

# **DEVELOPMENTAL EFFECTS OF ELECTROMAGNETIC FIELDS**



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# Radiofrequency fields

- RF fields are teratogenic!
- Effects shown in about 20 studies
- Thermal effect

# RF <1 GHz, mammals

F, MHz	SAR, W/kg	Exposure days	Exposure duration	Species	Effects?	Reference	Notes
10	6.6	13	65 min	rat	+	Nelson 91	42°C, combined effect
27.12		1-16	≤10 min	rat	+	Dietzel 75	39, 40.5 or 42°C
27.12	11	1-13	20-40 min	rat	+	Lary 82	43°C
27.12	11	9		rat	+	Lary 86	Threshold 41.5°C
27.12	11	9		rat	+	Brown-Woodman 88	Threshold ΔT 2.5°C
27.12	1.1* 10 <sup>-4</sup>	0-20	24 h/d	rat	+	Tofani 86	
100	0.4	6-11	7 h/d	rat	-	Lary 83	
915	4	1-21	6 h/d	rat	-	Jensh 82a,b	No detectable temperature increase

# Tofani et al. 1986: pregnant rats exposed continuously to a 27.12 MHz field at 0.1 mW/cm<sup>2</sup> (SAR 0.11 mW/kg ?)

Exposure days	No. of gravid females	% Pre-implantation losses (S.E)	% Post-implantation losses (S.E.)	Dams with viable fetuses	Dams with total resorptions
Control	20	16 (5)	7 (2)	20 (100%)	0
0-20	20	25 (5)	58 (10)	10 (50%)	10 (50%)
0-6	10	21 (6)	52 (16)	5 (50%)	5 (50%)
6-15	10	16 (5)	38 (14)	8 (80%)	2 (20%)

Dams with viable fetuses:

- **No effects** on pre- or post-implantation losses, no. of viable fetuses, fetal weight.
- Decreased body weight of dams exposed on days 0-20

# RF > 1 GHz, mice

F, MHz	SAR, W/kg	Exposure days	Exposure duration	Effects?	Reference	Notes
2450	≤110	8	2-5 min	+	Rugh 74	
2450	38	11-14	10 min	-	Chernovetz 75	
2450	2,8,22	1-17	100 min/d	+	Berman 78	Highest exposure: fetal weight↓
2450	7,28,40	1-6, 1-15	8 h/d	+	Nawrot 81,86	ΔT 1-2.3°C
2450	16	6-17	100 min/d	+	Berman 82a,84b	
2450	6-9	1-7,8-18, 1-18	2 h/d	+	Chazan 83	ΔT 1.5-2.0°C
2450	0.5,4-5, 16-18	1-18	2 h/d	+	Marcickiewites 86	Combined effect, high exposure level

# RF >1 GHz, rats

F, MHz	SAR, W/kg	Exposure days	Exposure duration	Effects?	Reference	Notes
2450	4	6-15	100 min/d	-	Berman 81	40°C
2450	6	6-15	100 min/d	+	Berman 84a	40°C
2450	4-5	1-21	6 h/d	-	Jensh 83a,b	
2450	31	10-17	20 min	+	Chernovetz 77	$\Delta T$ 3.5°C
2450	2	4-21	3h/d	-	Inouye 83	Postnatal exposure until 40 days
2450	0.4	2-18	24 h/d	-	Merrit 84	
2450	0.4	2-18	24 h/d	-	Schmidt 84	
6000	7	1-21	8 h/d	(+)	Jensh 84a,b	

# RF fields: rat embryos *in vitro*

## Klug et al., 1997:

- 150 MHz, modulation 16, 60 or 120 Hz, 60-600 V/m, 0.2-2  $\mu$ T
- 900 MHz, modulation 217 Hz, SAR 0.2, 1 or 5 W/kg
- **no significant effects** on growth and differentiation of embryos *in vitro*

# RF fields: behavioral teratology

## **Bornhausen and Scheingraber 2000:**

- rats, 900 MHz, pulse modulated at 217 Hz, 0.1 mW/cm<sup>2</sup> (17.5-75 mW/kg), continuously during pregnancy
- offspring tested at 3 months of age using nine operant-behaviour performance tests with increasing test requirements
- **no performance deficits** were observed in the exposed animals

# RF fields: behavioral teratology

## Cobb et al., 2000:

- rats, ultra-wideband pulses (55kV/m peak, 1.8 ns pulse width, 300 ps risetime, 1000 pulses/s, 0.1-1 GHz, SAR 0.45 mW/kg)
- exposure (a) 2 min/day during gestation days 3-18, or (b) both prenatal and postnatal (10 days) exposure
- **No changes found in 39 of 42 endpoints.** Authors concluded no unifying physiological or behavioral relationship among the differences observed (more stress vocalizations, longer medial-to-lateral length of the hippocampus, less frequent mating in exposed males but no difference in fertilization)

# RF field effects on bird embryos

- Japanese quail embryos exposed to 2.45 GHz fields at 3.2-25 W/kg:

**no effects** unless egg temperature is increased by a few degrees

(Hamrick and McRee 1975, McRee et al. 1975, Hamrick et al. 1977, Inouye et al. 1982, McRee et al. 1983, Byman et al. 1985, Gildersleeve et al. 1987, Spiers and Baummer 1991)

# Extremely Low Frequency (ELF) and Intermediate Frequency (IF) fields

# **ELF electric fields: no adverse effects on reproduction and development**

## **Several large studies on rats:**

- Seto et al. 1984 (60 Hz, 80 kV/m)
- Sikov et al. 1984 (60 Hz, 100 kV/m)
- Rommereim et al. 1987 (60 Hz, 100 kV/m)
- Rommereim et al. 1989 (112-150 kV/m)
- Rommereim et al. 1990 (10-130 kV/m)

- Malformations $\uparrow$  and fertility $\downarrow$  in one experiment in Rommereim's first study. Not confirmed in the second experiment or in further studies
- No consistent effect in other studies

## **Three-generation study on miniature swine (Sikov et al. 1987):**

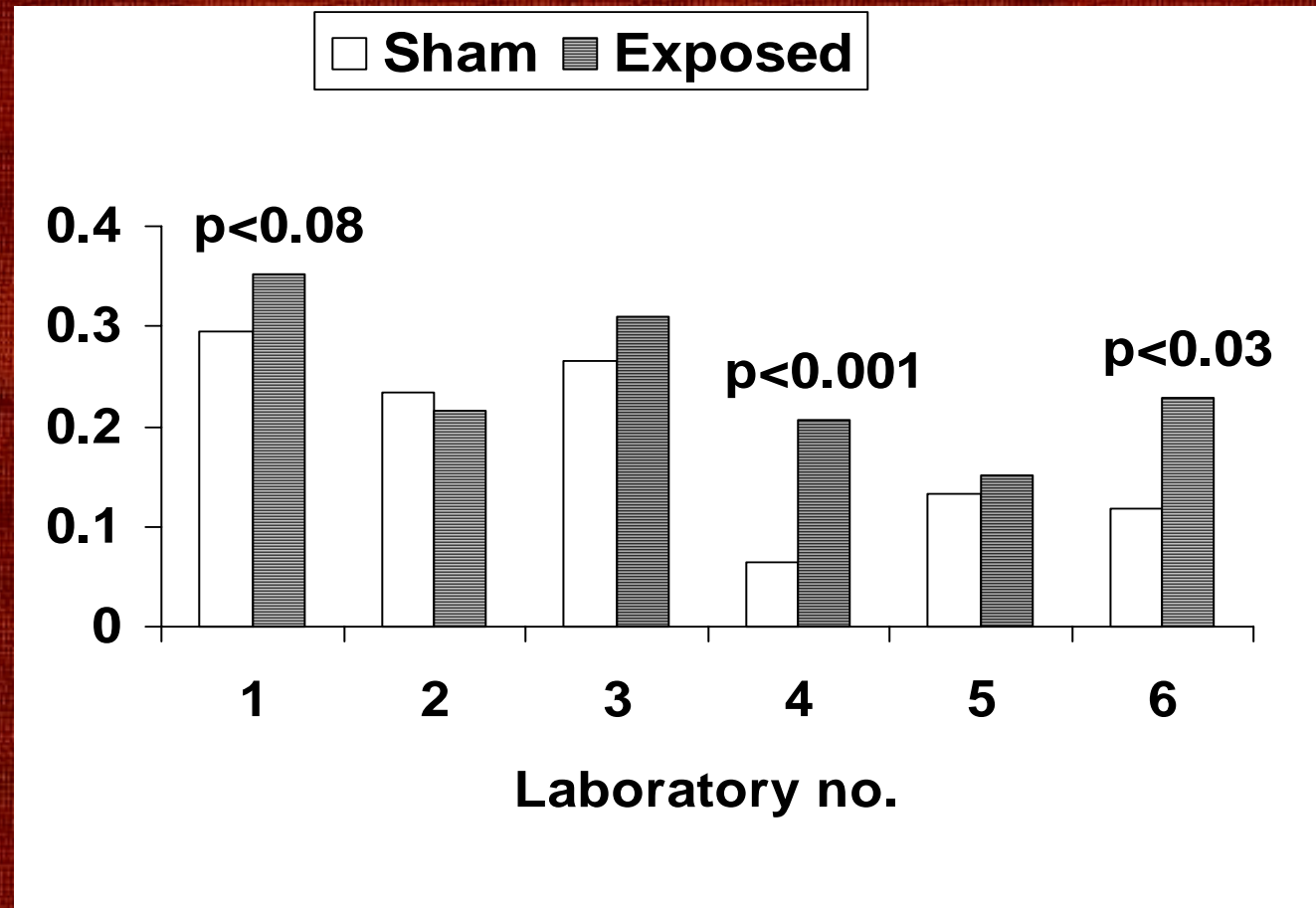
- Malformations $\uparrow$  in exposed animals, but not consistently in all generations

# ELF magnetid fields: chick embryos

The Henhouse Study (Berman et al. 1990)

- 100 Hz, 0.5 ms pulse duration, 2  $\mu$ s rise time
- Effect of MF:  $p < 0.001$ , effect of laboratory  $p < 0.001$

Proportion of  
abnormal embryos



## **ELF magnetid fields: chick embryos**

### **Koch and Koch, 1991 (Lab 2 of Henhouse study):**

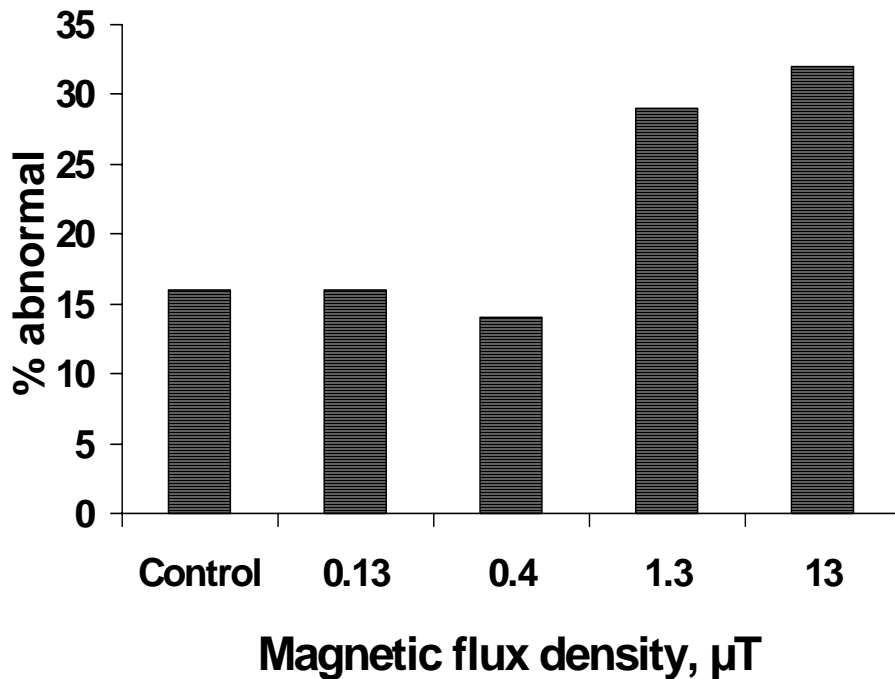
- Large study with hundreds of embryos,
- 1  $\mu\text{T}$  peak,
- various frequencies and waveforms  
(including 259 exposed and 260 controls using the Henhouse exposure parameters)

**NO EFFECTS**

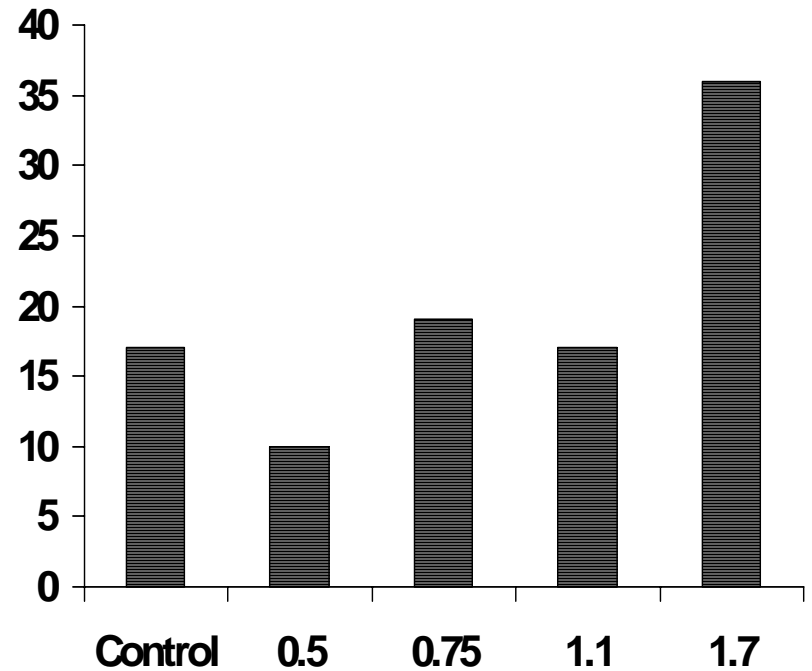
Juutilainen et al., 1987

## Abnormal development of chicken embryos exposed to 50 Hz magnetic fields with sinusoidal waveform

$p < 0.05$

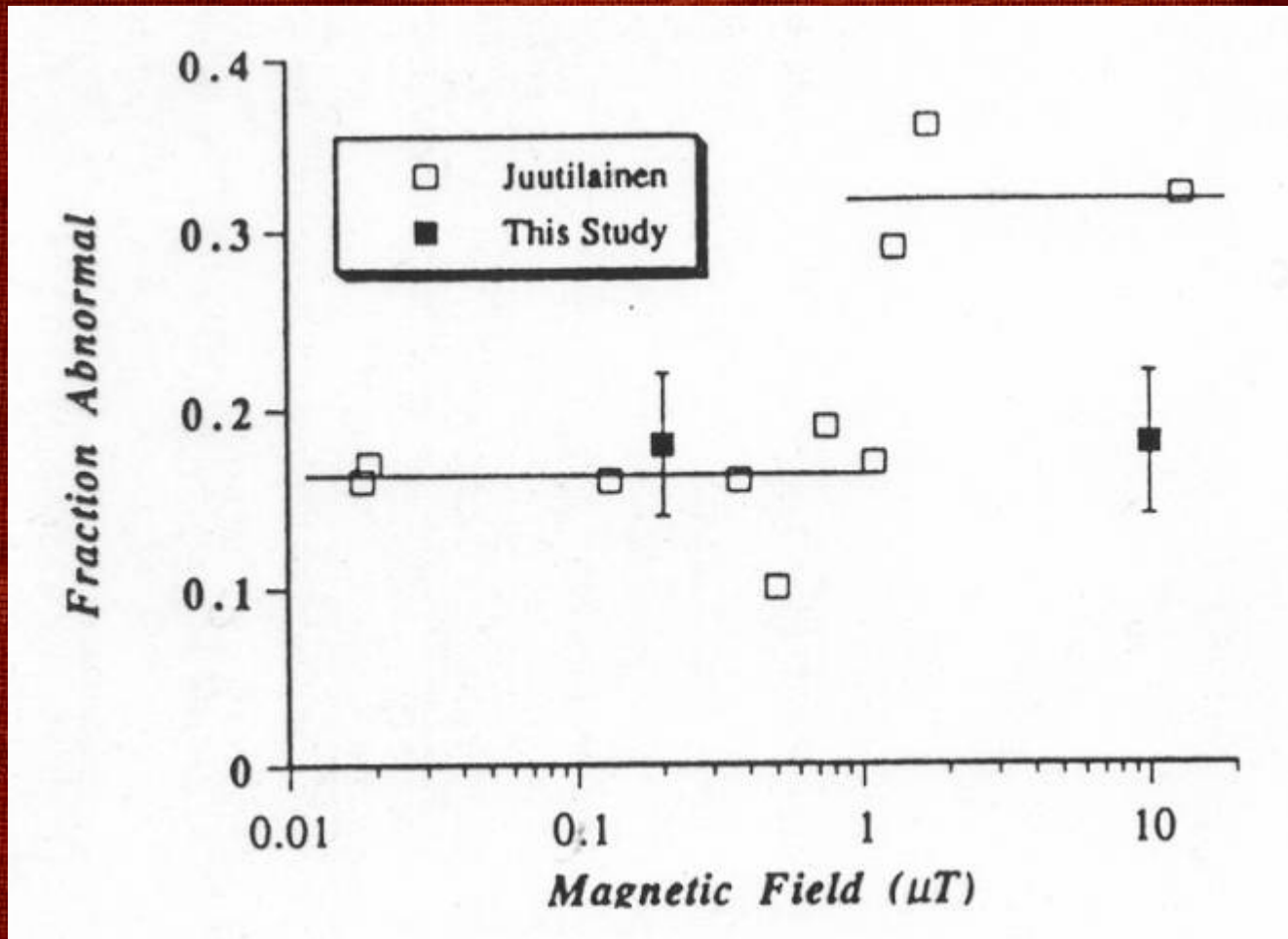


$p < 0.001$



# ELF magnetid fields: chick embryos

Comparison of the results of  
Juutilainen et al., 1987 and Cox et al., 1993



# ELF magnetid fields: chick embryos

Farrell et al., 1997

- over 2500 embryos
- 100 Hz, 1  $\mu$ T, 0.5 ms pulses
- or 60 Hz, 4  $\mu$ T, sinusoidal

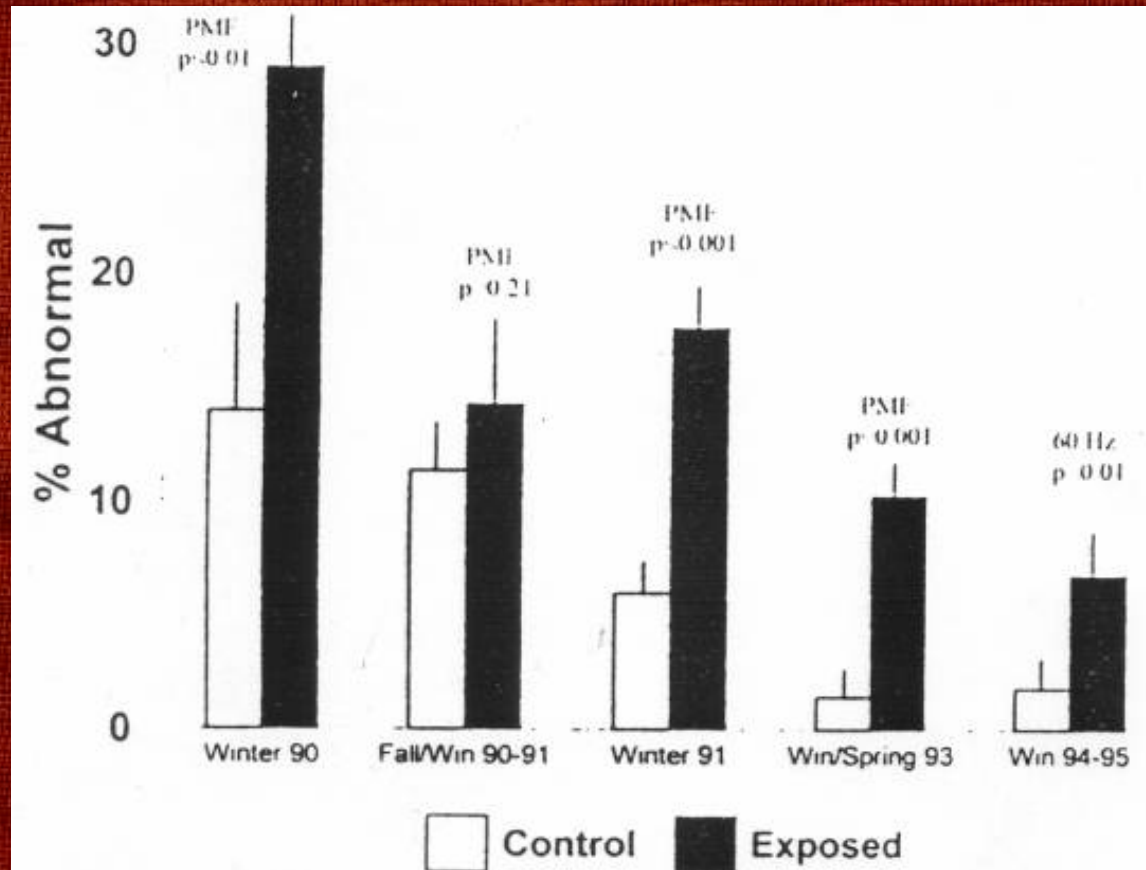


Fig. 1. Abnormality rates in each of the four PMF campaigns (N = 57) and the 60-Hz campaign (N = 8). There were a total of 2096 live embryos evaluated in the PMF experiment and 507 live embryos in the 60-Hz experiment.

## **ELF magnetid fields: chick embryos, *interaction with known teratogens***

### **Pafková and Jerábek, 1994**

- X-rays 4-5 Gy on day 3 or 4 of development
- 50 Hz, 10 mT
- MF exposure before X-rays **protected** the embryos
- MF exposure after X-rays **increased** embryotoxicity

### **DiCarlo et al., 1999**

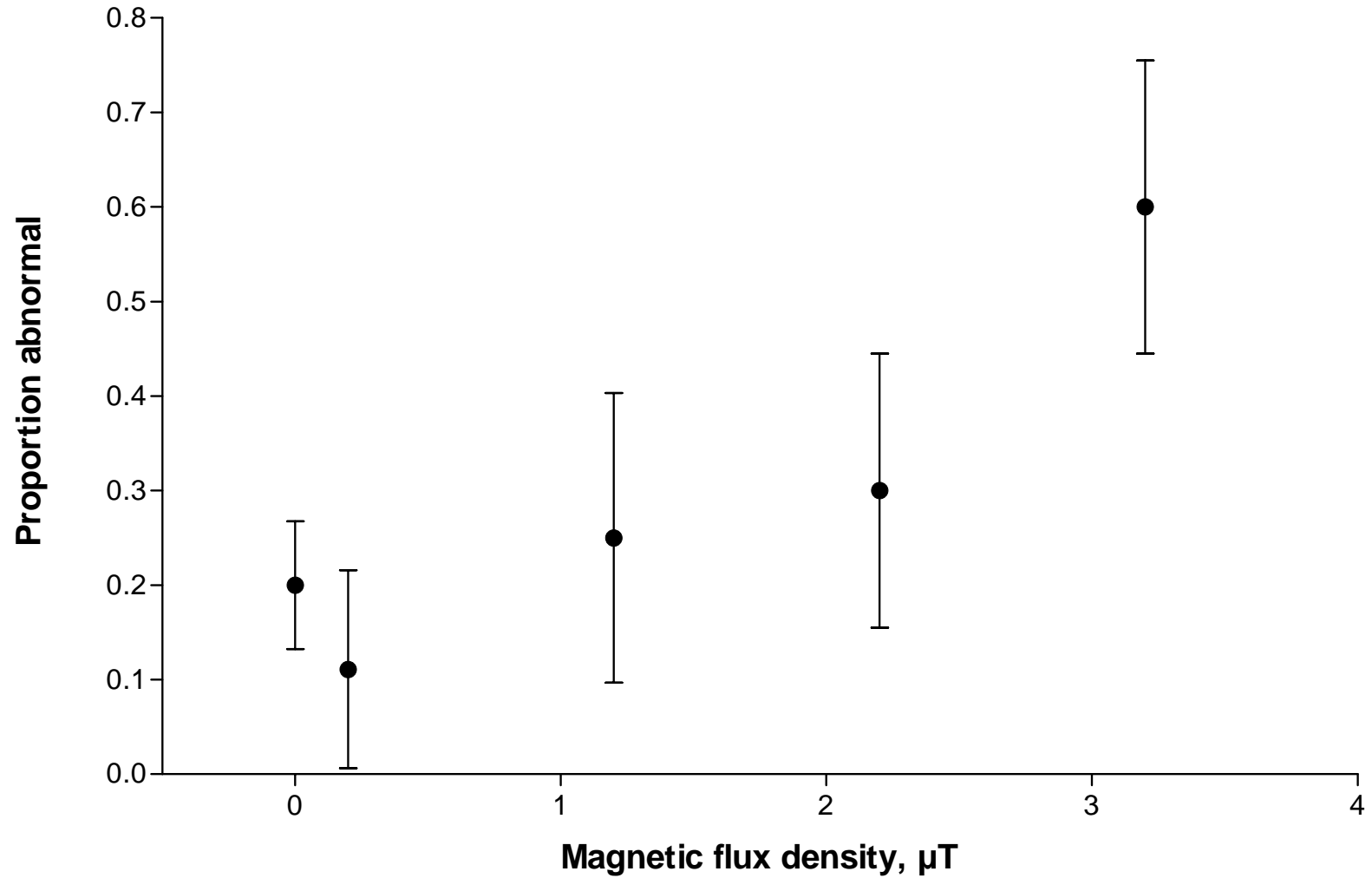
- 60 Hz, 8  $\mu$ T MF exposure before UV radiation
- Short MF exposure (20 min) **protects**
- long exposure (96 h) **increases** damage

## ELF magnetid fields: quail embryos

**Terol and Panchon, 1995**

- rectangular waveform, 50 Hz or 100 Hz
- 0.2, 1.2, 3.3 or 3.2  $\mu\text{T}$
- embryos examined at 48 h in a blind manner
- abnormalities were significantly increased

**Domestic quail embryos , 50 Hz square wave  
Terol & Pancheon, Int J Radiat Biol 68:321-330, 1995**



# ELF magnetid fields: chick and quail embryos

## Conclusion:

- Subtle effects on bird embryo development, modified by genetic differences or differences in experimental conditions (?)

# ELF magnetic fields: other non-mammalian species

Developmental effects have been reported in

- fish,
- sea urchins
- insects

**Graham et al., 2000:**  
**Growth and developmental stability of**  
***Drosophila melanogaster* in low frequency**  
**magnetic fields**

60 Hz, 1.5 or 80  $\mu\text{T}$ , continuously from egg to adult

*Developmental instability* was measured by

- fluctuating asymmetry
- frequency of phenodeviant

Results:

- reduced weight
- accelerated development (shorter larval period)
- reduced developmental stability at 80  $\mu\text{T}$

Graham et al., 2000:

Effect of 60 Hz magnetic fields on frequency of phenodeviants in *D. melanogaster*: **abdominal segmentation**

	Complete	Incomplete	Total n
Control	72%	28%	376
1.5 $\mu$ T	78%	22%	222
80 $\mu$ T	65%	36%	141

# ELF and IF magnetic fields, mammals

## **Mammals exposed to 18-20 kHz magnetic fields:**

- generally no increase in malformations or fetal loss
- **minor skeleton anomalies increased in several studies**
- resorptions (fetal loss) increased in one study in CBA/S mice

## Stuchly et al., 1988

Sprague-Dawley rats, 26 animals per group  
18 kHz magnetic field, sawtooth waveform

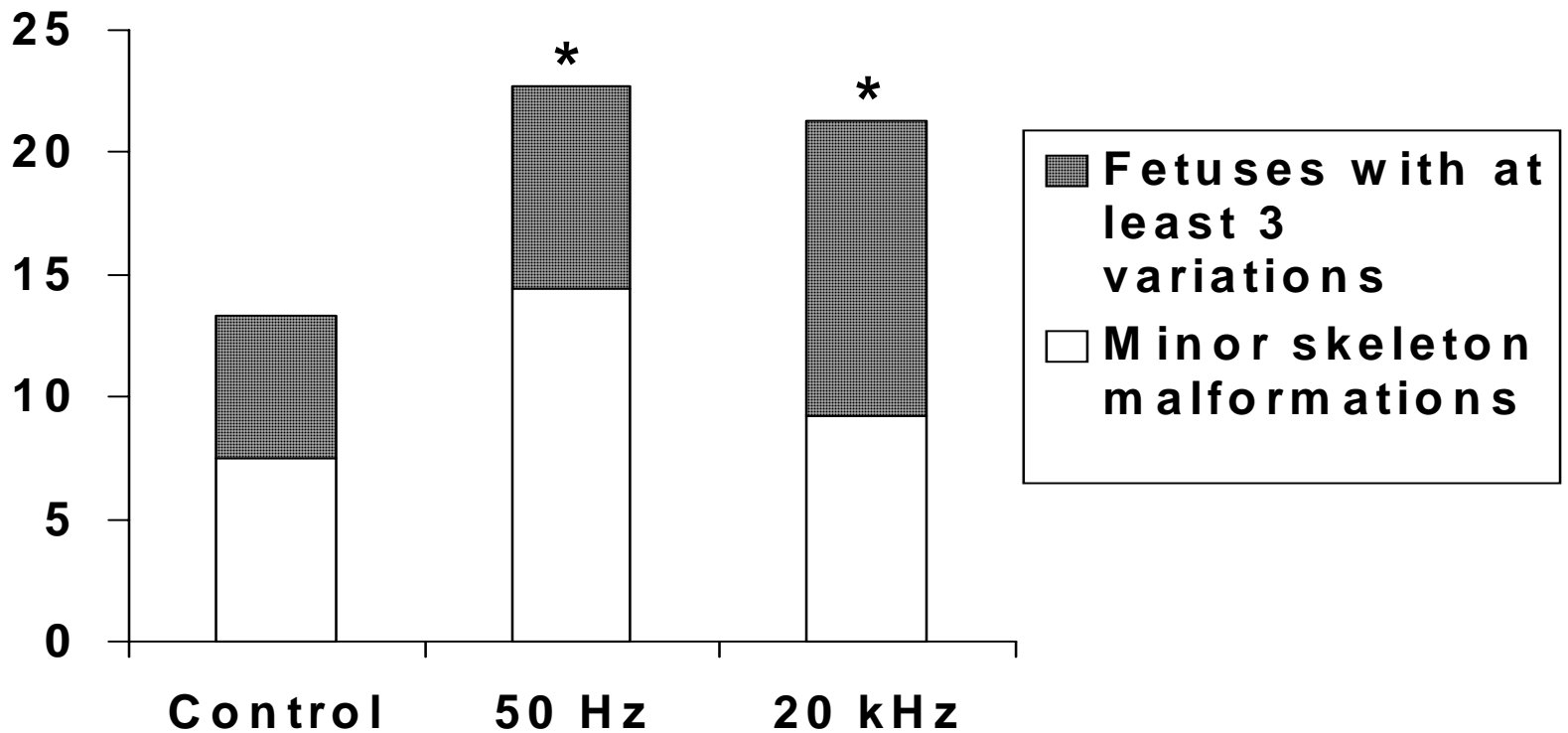
	Minor skeleton anomalies, litters	Minor skeleton anomalies, fetuses
Sham MF	9	18
5.7 $\mu\text{T}$	11	17
23 $\mu\text{T}$	12	25
66 $\mu\text{T}$	14	48***

# Huuskonen et al., 1993

Wistar rats,

20 kHz sawtooth, 15  $\mu\text{T}$  p-p or 50 Hz, 13  $\mu\text{T}$  r.m.s.

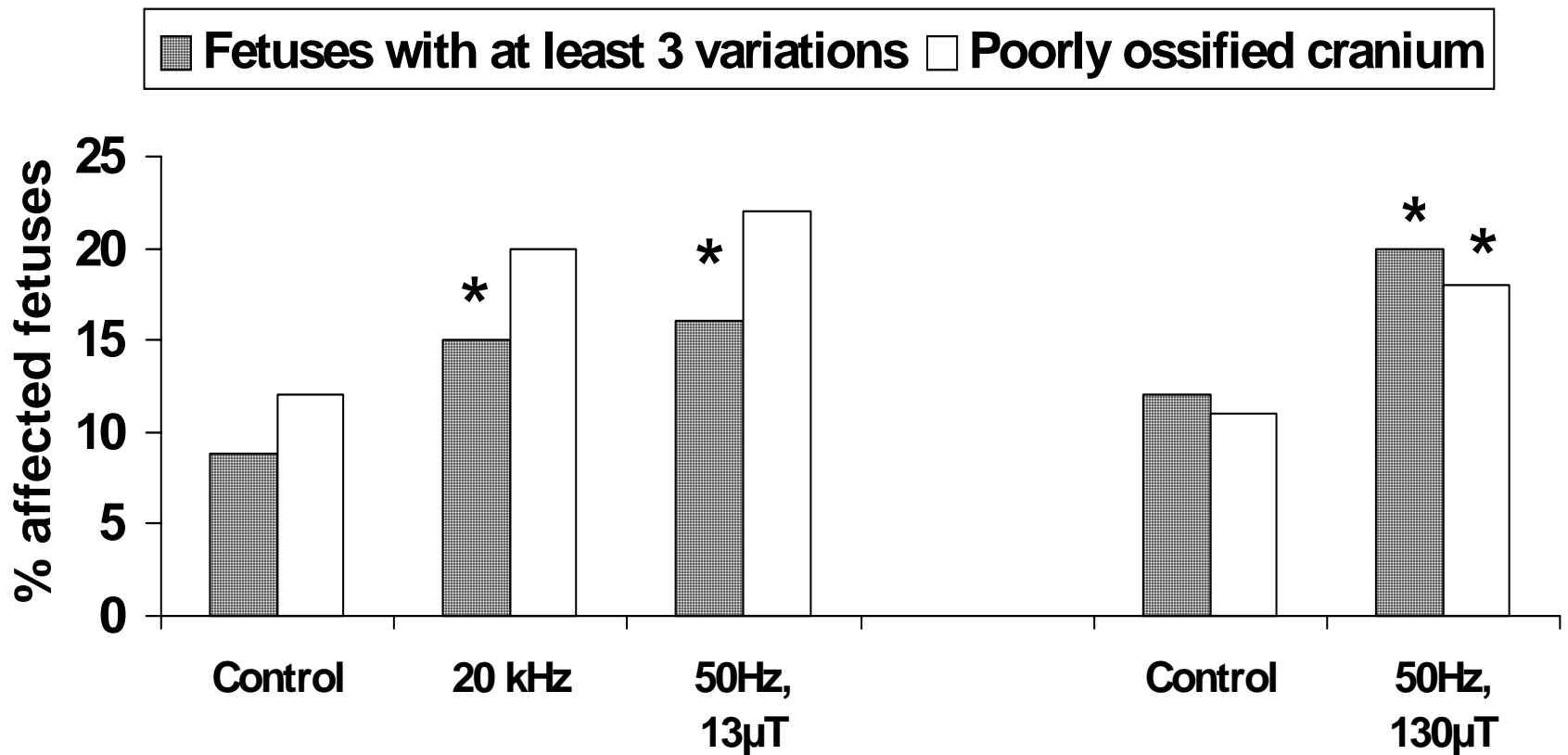
## Minor skeleton anomalies



## Huuskonen et al., 1998

- CBA/Ca mice: 20 kHz, 15  $\mu$ T p-p    50 Hz, 13 or 130  $\mu$ T

### Skeleton variations



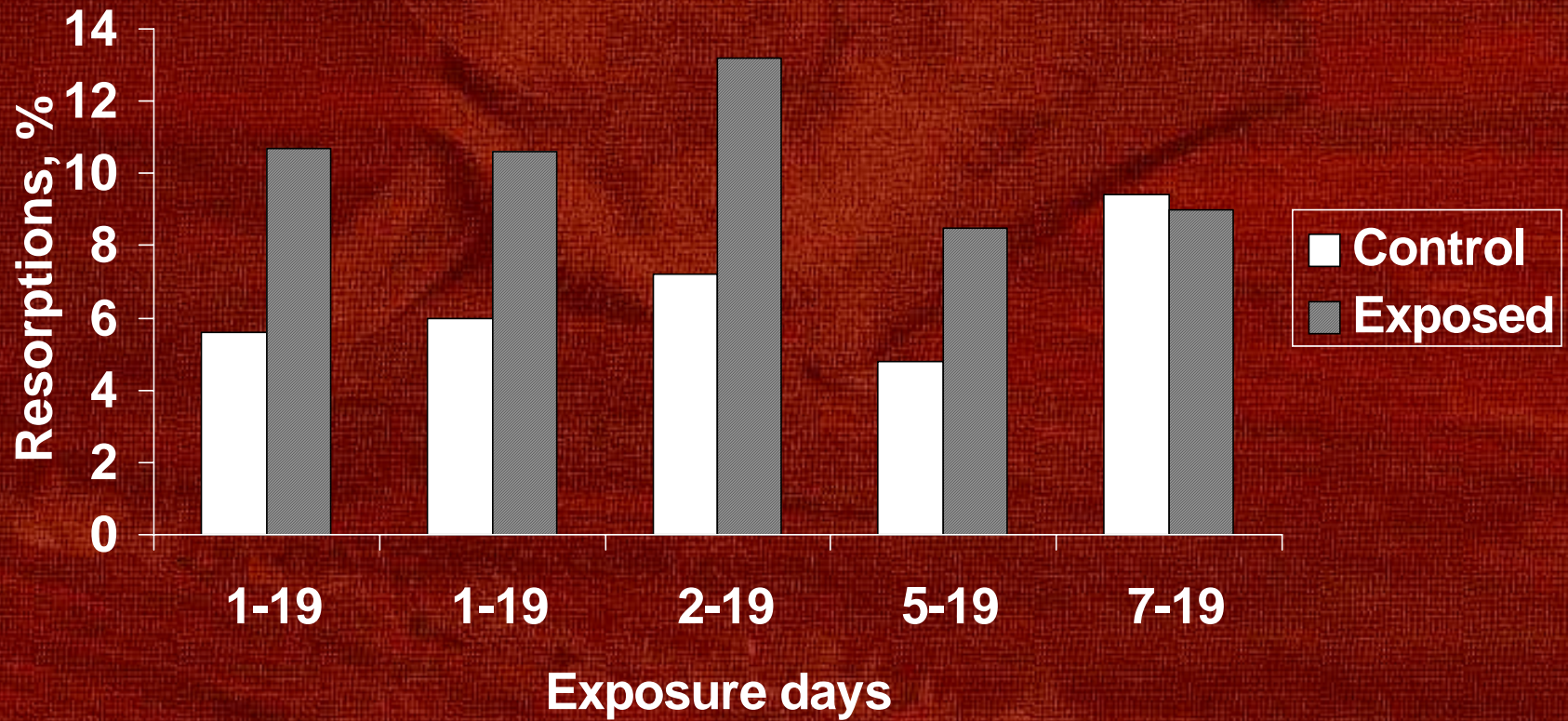
# ELF and IF magnetic fields, mammals

## **Mammals exposed to 18-20 kHz magnetic fields:**

- generally no increase in malformations or fetal loss
- minor skeleton anomalies increased in three studies
- **resorptions (fetal loss) increased in one study in CBA/S mice**

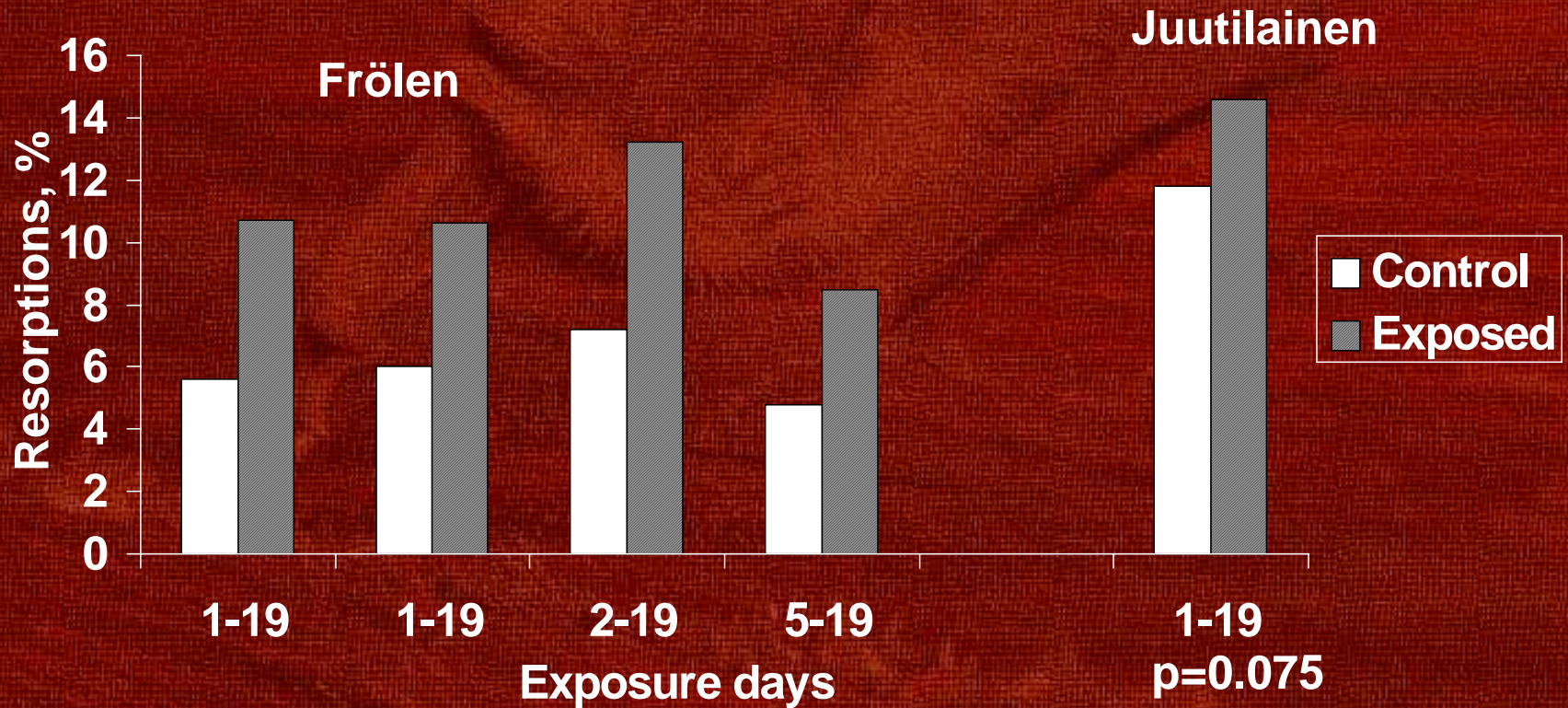
**Frölen et al., 1993**

CBA/S mice, 20 kHz sawtooth, 15  $\mu$ T p-p



# Comparison of the results of Frölen et al. (1993) and Juutilainen et al. (1996)

CBA/S mice, 20 kHz sawtooth, 15  $\mu$ T p-p



## **ELF magnetic fields: mammals**

### **Behavioural and other postnatal effects of in-utero exposure:**

- no consistent gross impairment of postnatal development

# Sienkiewicz et al., 1994: CD1 mice, 50 Hz, 20 mT

**TABLE 3. Results of the Activity and Coordination Behaviors**

Behavior	Age	Mean response		<i>P</i> <sup>a</sup>
		Sham	Exposed	
Open field activity <sup>b</sup>	Juvenile	161.3	172.2	>>0.1 <sup>g</sup>
	Adult	136.9	137.4	>>0.1 <sup>g</sup>
Head-dip activity <sup>c</sup>	Juvenile	21.7	21.9	>>0.1 <sup>g</sup>
	Adult	16.1	16.8	>>0.1 <sup>g</sup>
Rota-rod <sup>d</sup>	Juvenile	283.5	232.0	0.03 <sup>h</sup>
	Adult	253.4	227.8	0.10 <sup>h</sup>
Chimney test <sup>e</sup>	Adult	14.0	11.9	0.11 <sup>h</sup>
Activity wheel <sup>f</sup>	Adult	10,807	10,886	>>0.1 <sup>i</sup>

<sup>a</sup>After allowing for any sex-related effects.

<sup>b</sup>No. of crossings in 3 minute period.

<sup>c</sup>No. of head dips in 3 minute period.

<sup>d</sup>Running time (in seconds) to a maximum of 900 seconds.

<sup>e</sup>Escape time (in seconds) to a maximum of 30 seconds.

<sup>f</sup>No. of revolutions in a 24 hour period.

<sup>g</sup>Multivariate Poisson regression models.

<sup>h</sup>Proportional hazards models.

<sup>i</sup>Multivariate regression models.

**Sienkiewicz et al., 1996**  
CD1 mice, 50 Hz, 5 mT

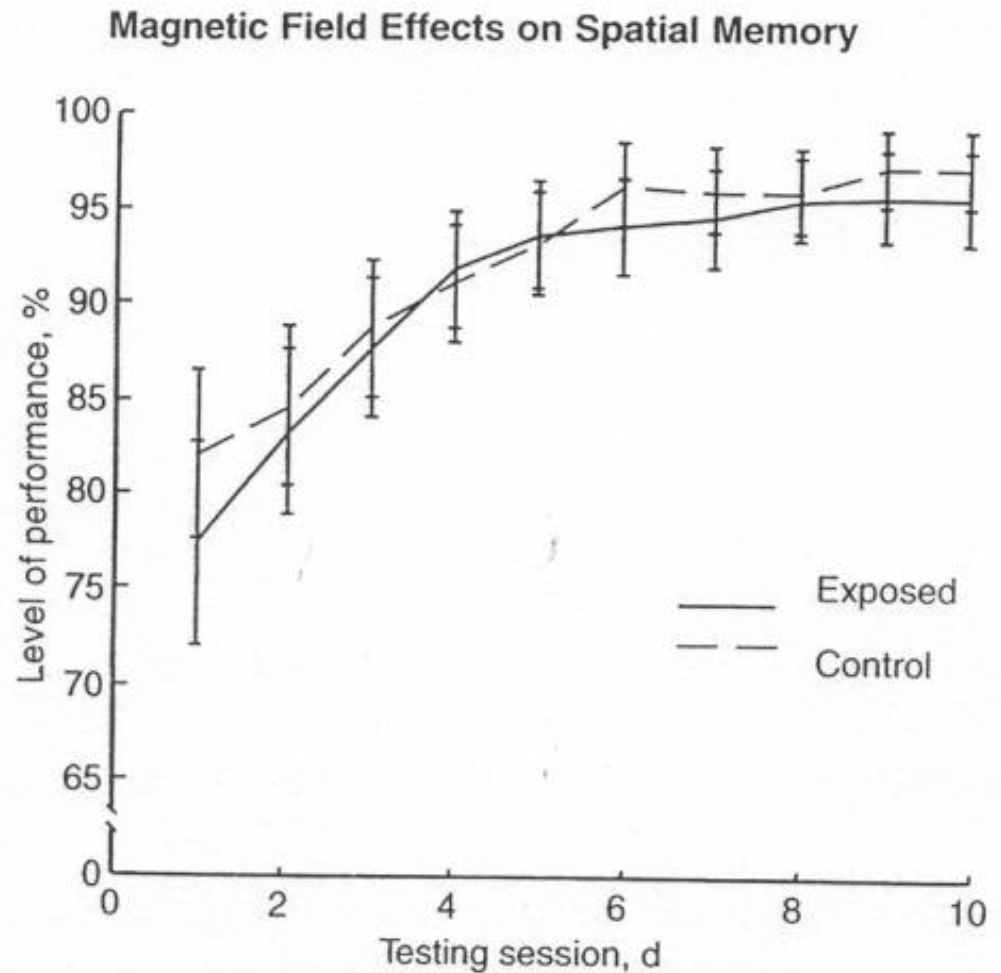


Fig. 1. Mean performance scores ( $\pm$  standard error) for adult mice ( $n = 10$  in both cases) in the radial-arm maze. Exposed animals were exposed to a 50 Hz magnetic field at 5 mT throughout gestation. Performance was measured as the probability of not reentering any given arm of the maze and is expressed as a percentage. There are no significant differences between the groups.

# Conclusions



# Conclusions

## *RF*

- temperature-related effects on fetal development
- no consistent effects at nonthermal exposure levels
  
- *ELF and IF*
- No strong adverse effects on mammalian development (no malformations)
- Weak **MF** effects on developmental stability?
  - bird embryo development?
  - minor skeleton anomalies in mammals?
  
- Additional studies might be useful to increase our understanding of ELF and IF magnetic field effects