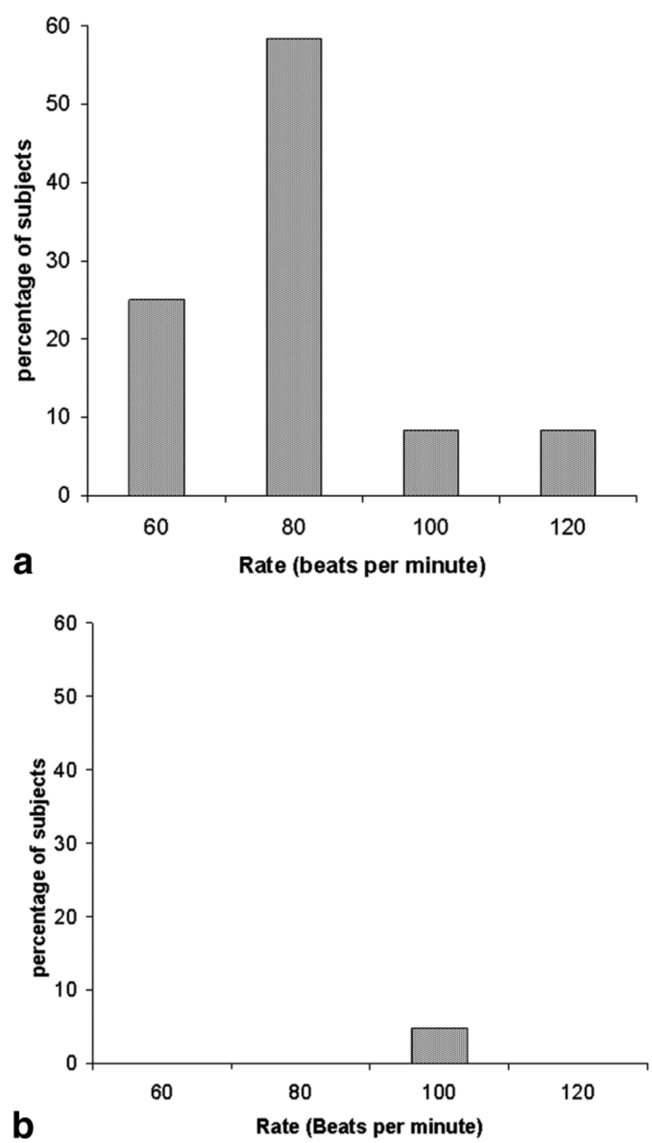

Figure 3. Percentage of subjects experiencing metallic taste for each rate of motion during head (**a**) shaking and (**b**) nodding.

task, but this subsided within a few minutes of completion of the experiment. Anecdotal evidence also suggests that opening the mouth reduces the perceived intensity of metallic taste.

Figure 1 shows that very large dB/dt values can be created by relatively normal movements in the stray field of a 7-T magnet, far exceeding the Action Value given in the EU Physical Agents Directive. This means that further modeling is required to determine whether the absolute exposure limit corresponding to a current density of 40 mAm^{-2} is being exceeded, although existing literature suggests that it would be (7).

Figure 2 shows that the differences in perceptual threshold with the instructed rate of movement did not correspond to differences in the induced rate of change of field measured on the surface of the head. However, this study indicates that 50% of subjects will perceive a metallic taste during head shaking at 80 bpm (field in an anterior/posterior direction) causing a dB/dt of 2.3 ± 0.3 T/second. In the case of the nodding experiment, only one subject reported a taste sensation, which occurred when the subject was moving at 100 bpm, generating a mean peak rate per cycle of change of field of 1.2 ± 0.2 T/second. Other subjects generated larger mean peak rate of change of field during the nodding, but did not report any sensation of taste. Comparing the responses of the subjects during both the head shaking and nodding tasks it is apparent that the taste sensation is more readily elicited by shaking rather than nodding. The dB/dt magnitudes achieved during shaking were higher than those achieved during nodding, suggesting that a taste threshold might be detected at a much higher rate of nodding. However, there is also the possibility that the geometry of the oral cavity may influence the nature of the induced current loops created, which may also explain the observation that having the mouth open reduces the effect.

It is difficult to extrapolate these results to other magnets or other field strengths since the dB/dt will depend so crucially on the field gradients around the magnet. The 7-T magnet is not self-shielded, which means that the field will be relatively higher outside the end of the bore than for most lower field scanners. However, as a first approximation it would be reasonable to assume that the threshold for detecting the metallic taste (in bpm) would scale in inverse relation to field strength. It would also be interesting to extrapolate these results to subject being pushed into the bore of a scanner. In this situation the directions of the field and field gradients relative to the direction of motion are different than those tested here. However, the situation is probably most similar to head nodding, which may be why subjects rarely complain of a metallic taste while they are being pushed into the scanner (they are much more likely to report experiences related to apparent motion).

Metallic taste resulting from movement in a magnetic field has been widely reported. Electrogustometry (8–10) is a well-established clinical tool for estimating taste detection thresholds and assessing the integrity of taste pathways using directly applied currents. Schenck (2) suggested that the source of the metallic taste in a magnetic field was "electrolysis of metallic chemicals . . . in teeth fillings." However, this cannot fully explain the phenomenon since three of the 12 volunteers in this study reported experiencing the metallic taste, but did not have such fillings (Table 1). However, it is worth noting that a recent study has shown that metallic dental materials can produce significant EMFs as they form galvanic cells with the mucosa or other dental implants. It is possible that such EMFs could combine with the induced current in such a way as to reduce the threshold for sensing a metallic taste (11). It is also reasonable to assume that the conductive pathways around the oral cavity and across the tongue will be modified by the presence of metal fillings.

Taste buds are found on the surface of papillae on the anterior tongue and the thresholds for detecting chemical tastants is inversely related to the number of papillae (12,13). Application of a tastant to the taste hairs causes depolarization of the membrane of the taste cell. The decrease in potential is approximately proportional to the logarithm of the concentration of the stimulating substance. The mechanism by which most stimulating substances react with the taste villi is by binding of the taste chemicals to protein receptor molecules that protrude through the villus membrane. This in turn opens ion channels, which allow positively-charged sodium ions to enter and depolarize the cell. The tastant is then gradually washed away from the taste villus by the saliva. The type of receptor protein in each taste villus determines the type of taste that will be perceived. The chemoreceptors responsible for the sensation of taste are believed to detect only four primary taste sensations (sour, hydrogen ions; salty, sodium ions; sweet, probably sugars, glycols, amino acids, and small proteins; and bitter, probably alkaloids and long-chain organic compounds containing nitrogen). For sweet and bitter taste sensations, the receptor protein molecules activate second-messenger transmitter substances inside the taste cells, which in turn cause intracellular chemical changes that create the taste signals.

Previous studies suggest there are at least two mechanisms of electrical taste stimulation that depend on various parameters including the duration of the applied current, its amplitude, whether it is continuous or discontinuous, the size of the area of stimulation (8,10), and the current density (9). The first is direct nerve stimulation and the second is due to the electrolysis of saliva and extracellular fluids by induced currents and hence internal electric fields. In particular, direct current (DC) pulses of sufficiently long duration are believed to cause electrolysis of saliva, producing H^+ and OH^- ions (10), resulting in sour and bitter tastes. The apparent persistence of the magnetically-induced metallic taste after the field has been removed might suggest that electrolysis is occurring so that the ions remaining in the mouth cause the continuing perception of taste. Furthermore, the taste detected is similar to that experienced when some metals are put in the mouth in the absence of an electric current, and it is likely that the metal is tasted because of a chemical reaction between the metal and the alkaline conditions in the mouth, leading to the formation of galvanic cells. Similarly, the taste is similar to that perceived if the terminals of a battery are placed across the tongue.

These observations would also support the suggestion that the taste is detected via electrolysis.

Although a transient metallic taste is commonly reported by people moving in high magnetic fields (along with the perception of vertigo (5)), there is no evidence to suggest that the metallic taste is connected to any long-term risks to health. However, it may have some significance for the practice of MRI. Considering the scanning of patients and volunteers, over 16 months we performed 514 research scans involving 164 different individuals on a passively shielded, Philips, 7-T scanner. We did not actively ask subjects about their sensory perceptions, as it is likely that this would have led to overreporting, but many subjects did mention that they had experienced low level sensory disturbances ("funny taste," "bed moving in a curve"). However, only four of these reached a level that caused the scanner operator to note them as an adverse incident on the daily scanner record sheet. These were that two subjects felt dizzy, one (a patient) felt very sick and another subject (also a patient) actually vomited. For various reasons these patients were anxious and it is likely it is not simply exposure to the field that caused them to vomit. However, it is quite possible that any experience of vertigo or metallic taste will have heightened any existing sense of nausea. This implies that nervous subjects must be handled particularly carefully at ultrahigh field. To avoid rapid movements that might induce large currents in the head; we make use of the undockable bed on our scanner so as to load vulnerable subjects away from the field. Furthermore, it should be noted that when contrast agents are administered, subjects are often warned to report any strange tastes that they may experience as the contrast agent is injected. If for some reason they move after the contrast agent has been injected, and then report a strong metallic taste, the imaging may be curtailed needlessly.

In terms of staff exposure, the vertigo effect is reported to be disturbing for people working inside large magnetic fields for extended periods of time, and it is likely that this is made worse by the accompanying metallic taste. In our laboratory, engineers who have to work in the magnets for extended periods (for instance during checking of gradient coils) are told to work for brief periods and to stop to rest whenever they wish to. In practice, this means they generally work in the field for no longer than 20 minutes at a time. However, for staff simply positioning volunteers in the 7-T magnet, the perception of magnetically-induced vertigo can cause them to modify their working practices, but does not stop them from carrying out their work. However, the responses to the questionnaire used here showed that for normal types of staff exposure, the metallic taste did not make people modify their behavior, or to report the experience as an adverse incident.

In conclusion, this study has shown that time-varying fields of 2 T/second can be generated by relatively normal movements in the stray field of a whole body 7-T scanner. It has also been shown that the threshold for perception of metallic taste varies between individuals, although in this study no subject detected the effect at rates of field change of less than 1.3 T/second.

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