

Current ICNIRP Guidelines regarding electric fields induced by movement of the human body in a static magnetic field¹⁾

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¹⁾Health. Phys. 106:418-425; 2014

Content

Established health effects of static magnetic fields

Electric field induced by motion in static magnetic field

ICNIRP guidelines for static magnetic field (2009)

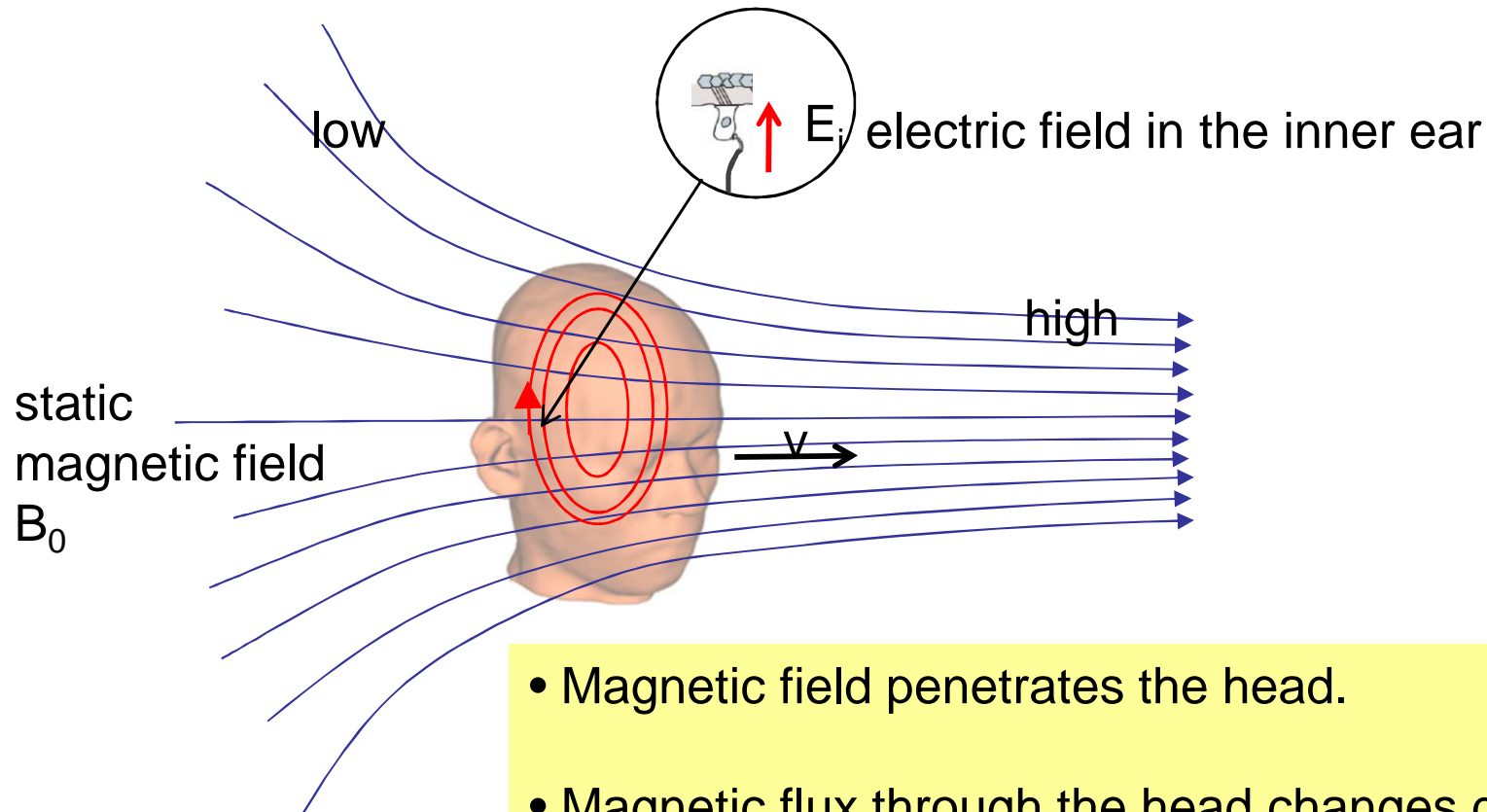
ICNIRP new guidelines for motion induction (2014)

Biophysical mechanisms of vertigo

Established health effects of static magnetic fields

- 1) Movement induced electric field effects ($> 2T$)
 - **vertigo, nausea, ocular movements (nystagmus)**
 - cognitive effects and disturbance in eye-hand coordination ?
 - **magnetophosphenes (visual sensations)**
 - **electrical stimulation of nerves**
 - metallic taste in mouth
- 2) Magnetic force on moving charges ($> 2T$)
 - induction of (blood) flow potentials
 - EKG changes
 - blood pressure changes
 - **vertigo, nausea, ocular movements (nystagmus)**
- 3) Acceleration of heavy or sharp metallic bodies ($> 30 \text{ mT}$)
- 4) Movement of metallic body implants ($>30 \text{ mT}$)
- 5) EM interference of cardiac pacemakers and fibrillators ($>0,5 \text{ mT}$)

Electric field induced in the head moving through a magnetic field gradient



Faraday's law

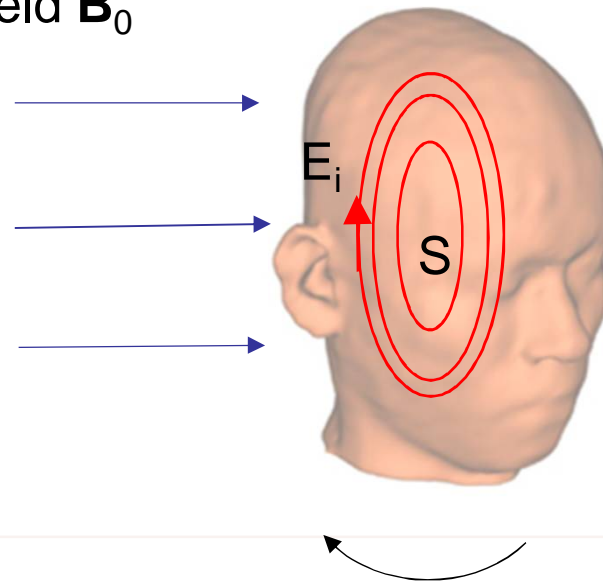
$$\oint \mathbf{E}_i \cdot d\mathbf{l} = -\int \frac{d(\mathbf{B}_0 \cdot d\mathbf{S})}{dt}$$

- Magnetic field penetrates the head.
- Magnetic flux through the head changes due to the movement.
- Circulating electric field is induced in the periphery of the head (Faraday's law).

Electric field induced in the head rotating in a homogeneous magnetic field

static magnetic field \mathbf{B}_0

rotation axis \mathbf{z}



Circulating electric field is induced in cross-section S because the flux through S changes.

direction of rotation

ICNIRP limits of exposure to static magnetic field (2009)

Exposure characteristics	Magnetic flux density
Occupational	
Exposure of head and trunk	2 T
Exposure of limbs	8 T
General public	
Exposure of any part of the body	400 mT

For specific work applications, exposures up to **8 T** can be justified if the environment is controlled and appropriate work practices are to control movement induced effects

These guidelines were amended by guidelines for the induced electric field

Movement induction limits I Basic Restriction for ΔB

Critical effect: Vertigo due to movement

In normal work (uncontrolled) maximum ΔB is **2 T** determined over any 3s period.

For specific work applications ΔB may exceed 2T provided that

- B does not exceed 8T
- movements are controlled in order to minimize vertigo sensations

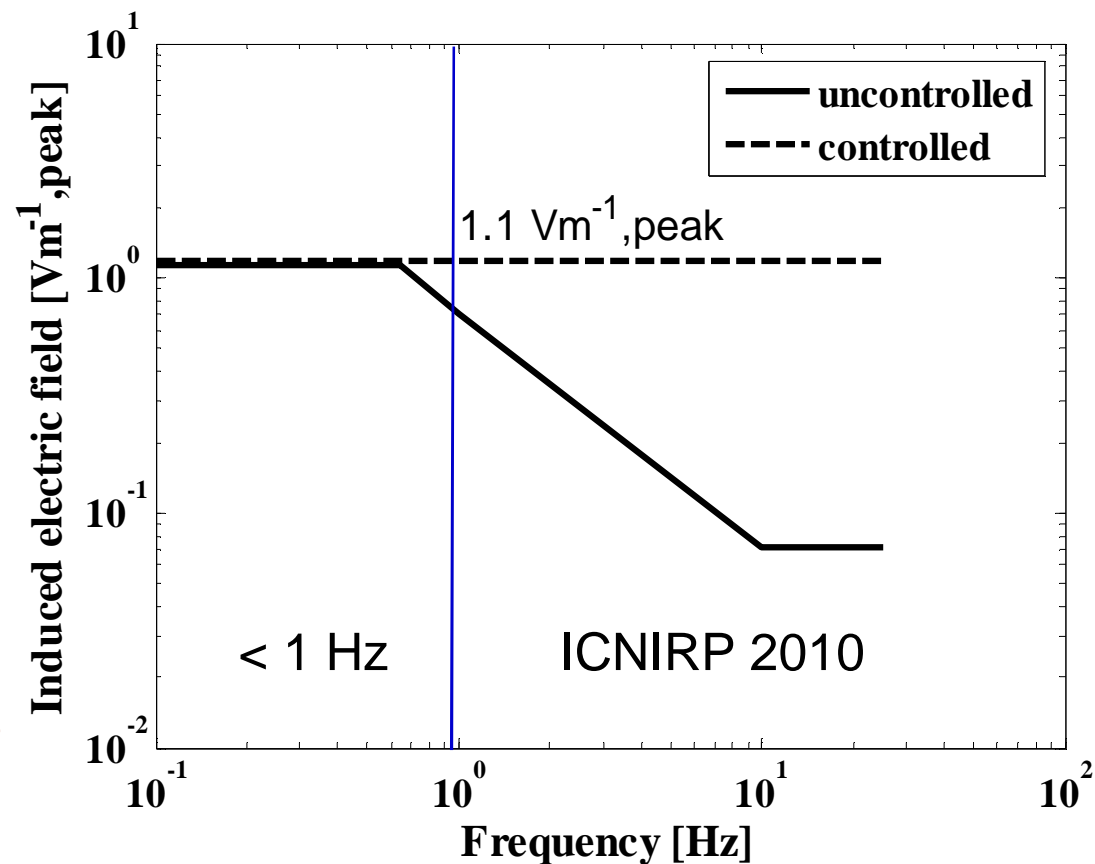


ΔB = change of the magnetic flux vector

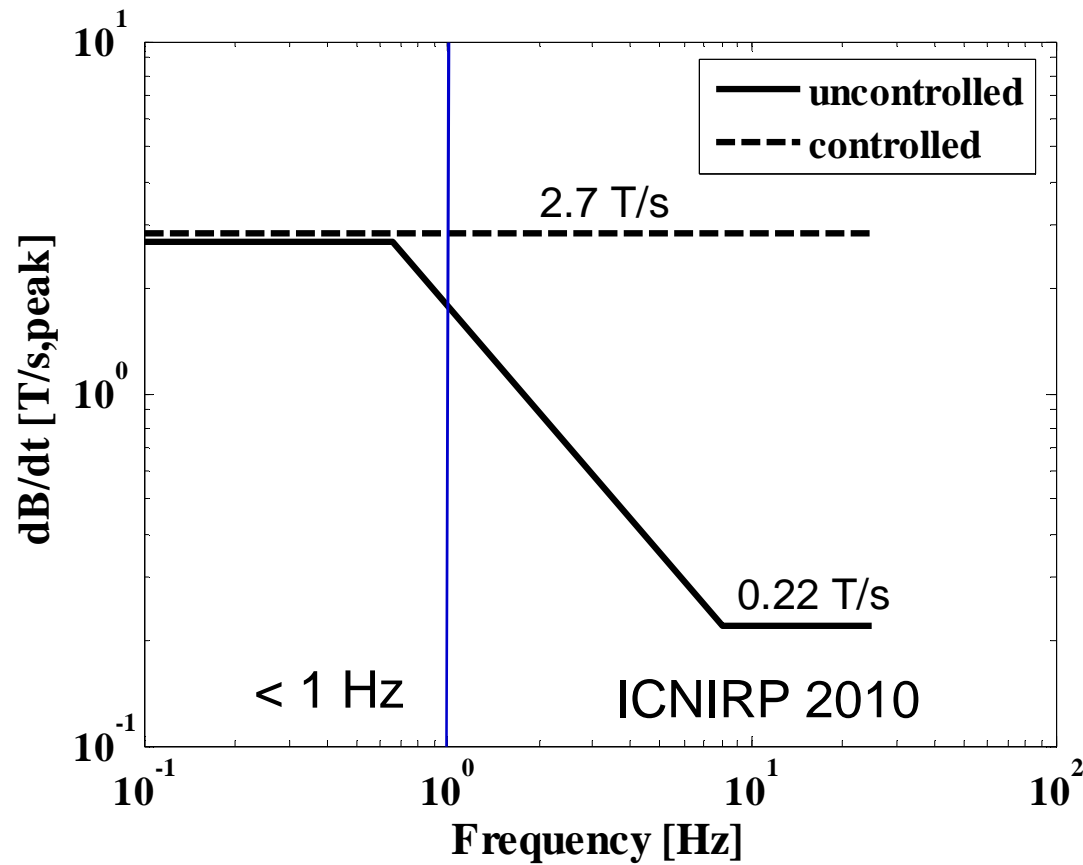
Movement induction limits II.

Basic restrictions for induced electric field below 1 Hz

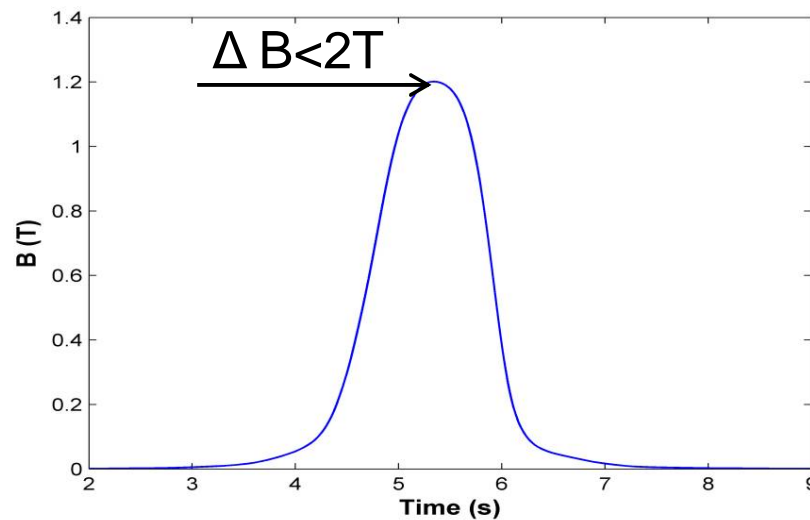
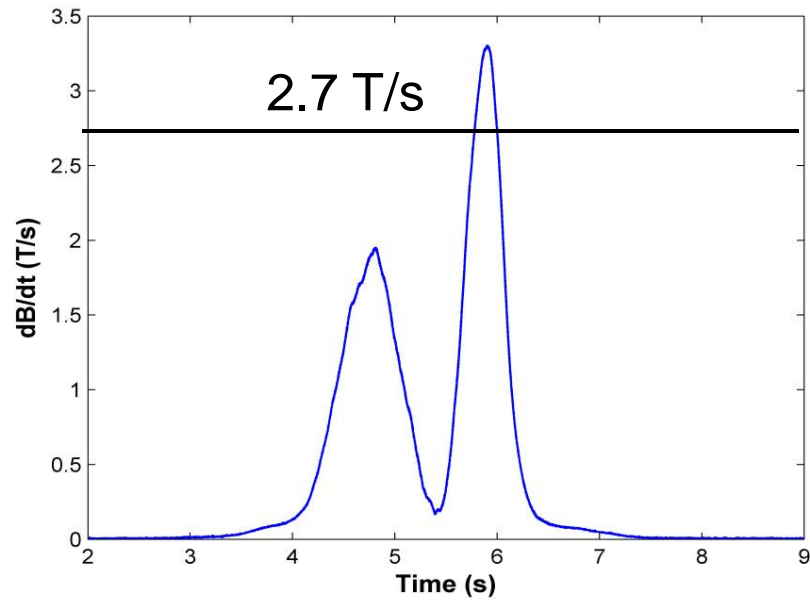
Critical effect: stimulation of nerve cells



Movement induction limits III. Reference levels for dB/dt below 1 Hz



Magnetic field measurement in the bore of a 1.5 T MRI scanner



Balance disturbance due to galvanic currents (electric field) is well known, but above 2 T disturbance occurs also above without movements

This indicates that both the static magnetic field and movement induced electric field need to be restricted

Glover PM, Li Y, Antunes A, Mian OS, Day BL. 2014. A dynamic model of the eye nystagmus response to high magnetic fields. *Phys.Med.Biol.*59: 631-645

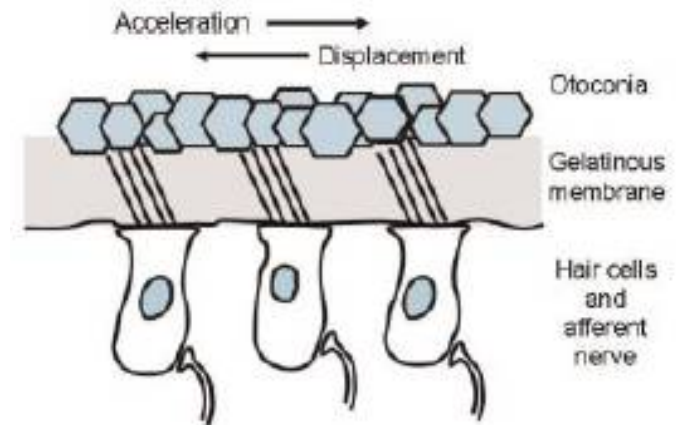
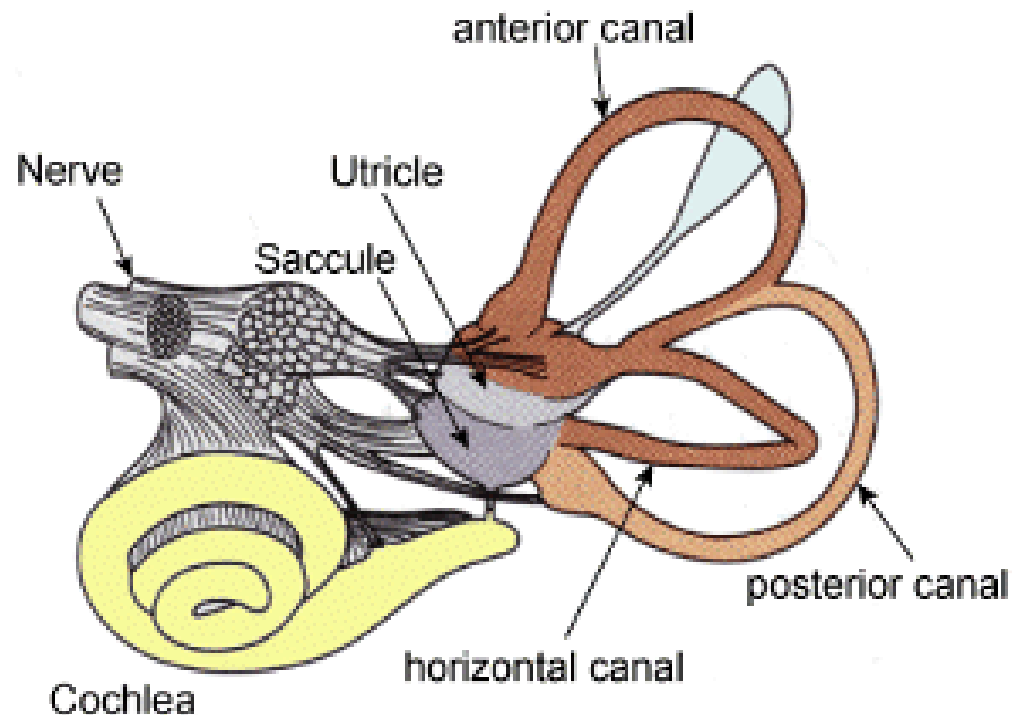
Mian OS, Li Y, Antunes A, Glover PM, Day BL. 2013. On the vertigo due to static magnetic fields. *PLoS ONE.* 8(10):e78748. doi:10.1371/journal.pone.0078748

Balance and motion sensors in the inner ear

Utriculus: head position and horizontal acceleration in 2 dimensions

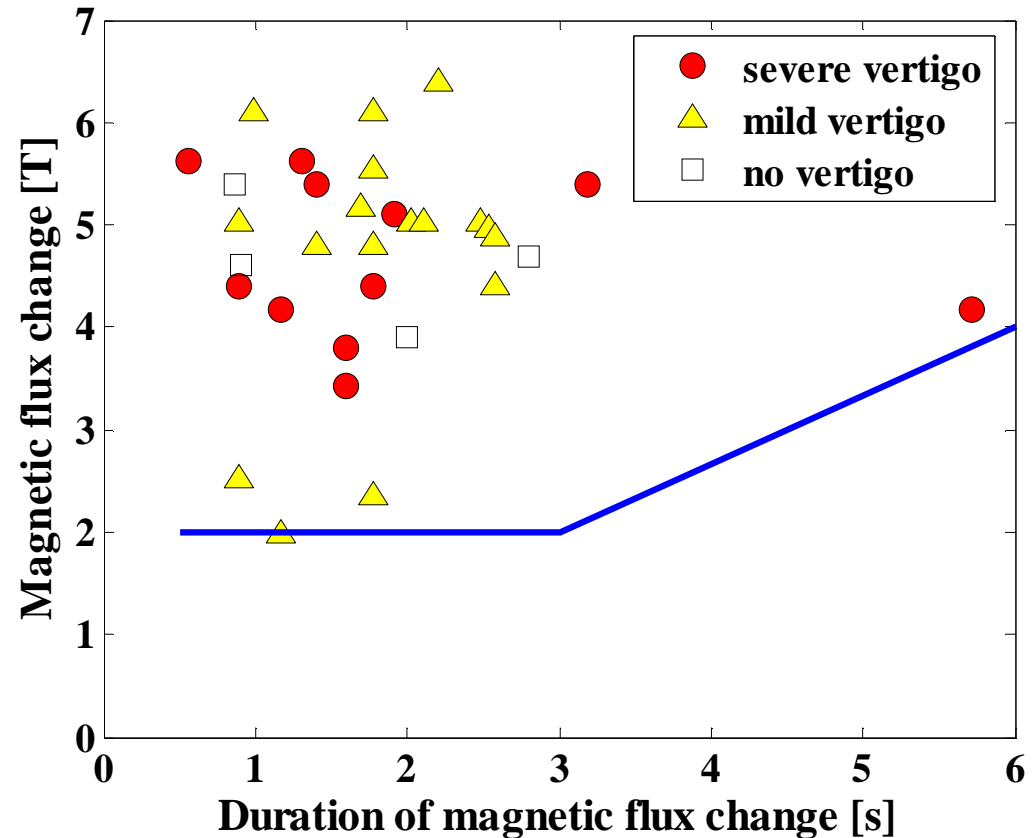
Sacculus: head position and vertical acceleration (1 dimension)

3 semicircular channels: rotational movement of head in 3 dimensions



Receptors for position and acceleration in utricle and sacculus

Vertigo threshold and limit for ΔB



Glover et al. 2007. Bioelectromagnetics 28:349-361

ICNIRP. Health. Phys. 106:418-425; 2014

Is vertigo caused by the electric field or direct magnetic field mechanism ?

Electrical stimulation of the receptors and nerves in the balance organ

- A lot of data on vertigo caused by galvanic currents from ear to ear

Magnetic force effect on ionic currents by the static magnetic field

- Occurs without movement at 7 T
- Recent human and animal data fits with the magnetic force mechanism

Good evidence that both mechanisms exist, but which of them is more significant ?

Conclusions on working in high static magnetic fields

- No annoying sensory disturbances below 2 T
- Adverse health effects above 8 T ?
- Avoid fast movements
- Keep $\Delta B < 2$ T during any 3 s period
- Keep $dB/dt < 2.7$ T/s

Thank you for your attention