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Corrigendum

Corrigendum to "Effects of radiofrequency electromagnetic field (RF-EMF) exposure on male fertility: A systematic review of experimental studies on non-human mammals and human sperm *in vitro*" [Environ. Int. 185 (2024) 108509]

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The authors of the article with the title "Effects of radiofrequency electromagnetic field (RF-EMF) exposure on male fertility: A systematic review of experimental studies on non-human mammals and human sperm *in vitro*" regret to report a few inconsistencies detected in the article after its publication, due to errors that inadvertently occurred in the extraction of the original data and in the misfiling of one study for its RoB assessment before the elaboration of the forest plots.

One error involved the way in which we extracted the data on the endpoint "Nonpregnant females over paired females" of Saunders et al. (1983) and Goud et al. (1982), and the data on the endpoint "Litter size" of Goud et al. (1982).

In particular, in the Saunders study on the rate of nonpregnant females, a group of 24 exposed male mice, matched with a group of 18 sham exposed mice, were mated at different times after exposure, for a total of 10 matings, to groups of unexposed females. In the Goud studies on the rate of nonpregnant females and on the litter size, a group of 25 exposed male mice, matched with a group of 25 sham exposed mice, were mated at different times after exposure, for a total of 3 matings, to groups of unexposed females.

We erroneously considered each mating as an independent experiment, thus not applying a weighting correction for using a single group of exposed animals for multiple matings. This resulted in an excessive weighting given to the results from the Saunders and Goud studies. The error has been corrected by aggregating all pregnancy events from all mating rounds as a single result, even though this approach may have blurred a possible differential germ cell stage sensitivity.

Another error consisted in misfiling the study of Ma et al. (2014) as "low or some concern" instead of as "high concern" (as correctly reported in all supplementary files relative to RoB) before the elaboration of the "Nonpregnant females over paired females" and "Litter size" forest plots. The errors have been corrected by attributing the correct RoB classification to the study.

The correction of these errors resulted in the following changes:

Rate of "nonpregnant females over paired females"

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[1] Retired.

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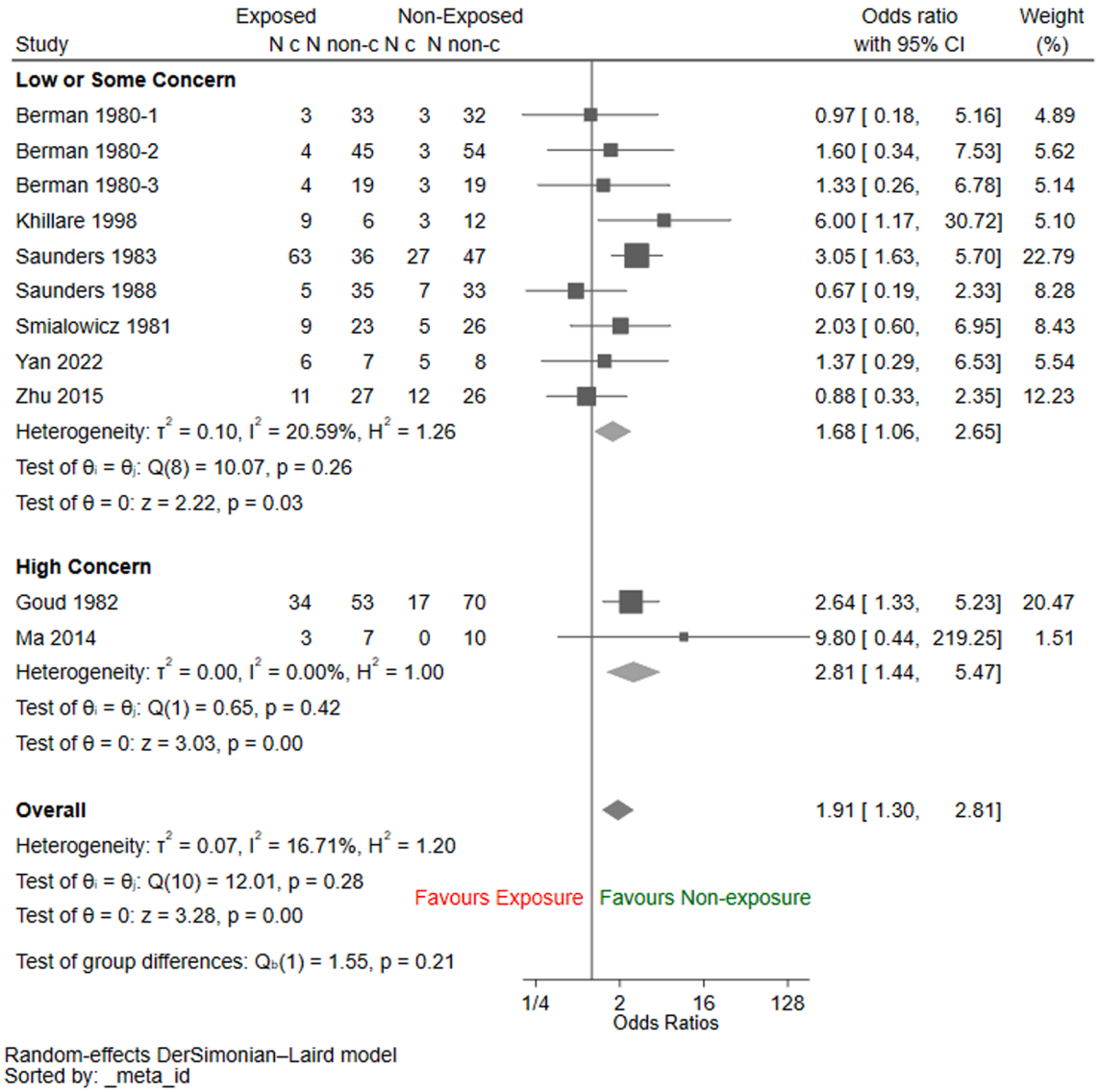


Revised Figure 5. Forest plot of experimental animal studies on the incidence of nonpregnant females, categorised as "low or some concern" or "high concern" for RoB. The bottom lines report the results and statistics of the meta-analysis for all included studies. Progressive numbers after a reference indicate different studies reported in the same paper.

The number of studies rated as "low or some concern" changed from 19 to 9 and the pooled OR decreased from 2.39 (95% CI 1.52 to 3.74) to 1.68 (95% CI 1.06 to 2.65).

The measure of heterogeneity I^2 decreased from 59.99% to 20.59%.

The grade of certainty attributed to the pooled effect size according to the GRADE criteria changed from "moderate" to "high" since it was no longer downgraded by one level for "inconsistency".

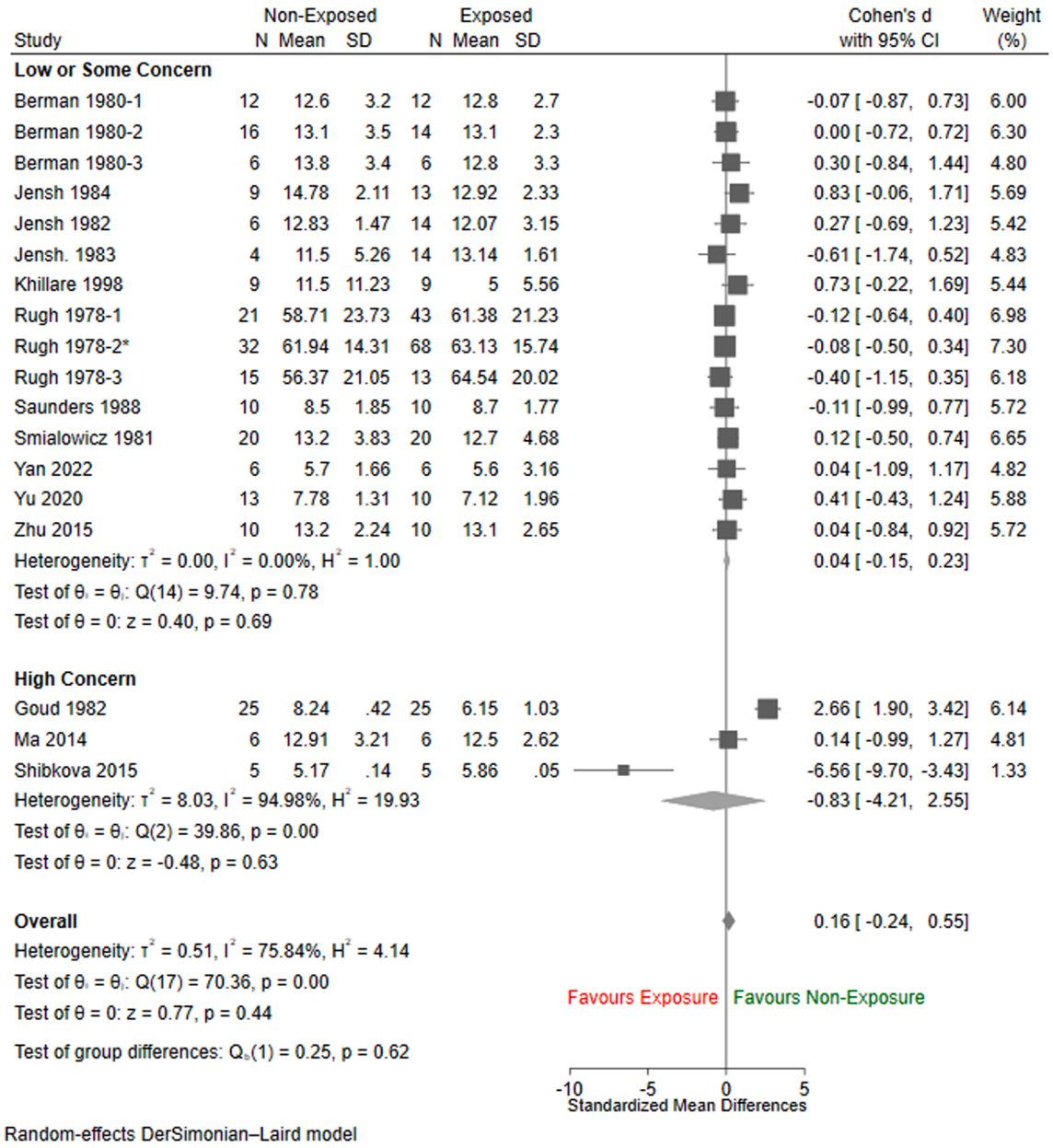
Litter size

The number of studies rated as "low or some concern" changed from 16 to 15 without any change in the pooled SMD value.

The corrections resulted in changes to part of the text and some of the tables, figures and supplementary files.

Text changes

- In the abstract, the text "The assessment of certainty according to the GRADE methodology assigned a moderate certainty to the reduction of pregnancy rate and…" is replaced by "The assessment of certainty according to the GRADE methodology assigned a high certainty to the reduction of pregnancy rate (an effect largely driven by a single study carried out at an extremely high SAR) and…"
- In the abstract, the text "Nevertheless, the associations between RF-EMF exposure and decrease of pregnancy rate and sperm count, to which moderate and low certainty were attributed,…" is replaced by "Nevertheless, the associations between RF-EMF exposure and decrease of pregnancy rate and sperm count, to which high and low certainty were attributed,…"



Revised Figure 6. Forest plot of studies on the size of litters sired by experimental males, categorised as "low or some concern" or "high concern" for RoB. The bottom lines report the results and statistics of the meta-analysis for all included studies. Asterisks mark studies in which data from multiple exposure groups were combined to match a single comparator group. Progressive numbers after a reference indicate different studies reported in the same paper.

- Within the paragraph *"3.5.2.1. Decrease of fertility",* the text of the section *"Number of nonpregnant females over paired females"* is changed as follows: "Nine studies, rated at "low or some concern" RoB level, evaluated male fertility by the number of nonpregnant females over the number of paired females. The pooled OR value of these studies was 1.68 (95 % CI 1.06 to 2.65), suggesting an RF-EMF exposure-associated decrease of male fertility (revised Fig. 5). The average SAR tested in these studies was 6.98 W/kg (SD 13.78, 0.31–43.4 min–max). Two further studies rated at "high concern" RoB level yielded an OR value of 2.81 (95 % CI 1.44 to 5.47). In the section *"Number of nonpregnant females over paired females: Subgroup analysis"*, the text "although only the latter yielded a statistically significant pooled OR value." is deleted.
- Within the same paragraph *3.5.2.1.*, the text of the section "*Litter size*" is changed as follows: "The pooled SMD of 0.04 (95 % CI −0.15 to 0.23) for the 15 studies at "low or some concern" RoB level showed that there was not a statistically significant decrease of litter size after RF-EMF exposure. The average SAR tested in these studies was 25.83 W/kg (SD 48.08, 0.31–141.4 min–max). Three further studies rated at "high concern" RoB level yielded a SMD value of −0.83 (95 % CI −4.21 to 2.55) (revised Fig. 6)."
- Within the paragraph *"3.8. Certainty assessment",* the text of the section *"Effects on fertility"* is changed as follows: "The OR for infertile males, spanning from 0.32 to 5.94, is consistent with null. We downrated the certainty to very low, for RoB by one level, all studies being at "some concern", and for imprecision by 2 levels, due to the width of the 95 % CI of the pooled effect size crossing the null hypothesis, and the limited number of studies. The SMD for litter size is similarly consistent with no effect, spanning from − 0.15 to 0.23. We downrated the certainty to moderate, for RoB by one level, all but one study being at "some concern". In spite of a significant Egger's test, we did not downgrade for publication bias because the pooled effect size was consistent with null. The result was not upgraded for consistency across species because the between-group difference was borderline significant. The OR for nonpregnant females, spanning from 1.06 to 2.65, is consistent with a detrimental effect of exposure. We downrated the certainty for RoB by one level, all but one study being at "some concern". We upgraded the certainty to high for consistency among species. We point out that the exclusion of the Saunders 1983 study that tested a SAR of 43.4 W/kg, i.e. an exposure level about 100 times higher than the current exposure limits for general population, would decrease the pooled OR from 1.68 to 1.32 with confidence interval crossing the null hypothesis. Therefore, a detrimental effect on the pregnancy rate at exposure levels relevant for human populations remains questionable.
- In the discussion, paragraph *4.1. Summary of the evidence and interpretation of the results,* the text "From experimental animal studies there is moderate certainty of evidence that RF-EMF exposure reduces rate of pregnancy…" is replaced by "From experimental animal studies there is high certainty of evidence that RF-EMF exposure reduces rate of pregnancy…". In addition, the sentence "The result on the decrease of pregnancy rate is consistent with this hypothesis, as shown by the observation that the pooled effect size is statistically significant only in the subgroup of studies exposed to SAR equal to or higher than 5 W/kg and the statistically significant slope of the linear dose-response relationship." is replaced by "The statistically significant slope of the linear dose-response relationship for the decrease of pregnancy rate would support this hypothesis."
- In the paragraph *"4.4. Implications for policy and research"*, the sentence "In conclusion, our systematic review and meta-analyses indicate a possible detrimental effect of RF-EMF exposure on pregnancy rate…" is replaced by "In conclusion, our systematic review and meta-analyses indicate a detrimental effect of RF-EMF exposure on pregnancy rate…". In addition, in the sentence "75–80 % tested exposure levels above 0.4 W/kg (ICNIRP basic restriction for workers) and 46–53 % tested exposure levels above 4 W/kg (ICNIRP health effect level) (ICNIRP, 2020).", "46–53 %" is replaced by "32–53 %".

Changes to tables, figures and supplementary files

The corrected tables (revised Tables 3 and 5) are shown below, where changes are highlighted in bold. The corrected figures (revised Figs. 5 and 6) are similarly reported in this corrigendum, whereas the corrected supplementary files (revised Supplementary Files 4a, 5, 6 and 8) are included as supplementary materials. Wherever in the paper the Tables 3 and 5, Figs. 5 and 6 or Supplementary Files 4a, 5, 6, and 8 are mentioned, it is intended that they are replaced by the revised versions included in this corrigendum.

The authors would like to apologise for any inconvenience caused.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.envint.2025.109449.

Revised Table 3

Distribution of papers and studies by investigated endpoint. Figures in italics correspond to papers on EMP.

Endpoint	Metrics	Studies entered into a meta-analysis		Papers presented by a narrative synthesis
		No. papers (No. studies)[1]	Effect size measure	No. papers
Decrease of fertility				
Rate of infertile males	Number of males with unsuccessful copulation	4 (7)	OR	
Nonpregnant females over paired females	Number of nonpregnant females over paired females	9 **(11)** *1 (5)*	OR	*1*
Litter size	Number of offspring per mated female	13 **(15)** *2 (6)*	SMD	
	Total number of offspring per female after multiple pregnancies	1 (6)		
In vitro fertilization rate	*% in vitro* blastocysts			1
	% *in vitro* fertilized oocytes			1
Effects on semen quality-experimental animal studies				
Sperm count	Sperm count[2]	41 (121) *3 (14)*	SMD	3

(*continued on next page*)

Revised Table 3 (*continued*)

Endpoint	Metrics	Studies entered into a meta-analysis		Papers presented by a narrative synthesis
		No. papers (No. studies)[1]	Effect size measure	No. papers
Sperm morphology	% abnormal sperm	27 (92) *3 (13)*	MD	3
Sperm vitality	% immotile or dead sperm	23 (44) *2 (10)*	MD	1
Sperm DNA/chromatin alterations	% DNA fragmented sperm	1 (3)	SMD	
	Mean level DNA damage	2 (2)		
	% apoptotic sperm	2 (2)		
Effects on semen quality-experimental studies on human sperm in vitro				
Sperm morphology	% abnormal sperm	2 (3)	MD	
Sperm vitality	% immotile or dead sperm	7 (29)	MD	1
Sperm DNA/chromatin alterations	% oxidative stress positive cells	1(2)	SMD	
	% DNA fragmented sperm	5 (16)		
Reproductive organ toxicity				
Testis-epididymis weight	Testis weight (g)	39 (73) *2 (10)*	SMD	7
	mg testis/g body weight	1 (1)		
	% testis/body weight	4 (9)		
	epididymis weight (g)	2 (5)		
	mg epididymis/g body weight	1 (2)		
Testis histomorphometry	Seminiferous tubule diameter (μm)	26 (39) *2 (10)*	SMD	
	Seminiferous tubule area × 10000 μm^2	1 (2)		
	germinal epithelium height (μm)	1 (3)		
Testis or epididymis histology	Johnsen's histopathology score (#)	14 (27)	MD	3
	histopathology score (#)			
Testicular cell death	% death[3]	9 (30)	SMD	3
	Apoptosis gene expression (arbitrary units)	4 (6)		*1*
	Number of dead cells	4 (10) *1 (5)*		
Testicular sperm production	Number of testis sperm per tubule	3 (14)	SMD	
	Number of testis sperm per gram testis ($\times 10^6$)	1 (6)		
	Number of testis sperm per ml ($\times 10^7$)	1 (2)		
	% flow cytometric haploid cells	1 (1)		
	daily sperm production per g of testis ($\times 10^6$)	8 (33)		
Hormonal effects				
Testosterone level	Testis testosterone (ng/mg protein)	2 (3)	SMD	1
	Testis testosterone (ng/ml)	4 (11)		*2*
	Serum testosterone (ng/ml)	25 (39) *2 (23)*		

[1]The number of studies here corresponds to the number of different exposure groups reported in the papers. This number may be higher than the number of studies analysed in the results synthesis because when multiple exposure groups shared the same comparator, their data were averaged and considered as one study only.
[2]Numbers in different studies correspond to a variety of often unclear metrics, including epididymal sperm count/ml ($\times 10^6$), No. sperm in 48 small Neubauer chamber squares, relative concentration of epididymal sperm, sperm count ($\times 0.02$ mm^3). For this reason, it was only possible to estimate the RF-EMF impact in terms of SMD, but not to infer the RF-EMF impact on the absolute sperm number.
[3]Including % dead cells, % apoptotic index, % TUNEL positive tubules, % area of caspase-3 immunopositive cells.
Abbreviations: MD: Mean Difference; OR: Odds Ratio; SMD: Standardized Mean Difference.

Revised Table 5
GRADE Evidence Profile.

Certainty assessment								Summary of findings				Certainty	Importance**
								No. of participants		Effect			
No. of studies	Design	RoB	Inconsistency	Indirectness	Imprecision	Publication bias*	Consistency across species	Exposure	Comparator	Relative(95% CI)	Absolute (95% CI)		
Decrease of fertility													
Rate of infertile males													
4	(a)	−1	0	0	−2	NA	NA	89	55	OR 1.38 (0.32 to 5.94)		Very low	4
Nonpregnant females over paired females													
9	(a)	−1	**0**	0	0	0	+1	**345**	**325**	**OR 1.68 (1.06 to 2.65)**		**High**	7
Litter size (an SMD positive value indicates a detrimental RF-EMF effect)													
15	(a)	−1	0	0	0	0	0	**262**	**189**	SMD 0.04 (−0.15 to 0.23)		Moderate	8
In vitro fertilization rate: No meta-analysis was done because the database included only one paper													
Effects on semen quality-experimental animal studies													
Sperm count (an SMD positive value indicates a detrimental RF-EMF effect)													
80	(a)	-1	−1	0	0	−1	+1	752	569	SMD 0.74 (0.51 to 0.98)		Low	8
Sperm morphology (an MD negative value indicates a detrimental RF-EMF effect)													
65	(a)	−1	−1	0	0	−1	0	567	436		MD −0.94 (−1.28 to −0.59)	Very Low	7
Sperm vitality (an MD negative value indicates a detrimental RF-EMF effect)													
32	(a)	−1	−2	0	0	−1	+1	334	265		MD −10.83 (−15.2 to -6.47)	Very Low	8
Sperm DNA/chromatin alterations (an SMD negative value indicates a detrimental RF-EMF effect)													
6	(a)	−1	−1	−1	0	0	0	56	55	SMD −1.92 (−2.78 to −1.05)		Very Low	4
Effects on semen quality-studies on human sperm in vitro													
Sperm morphology (an MD negative value indicates a detrimental RF-EMF effect): No meta-analysis was done because the database included only one study that was not at "high concern" for RoB													
Sperm vitality (an MD negative value indicates a detrimental RF-EMF effect)													
23	(b)	−1	−1	−1	0	−1	NA	455	455		MD −1.37 (−2.46 to -0.28)	Very Low	8
Sperm DNA/chromatin alterations (an SMD negative value indicates a detrimental RF-EMF effect)													
13	(b)	−1	−1	−2	0	0	NA	215	195	SMD −0.17 (−0.48 to 0.13)		Very Low	4
Reproductive organ toxicity													
Testis-epididymis weight (an SMD positive value indicates a detrimental RF-EMF effect)													
55	(a)	−1	−1	−1	0	−1	+1	725	503	SMD 0.29 (0.10 to 0.47)		Very Low	6
Testis histomorphometry (an SMD positive value indicates a detrimental RF-EMF effect)													
24	(a)	−1	−2	−1	0	−1	0	173	162	SMD 0.90 (0.32 to 1.49)		Very Low	2
Testis or epididymis histology (an MD positive value indicates a detrimental RF-EMF effect)													
17	(a)	−1	−2	0	0	−1	0	125	108		MD 0.69 (0.45 to 0.92)	Very Low	5
Testicular cell death (an SMD negative value indicates a detrimental RF-EMF effect)													
23	(a)	−1	−1	−1	0	−1	+1	285	168	SMD −1.18 (−1.82 to −0.54)		Very Low	3
Testicular sperm production (an SMD positive value indicates a detrimental RF-EMF effect)													
36	(a)	−1	−1	−1	0	0	0	364	243	SMD 0.87 (0.51 to 1.22)		Very Low	4
Hormonal effects													
Testosterone level (an SMD positive value indicates a detrimental RF-EMF effect)													
29	(a)	−1	−2	0	0	−1	+1	462	321	SMD 0.87 (0.43 to 1.30)		Very low	6

(a) Controlled experimental animal studies.
(b) Controlled experimental *in vitro* studies
*All studies considered, irrespective of their RoB rating.
**The importance of each endpoint in relation to human male infertility was rated on a scale 1–10 from the least to the most important.
NA: Not applicable.