# Association between self-reported mobile phone use and the semen quality of young men

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**Objectives:** To investigate the association between mobile phone exposure and semen parameters.
**Design:** A nationwide cross-sectional study.
**Setting:** Andrology laboratories in close proximity to 6 army recruitment centers.
**Patients:** In total, 2886 men from the general Swiss population, 18–22 years old, were recruited between 2005 and 2018 during military conscription.
**Intervention:** Participants delivered a semen sample and completed a questionnaire on health and lifestyle, including the number of hours they spent using their mobile phones and where they placed them when not in use.
**Main Outcome Measures:** Using logistic and multiple linear regression models, adjusted odds ratios and $\beta$ coefficients were determined, respectively. The association between mobile phone exposure and semen parameters such as volume, sperm concentration, total sperm count (TSC), motility, and morphology was then evaluated.
**Results:** A total of 2759 men answered the question concerning their mobile phone use, and 2764 gave details on the position of their mobile phone when not in use. In the adjusted linear model, a higher frequency of mobile phone use (>20 times per day) was associated with a lower sperm concentration (adjusted $\beta$: −0.152; 95% confidence interval: −0.316; 0.011) and a lower TSC (adjusted $\beta$: −0.271; 95% confidence interval: −0.515; −0.027). In the adjusted logistic regression model, this translates to a 30% and 21% increased risk for sperm concentration and TSC to be below the World Health Organization reference values for fertile men, respectively. This inverse association was found to be more pronounced in the first study period (2005–2007) and gradually decreased with time (2008–2011 and 2012–2018). No consistent associations were observed between mobile phone use and sperm motility or sperm morphology. Keeping a mobile phone in the pants pocket was not found to be associated with lower semen parameters.
**Conclusion:** This large population-based study suggests that higher mobile phone use is associated with lower sperm concentration and TSC. The observed time trend of decreasing association is in line with the transition to new technologies and the corresponding decrease in mobile phone output power. Prospective studies with improved exposure assessment are needed to confirm whether the observed associations are causal. (Fertil Steril® 2023;120:1181-92. ©2023 by American Society for Reproductive Medicine.)
**El resumen está disponible en Español al final del artículo.**

**Key Words:** Electromagnetic radiation (EMR), mobile phone position, mobile phone use, semen quality, sperm concentration, total sperm count (TSC)

Approximately one in 6 couples suffer from infertility, which is defined as the inability to conceive a child after 1 year of regular, unprotected sexual intercourse (1, 2). Around half of the clinical causes of infertility are attributable to the male partner, but the etiology of poor semen quality remains insufficiently understood (3, 4). A significant decline in sperm count has been reported over recent decades without a clear identification of possible causes (5). A variety of environmental and lifestyle factors have been associated with this decline (6–8), including obesity (9, 10), smoking (11–13), alcohol consumption (13–15), and psychological stress (16, 17), among many others.

The use of mobile phones has increased substantially in recent decades, and there is a growing concern about the possible detrimental effects of radiofrequency electromagnetic fields (RF-EMFs) emitted by these devices on human health and particularly on reproductive functions. Mobile phones emit low-level RF-EMF (800–2200 MHz) that can be absorbed by the human body (18, 19). Studies

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evaluating this relationship are either experimental (on rodents and in human sperm exposed in vitro) or observational. Experimental studies in rats have suggested that RF-EMF can affect the germ cell cycle, increase sperm death, and cause histological changes in the testes (20–23). RF-EMF exposure has been linked also to a significant increase in abnormal histological changes in seminiferous tubules, suggesting an impairment of male fertility in mice (24). However, these effects are not always reproduced, mainly because of protocol differences, despite the numerous animal studies conducted since the 1970s (25). In addition, there are fundamental differences between spermatogenesis in humans and rodents (8). Experimental studies on human sperm in vitro, comparing RF-EMF-exposed with unexposed samples, mostly reported a significant increase in DNA fragmentation and reduced motility (22, 26–30). However, exposure set-ups in these studies were mostly insufficiently characterized and are unlikely to be comparable to in vivo exposure from typical mobile phone use because they were short-term exposures occurring directly on semen after ejaculation (31). In addition, bias related to exposure-induced temperature increase is another plausible explanation for the observed effects (32).

In humans, observational studies investigating the relationship between mobile phone use and reproductive health have associated primarily a high frequency of mobile use with decreased sperm motility, morphology, and viability, although effects on sperm concentration were more equivocal (18, 26, 27, 33–38). Although ubiquitously used and considered safe, the number of observational studies investigating the impact of mobile phone use on reproductive health and semen quality is limited. Most of these studies recruited participants during their visits to fertility clinics, included a relatively small number of individuals, and adjusted for only a few, when any confounders (reviewed in (39–41)). Thus, selection, confounding, and publication bias are of concern. In addition, in such a setting, retrospective reports of mobile phone use are vulnerable to recall bias (42).

In this study, we analyzed data collected from 2886 young Swiss men from the general population without prior knowledge of their fertility status. Participants provided details on their mobile phone use habits at the time they answered the questionnaire, making recall bias very unlikely or impossible. After adjusting for numerous potential confounding factors, we examined the association between self-reported mobile phone use, position when not in use, and semen parameters. Because recruitment of these men began in 2005, before the widespread use of smartphones, we also evaluated the association between frequency of use and semen parameters over different time periods.

## MATERIALS AND METHODS

### Study Population

In Switzerland, all men aged 18–22 years must attend a 3-day camp to determine their fitness for military service. This accounts for 97% of the population of young men, although the remaining 3% were excluded because of a previously diagnosed chronic disease or disability. For this study, men were contacted 3 months before their military recruitment and invited to participate once the camp was completed, regardless of whether they were declared fit for military service or not. They received a detailed description of the study, a consent form, and 2 questionnaires: one for themselves related to their general health and lifestyle habits, and one for their parents related to the preconception period as described previously (43). The 6 Swiss recruitment centers, each in a different canton, were located in Lausanne (Vaud), Windisch (Aargau), Monteceneri (Ticino), Rüti (Zürich), Sumiswald (Bern), and Mels (St-Gallen). They were involved sequentially in the sampling process over a period spanning September 2005 to November 2018. A total of 106,924 men were contacted, and 5605 (5.3%) sent back their documents completed with personal information. Of these, 2886 (3.1%) contributed biological material to the study. No exclusion criteria were applied during data collection.

### Ethical Approval

Ethical approval was obtained according to the requirements of local committees in the cantons of Vaud (17-01-2005, 01/02), Zürich (EK-StV-Nr. 27-2006), Ticino (Rif. CE 1886), and Geneva (2016-01674 and 2021-00574). All participants gave informed consent.

### Physical Examination and Sample Collection

Men who consented to provide biological samples were given appointments in an andrology laboratory near each army recruitment center. They underwent a physical examination by a trained urologist who examined the anatomy of the genital area (presence of surgical scars, hypospadias, and varicocele) and measured the testicular volume as previously described (43). In addition, weight and height were measured, and body mass index (BMI) in $kg/m^2$ was calculated. Men were asked to provide a semen sample obtained by masturbation in a private room. Dates and times of current and last ejaculation were recorded, and the duration of abstinence was calculated in hours.

### Semen Analysis

Semen samples were analyzed in all 6 collaborating laboratories using the same protocols and following the guidelines set by the World Health Organization (WHO) for semen analysis (1). The detailed protocol has been described previously (43). Briefly, semen volume was determined by weighing the tube before and after collection, and samples were incubated for 20–40 minutes at 37 °C to allow liquefaction. Aliquots (5 $\mu$L) of the semen sample were transferred to a 20 $\mu$m-deep counting chamber (Leja Products BV, GN Nieuw-Vennep, The Netherlands) after dilution using a commercialized 4-(2-hydroxyethyl) piperazine-1-ethanesulfonic acid buffer supplemented with 0.4% human serum albumin (IVF basics, Gynotec B.V., the Netherlands). The slide was placed on a thermostatic (37 °C) microscope stage and analyzed using the Computer Assisted Sperm Analyzer (CASA, Sperm Class Analyzer-SCA, Microptic, Spain). Semen parameters

## TABLE 1

**A general description of the total number of men and of groups of men stratified according to the frequency at which they use their mobile phones.**

| | | | Mobile phone use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N with data | Total population (n = 2886) | < Once/wk (n = 223, 8.6%) | 1–5 times/d (n = 667, 24.2%) | 5–10 times/d (n = 592, 21.5%) | 10–20 times/d (n = 669, 24.2%) | > 20 times/d (n = 608, 22%) | *P* value[g] |
| **A- General characteristics** | | | | | | | | |
| Age (y) | 2883 | 19 (19–20) | 20 (19–20) | 20 (19–20) | 20 (19–20) | 19 (19–20) | 19 (19–20) | **< .001** |
| Height (cm) | 2634 | 179 (174–183) | 178 (174–183) | 179 (174–183) | 179 (174–183) | 179 (175–183) | 179 (175–184) | .8 |
| Weight (kg) | 2636 | 72 (66–80) | 70 (65–77) | 72 (66–79) | 72 (65–78) | 73 (66–80) | 73 (67–81) | **.004** |
| Body mass index (kg/m$^2$) | 2633 | 22.6 (20–24) | 21.9 (20–23) | 22.5 (21–24) | 22.5 (21–24) | 22.8 (21–24) | 22.8 (21–25) | **.003** |
| Self-reported health – excellent or good (%) | 2784 | 97.4 | 98.2 | 97.7 | 97.1 | 96.7 | 97.9 | **.04** |
| Medication last 3 mo (%)[a] | 2820 | 10.1 | 8.1 | 7.6 | 10.0 | 12.5 | 11.8 | **.02** |
| Ever fathered a child (%) | 2785 | 1.7 | 0.4 | 0.9 | 1.9 | 1.9 | 2.3 | .30 |
| Experienced fertility problem (%)[b] | 2738 | 0.1 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | .2 |
| Educational level, until obligatory school or higher (%) | 2791 | 98.0 | 99.6 | 98.7 | 97.8 | 96.9 | 98.4 | .05 |
| Recruitment y (%) | 2886 | | | | | | | |
| 2005–2007 | 871 | 30.2 | 56.5 | 47.5 | 39.0 | 19.7 | 8.2 | **< .001** |
| 2008–2011 | 1147 | 29.7 | 38.6 | 45.9 | 47.1 | 38.9 | 24.5 | |
| 2015–2018* | 868 | 30.1 | 4.9 | 6.6 | 13.9 | 41.4 | 67.3 | |
| **B- Lifestyle factors** | | | | | | | | |
| Cigarette smokers (%) | 2794 | 29.0 | 16.6 | 24.4 | 31.1 | 32.4 | 33.1 | **< .001** |
| Cigarettes/d, smokers only | 809 | 7.0 (2.0–15.0) | 5.0 (1.7–16.0) | 5.0 (2.0–10.0) | 8.0 (2.5–15.0) | 10.0 (2.0–15.0) | 6.0 (1.6–12.8) | .3 |
| Alcohol consumers (%)[c] | 2795 | 77.1 | 64.6 | 79.8 | 81.4 | 82.1 | 81.1 | **< .001** |
| Alcohol, consumers only (units/wk) | 2226 | 5.0 (3.0–9.0) | 4.0 (2.0–9.0) | 5.0 (3.0–9.0) | 5.0 (3.0–10.0) | 5.0 (3.0–9.0) | 5.0 (2.2–10.0) | .2 |
| Mother smoked during pregnancy (%) | 2109 | 12.6 | 11.0 | 10.7 | 15.9 | 11.6 | 13.3 | .3 |
| **C- Previously diagnosed/ treated** | | | | | | | | |
| Fever (%)[d] | 2821 | 5.5 | 4.5 | 5.6 | 4.9 | 6.8 | 5.0 | .3 |
| Major diseases (%)[e] | 2568 | 11.6 | 10.9 | 11.5 | 12.2 | 14.6 | 9.6 | .1 |

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## TABLE 1

**Continued.**

| | N with data | Total population (n = 2886) | Mobile phone use: < Once/wk (n = 223, 8.6%) | 1–5 times/d (n = 667, 24.2%) | 5–10 times/d (n = 592, 21.5%) | 10–20 times/d (n = 669, 24.2%) | > 20 times/d (n = 608, 22%) | *P* value[g] |
|---|---|---|---|---|---|---|---|---|
| Cryptorchidism treated (%) | 2700 | 2.0 | 0.5 | 1.4 | 3.2 | 2.5 | 1.5 | .05 |
| Varicocele operated (%) | 2799 | 1.0 | 0.4 | 1.5 | 0.8 | 0.7 | 1.0 | .90 |
| **D- Physical examination** | | | | | | | | |
| Varicocele (%) | 1662 | 19.3 | 18.7 | 16.2 | 16.7 | 22.0 | 21.0 | .2 |
| Testicular volume, mean ± SD (mL)[f] | 1655 | 17.6 (± 4.4) | 18.0 (± 4.5) | 17.8 (± 4.5) | 17.3 (± 4.2) | 17.5 (± 4.3) | 17.8 (± 4.4) | .4 |
| **E- Semen parameters** | | | | | | | | |
| Ejaculation abstinence (d) | 2886 | 2.8 (2.0–3.8) | 3.0 (2.0–4.2) | 2.9 (2.0–13.8) | 2.8 (2.1–3.8) | 2.8 (2.1–3.8) | 2.8 (1.8–3.7) | **.001** |
| Volume (mL) | 2886 | 2.8 (2.0–3.8) | 2.8 (2.0–3.9) | 2.9 (2.0–3.8) | 2.8 (2.1–3.8) | 2.8 (2.0–3.8) | 2.7 (2.0–3.6) | .1 |
| Volume (% below 1.5 mL) | 2886 | 10.5 | 10.30 | 9.7 | 10.3 | 10.8 | 11.3 | .9 |
| Sperm concentration (Mio/mL) | 2886 | 47.6 (22.0–87.4) | 56.5 (27.5–105.2) | 47.9 (25.2–89.0) | 45.0 (19.8–88.4) | 47.1(23.0–85.0) | 44.5 (21.4–80.9) | **.04** |
| Sperm concentration (% below 15 Mio/mL) | 2886 | 16.4 | 16.60 | 13.6 | 19.1 | 15.4 | 17.6 | .09 |
| Total sperm count (Mio) | 2886 | 127 (59.6–249.4) | 153.7 (59.8–303.8) | 133.1 (67.6–270.0) | 121 (55.5–245.5) | 122.0 (59.7–244.8) | 120.0 (56.2–224.2) | **.008** |
| Total sperm count (% below 39 Mio) | 2886 | 16.7 | 13.90 | 14.7 | 18.1 | 16.7 | 18.4 | .2 |
| Motile sperm (%) | 2886 | 53.5 (40.0–66.3) | 53 (40.1–65.0) | 53 (38.8–64.7) | 53.7 (39.7–65.8) | 53.3 (39.9.4–66.0) | 55.0 (42.3–68.0) | .2 |
| Motile sperm (% below 40%) | 2886 | 24.0 | 22.80 | 26.4 | 24.6 | 24.2 | 20.6 | .1 |
| Normal morphology (%) | 2664 | 4.2 (2.0–8.0) | 4.0 (2.0–9.0) | 4.0 (2.0–8.0) | 4.7 (2.0–8.5) | 4.2 (2.0–8.0) | 4.4 (2.0–8.0) | .6 |
| Normal morphology (% below 4%) | 2664 | 43.0 | 42.00 | 43.1 | 41.5 | 43.0 | 42.3 | .9 |

Section E, highlighted in gray: the proportion of men having semen parameters below the reference values of the World Health Organization for fertile men (2010).
Results are presented as medians (25th–75th percentiles) for continuous variables or percentages for categorical variables.
Testicular volume is represented as mean ± standard deviation (SD).
[a] Taken any medication during the 3 months immediately before participating in the study.
[b] Unable to conceive a child despite their willingness.
[c] Sum of intake of beer, wine, and strong alcohol in recent weeks before participation in the study.
[d] Suffered from fever 3 months immediately before participating in the study.
[e] Suffering from autoimmune diseases and/or cancer and/or diabetes and/or hepatitis and/or hypertension and/or thyroid.
[f] Mean of the right and left testicular volumes measured with Prader's Orchidometer and/or ultrasound. A correction factor of 1.5 was applied to correct for under-estimated values measured with ultrasound.
[g] *P* value for comparison of results between semen quality categories. The Kruskal-Wallis test has been used for continuous variables and the Chi-square test for categorical variables. A *P* value < .05 was considered statistically significant and was highlighted in bold.
* Includes 29 volunteers that were recruited in 2013 and 2014.

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## TABLE 2

**Unadjusted and adjusted results from linear regression analyses of semen quality by frequency of mobile phone use introduced as a categorical variable.**

| | Volume (Cubic-root transformed) | | | Concentration (Cubic-root transformed) | | | Total sperm count (Cubic-root transformed) | | | Motility | | | Morphology | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value |
| **Unadjusted results** | | | | | | | | | | | | | | | |
| Frequency of mobile phone use | | | | | | | | | | | | | | | |
| <once/wk | −0.002 | −0.036; 0.031 | .898 | 0.101 | −0.090; 0.292 | .302 | 0.144 | −0.141; 0.431 | .322 | 0.026 | −2.809; 2.861 | .986 | 0.524 | −0.432; 1.480 | .280 |
| **1–5 times/d** | **Reference** | | | **Reference** | | | **Reference** | | | **Reference** | | | **Reference** | | |
| 5–10 times/d | 0.000 | −0.025; 0.025 | .990 | −0.099 | −0.239; 0.041 | .165 | −0.153 | −0.361; 0.054 | .148 | 0.499 | −1.608; 2.607 | .642 | 0.326 | −0.286; 0.937 | .296 |
| 10–20 times/d | −0.019 | −0.044; 0.006 | .130 | −0.052 | −0.188; 0.083 | .447 | −0.150 | −0.350; 0.051 | .144 | 1.147 | −0.887; 3.181 | 0.269 | 0.379 | −0.210; 0.969 | .207 |
| >20 times/d | **−0.029*** | −0.05; −0.004 | .022 | −0.129 | −0.267; −0.010 | .069 | **−0.285** | −0.492; −0.078 | .007 | **2.298*** | 0.207; 4.388 | .031 | 0.167 | −0.450; 0.784 | .595 |
| Linear trend test | | | .012 | | | .018 | | | .001 | | | .025 | | | .920 |
| **Adjusted results** [#] | | | | | | | | | | | | | | | |
| Frequency of mobile phone use | | | | | | | | | | | | | | | |
| <once/wk | −0.00548 | −0.04; 0.029 | .758 | 0.108 | −0.085; 0.301 | .271 | 0.142 | −0.151; 0.436 | .342 | 0.379 | −2.390; 3.148 | .788 | 0.613 | −0.235; 1.461 | .156 |
| **1–5 times/d** | **Reference** | | | **Reference** | | | **Reference** | | | **Reference** | | | **Reference** | | |
| 5–10 times/d | 0.006 | −0.020; 0.032 | .637 | −0.075 | −0.218; 0.067 | .301 | −0.099 | −0.310; 0.113 | .362 | 0.454 | −1.619; 2.527 | .668 | 0.479 | −0.151; 1.108 | .136 |
| 10–20 times/d | −0.009 | −0.035; 0.018 | .515 | −0.063 | −0.210; 0.085 | .404 | −0.129 | −0.349; 0.091 | .252 | 0.980 | −1.123; 3.082 | .361 | **0.710** | 0.081; 1.339 | .027 |
| >20 times/d | −0.017 | −0.046; 0.012 | .263 | −0.152 | −0.316; 0.011 | .067 | **−0.271*** | −0.515; −0.027 | .030 | 1.202 | −1.126; 3.531 | 0.311 | 0.694 | 0.014; 1.374 | .046 |
| Linear trend test | | | .343 | | | .021 | | | .010 | | | 0.330 | | | .133 |

CI = confidence interval.

[#] *β* coefficient estimates of imputed data (pool of 20 iterations) adjusted for conscript's body mass index, alcohol consumption, smoking, educational level, maternal smoking during pregnancy, cryptorchidism, varicocele, abstinence, recruitment center, year, and season. Additional adjustment for sperm motility was the time before motility analysis.

* $P < .05$ (*) and $P < .01$ (**) were considered statistically significant and were highlighted in bold.

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## TABLE 3

**Unadjusted and adjusted results from linear regression analyses of semen quality by frequency of mobile phone use introduced as a continuous variable (10 times per day) shown stratified by recruitment year and for the total period.**

| | | Volume (Cubic-root transformed) | | | Concentration (Cubic-root transformed) | | | Total sperm count (Cubic-root transformed) | | | Motility | | | Morphology | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value | *β* | 95% CI | *P* value |
| **Unadjusted results** | Recruitment, y | | | | | | | | | | | | | | | |
| Frequency of mobile phone use | | | | | | | | | | | | | | | | |
| Per 10 times/d | 2005–2007 | −0.016 | −0.037; 0.004 | .124 | **−0.117*** | −0.232; −0.003 | .045 | **−0.211*** | −0.383; −0.039 | .016 | 0.472 | −1.378; 2.323 | .617 | 0.202 | −0.291; 0.695 | .695 |
| | 2008–2011 | −0.003 | −0.018; 0.011 | .653 | −0.075 | −0.158; 0.009 | .079 | −0.114 | −0.237; 0.008 | .067 | 0.769 | −0.456; 1.995 | .219 | 0.215 | −0.19; 0.62 | .620 |
| | 2012–2018 | −0.010 | −0.028; 0.007 | .250 | −0.042 | −0.132; 0.048 | .362 | −0.107 | −0.24; 0.026 | .115 | 0.356 | −0.896; 1.608 | .577 | 0.254 | −0.038; 0.545 | .545 |
| Per 10 times/d | 2005–2018 | **−0.011** | −0.02; −0.003 | .008 | **−0.049*** | −0.095; −0.004 | .034 | **−0.109** | −0.178; −0.041 | .002 | **0.828*** | 0.143; 1.513 | .018 | 0.002 | −0.197; 0.201 | .201 |
| **Adjusted results** [#] | | | | | | | | | | | | | | | | |
| Frequency of mobile phone use | | | | | | | | | | | | | | | | |
| Per 10 times/d | 2005–2007 | −0.011 | −0.032; 0.011 | .332 | −0.091 | −0.209; 0.026 | .128 | −0.153 | −0.326; 0.021 | .085 | −0.123 | −1.998; 1.752 | .898 | 0.163 | −0.37; 0.696 | .696 |
| | 2008–2011 | −0.003 | −0.017; 0.012 | .736 | −0.074 | −0.163; 0.016 | .108 | −0.107 | −0.24; 0.025 | .113 | 0.501 | −0.728; 1.729 | .424 | 0.166 | −0.235; 0.568 | .568 |
| | 2012–2018 | −0.006 | −0.023; 0.012 | .530 | −0.047 | −0.14; 0.046 | .326 | −0.096 | −0.235; 0.043 | .177 | 0.378 | −0.882; 1.638 | .556 | 0.108 | −0.192; 0.408 | .408 |
| Per 10 times/d | 2005–2018 | −0.006 | −0.016; 0.004 | .216 | **−0.062*** | −0.118; −0.005 | .032 | **−0.108*** | −0.193; −0.023 | .012 | 0.393 | −0.401; 1.187 | 0.332 | 0.177 | −0.056; 0.41 | .410 |

CI = confidence interval.

[#] *β* coefficient estimates of imputed data (pool of 20 iterations) adjusted for conscript's age, body mass index, health status, medication intake before participation, alcohol consumption, smoking, educational level, recruitment center, maternal smoking during pregnancy cryptorchidism, varicocele, abstinence, year of recruitment, and season. Additional adjustment for sperm motility was the time before motility analysis.

* $P < .05$ (*) and $P < .01$ (**) were considered statistically significant and were highlighted in bold.

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such as sperm concentration, total sperm count (TSC), and sperm motility were recorded. For each sample, a minimum of 500 sperm tracks were captured at a rate of 25 images per second. Identical CASA systems were used in all study locations. Fixed and Papanicolaou-stained smears were prepared for morphology assessment, either using the CASA or by a single trained technician according to the stricter criteria (44). Observations were made with a 10× phase contrast objective at a 100× final magnification.

### Data on the Frequency of Mobile Phone Use and its Position

Participants completed a questionnaire covering personal information related to their general and reproductive health, their lifestyle habits, and their education. In the lifestyle habits section, men were asked whether they have a mobile phone, how often they use it, and where they keep it when they are not using it. To the question concerning the frequency of use, men could choose one of the following answers: rarely, a few times per week (merged into group <once/week), 1–5 times per day, 5–10 times per day, 10–20 times per day, >20 times per day. The answers for the mobile phone location when not in use were pants pocket, jacket pocket, in a belt carrier, or elsewhere.

### Statistical Analysis

Medians with the 25th and 75th percentiles were used to describe continuous variables, and frequencies were used to describe categorical variables. Descriptive results are shown for the entire population as well as after stratification of men in 5 groups according to the frequency of their mobile phone use: <once per week, 1–5 times per day, 5–10 times per day, 10–20 times per day, and >20 times per day. For the phone position, 3 groups were created: not at body, in the jacket pocket, or in the pants pocket. The latter also included those who indicated the use of a belt carrier. Group differences were tested using the Kruskal-Wallis test for continuous variables and the Chi-square test for categorical variables. Logistic regression analysis was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for men having semen parameters below the WHO reference values (1) in relation to their mobile phone use and its position when not in use. In linear regression models, $\beta$ coefficient values were determined by introducing semen parameters as continuous variables and the frequency of mobile phone use either as a continuous variable (per 10 calls/day) or as a categorical variable. Trends in $\beta$ coefficients with respect to the level of exposure were tested by fitting the categorical exposure variable as a continuous variable using the midpoint of the categories. To correct for a skewed distribution, semen volume, sperm concentration, and TSC were normalized by a cubic-root transformation. Sperm motility and morphology were included untransformed. A sensitivity analysis was performed by excluding men with azoospermia (28 men, 1%) to evaluate whether the estimates from the linear regression model would be attenuated.

Potential confounders were selected on the basis of prior knowledge in the literature and on the descriptive factors found to be significantly different among the 5 frequency groups in Table 1. The final logistic and linear regression models were adjusted for the following factors: conscript BMI, alcohol consumption, smoking, educational level, maternal smoking during pregnancy, cryptorchidism, varicocele, abstinence, recruitment center, year, and season. The additional adjustment for sperm motility was the time before motility analysis. Covariates with missing values were imputed using multivariate imputation by chained equations under the assumption of missing at random data (45). Twenty data sets were generated, and the parameter estimates were pooled. A $P$ value $<.05$ was considered statistically significant. Data were analyzed using a commercially available package (IBM SPSS Statistics 26, NY, USA).

## RESULTS

### Description of the Study Population

A total of 2886 men were included in the study. Data on their mobile phone use was available for 2789 individuals, out of which 2759 answered the question regarding the frequency of their phone use, and 2764 gave details on the position of their phones when not in use. Table 1 summarizes the general characteristics, lifestyle factors, and semen parameters of the total population, according to the frequency of their mobile phone use, divided into 5 groups. Frequent phone users (>20 times/day) were slightly younger compared with men who used their phones <10 times per day or rarely (19 and 20 years old, respectively). Men who used their phones more often had a higher weight and consequently a higher BMI (22.8 kg/m$^2$) compared with men who rarely used their phones (21 kg/m$^2$). In general, a higher proportion of men who self-reported as being in excellent or good health consumed less medication before participation and a higher educational level was observed in the group of low mobile phone users, compared with high-frequency users (Table 1; A). In addition, a higher proportion of frequent users smoked cigarettes and consumed alcohol (Table 1; B). Interestingly, more than half of men (56.5%) used their phones less than once a week between 2005 and 2007, compared with only 5% in 2015 and 2018.

### The Association between the Frequency of Mobile Phone Use and Semen Quality

The median sperm concentration and TSC were significantly higher in the group of men who did not use their phones more than once per week (56.5 Mio/mL and 153.7 Mio; respectively) compared with men using their phones >20 times per day (44.5 Mio/mL and 120 Mio; respectively) (Table 1; E). This difference corresponds to a 21% decrease in sperm concentration and a 22% decrease in TSC for frequent (>20 times/day) compared with rare (<once/week) mobile phone users. The adjusted OR for having sperm concentration below the WHO reference value of 15 Mio/mL was significantly higher for men using their phone 5–10 times per day compared with men who used it 1–5 times per day or

**TABLE 4**

**Unadjusted and adjusted results from linear regression analyses of semen quality by position of mobile phone use.**

| | Volume (Cubic-root transformed) | | | Concentration (Cubic-root transformed) | | | Total sperm count (Cubic-root transformed) | | | Motility | | | Morphology | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | 95% CI | *P* value | β | 95% CI | *P* value | β | 95% CI | *P* value | β | 95% CI | *P* value | β | 95% CI | *P* value |
| **Unadjusted results** | | | | | | | | | | | | | | | |
| Position of mobile phone use | | | | | | | | | | | | | | | |
| Not at body | Reference | | | Reference | | | Reference | | | Reference | | | Reference | | |
| Jacket pocket | −0.012 | −0.06; 0.036 | .621 | −0.139 | −0.402; 0.124 | .301 | −0.227 | −0.623; 0.168 | .260 | −0.205 | −4.122; 3.712 | .918 | −0.578 | −1.81; 0.655 | .357 |
| Pants pocket | −0.004 | −0.033; 0.025 | .767 | −0.043 | −0.204; 0.117 | .595 | −0.079 | −0.319; 0.161 | .520 | −0.407 | −2.76; 1.947 | .735 | −0.287 | −1.039; 0.464 | .452 |
| **Adjusted results** [#] | | | | | | | | | | | | | | | |
| Position of mobile phone use | | | | | | | | | | | | | | | |
| Not at body | Reference | | | Reference | | | Reference | | | Reference | | | Reference | | |
| Jacket pocket | −0.010 | −0.058; 0.039 | .698 | −0.156 | −0.43; 0.119 | .265 | −0.230 | −0.647; 0.186 | .278 | −1.392 | −5.298; 2.515 | .485 | −0.602 | −1.753; 0.549 | .305 |
| Pants pocket | −0.001 | −0.031; 0.028 | .941 | −0.049 | −0.211; 0.113 | .552 | −0.064 | −0.311; 0.182 | .609 | −1.200 | −3.531; 1.131 | .313 | −0.277 | −0.975; 0.42 | .435 |

CI = confidence interval.
[#] β coefficient estimates of imputed data (pool of 20 iterations) adjusted for conscript's BMI, alcohol consumption, smoking, educational level, maternal smoking during pregnancy, cryptorchidism, varicocele, abstinence, recruitment center, year, and season. Additional adjustment for sperm motility was the time before motility analysis.

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less than once a week (adjusted OR: 1.409, 95% CI: 1.02–1.9) (Supplemental Fig. 1 and Supplemental Table 1, available online). In this logistic regression model, men using their phones >20 times per day had a 30% and a 21% increased risk of having sperm concentration and TSC below the WHO reference values for fertile men, respectively. However, the exposure-response trends were not significant. Differences in sperm motility and sperm morphology were not associated with the frequency of mobile phone use (Supplemental Fig. 1 and Supplemental Table 1). Linear models adjusted for potential confounding factors consistently showed that a high frequency of mobile phone use (>20 times/day) was significantly associated with reduced sperm concentration and TSC, while they showed significant exposure-response trends across the whole exposure range (Table 2). Introducing the frequency of mobile phone use as a continuous variable in the linear model resulted in a decrease in sperm concentration by 0.062 (95% CI: −0.118 to −0.005) and TSC by 0.108 (95% CI: −0.193 to −0.023) with every 10 uses per day (Table 3 and Supplemental Table 2, available online). The results were similar after excluding men with azoospermia (28 men, or 1% of the study population—Supplemental Table 3, available online). The association between mobile phone use and sperm concentration was higher in the years between 2005 and 2007 and progressively decreased in the subsequent periods (2008–2011 and 2012–2018), as shown in Table 3.

## The Association between Mobile Phone Position and Semen Quality

A total of 2368 men, corresponding to 85.7% of the studied population, reported keeping the phone when not in use in their pants pockets. The rest of the men had it either in their jackets (4.6%) or elsewhere, not on the body (9.7%) (Table 4 and Supplemental Fig. 2, available online). Carrying the phone in the pants was not associated with altered semen quality parameters compared with carrying the phone away from the body in both linear regression and logistic regression models (Table 4 and Supplemental Fig. 2 as well as Supplemental Tables 4 and 5, available online). In addition, this lack of association was observed in the stratified analysis according to the recruitment period (Supplemental Table 6, available online).

## DISCUSSION

Among the multiple lifestyle factors that can affect semen quality, mobile phone use has gained central importance because of the tremendous increase in its use over the past decades. In this study on a large sample of men from the general population, we observe significant exposure-response trends of decreasing sperm concentration and TSC with increasing frequency of mobile phone use. Semen volume, sperm motility, and morphology, however, were not associated with frequency of use. The position of the mobile phone when not in use was also not associated with any semen parameters.

In this cross-sectional study, we analyzed data from 2886 young men from the general population, from different regions of Switzerland, recruited during military conscription.

To our knowledge, this is the largest sample ever included in a study on semen quality and RF-EMF exposure from mobile phones. Another strength of the present study is that all participants are men from the general population and had no prior knowledge of their semen parameters or their fertility status, which makes selection bias unlikely.

Recruitment was performed over 14 years (2005–2018), spanning the period before the introduction of smartphones in 2007. A substantial variation in exposure was therefore available, ranging from men with little or no mobile phone use (< once a week, 8.6% equivalent to 223 men) to those who used it >20 times a day (22%, equivalent to 608 men). More importantly, and unlike most previous studies, all participants completed a comprehensive questionnaire on potential confounding factors such as BMI, maternal smoking, cigarette, and alcohol consumption. These factors were controlled for in all the analyzed models. Information bias in this regard is considered to be limited because participants were unaware of the results of their semen analysis when they completed the questionnaire, and neither the participants nor the researchers knew that this association study would be conducted. Men were asked to provide details of their mobile phone use in the period immediately before completing the questionnaire, which also makes recall bias very unlikely. The unadjusted and adjusted regression coefficients were similar. Given that we have included some of the most plausible potential confounders, this is an indication that residual confounding from factors that we could not consider does not play a substantial role in this study. Nevertheless, residual confounding may have biased our analysis when our covariates had been measured with low precision or when we had missed an important factor that was not represented at least partly by the covariates involved.

Reverse causality is theoretically possible in a cross-sectional observational study like this. However, it is difficult to imagine that semen quality would affect mobile phone use in this age group. Overall, this study can be considered to be substantially more informative than most previous research.

A major challenge in studying mobile phone use is assessing absorbed RF-EMF exposure from the owner's phone during daily life. Our study, like most epidemiologic studies investigating the effects of mobile phone use on semen quality, relied on self-reported data, which is a limitation. By doing so, the frequency of use reported by the individual was assumed to be an accurate estimate. Type of use (calling, texting, and using applications) was not reported and therefore could not be considered, and the number of times used per day was considered a valid surrogate of RF-EMF energy absorbed from mobile phone handsets. The energy absorbed by the body depends mainly on the transmission duration, the source's strength, and the distance to the source. The specific absorption rate decreases with the square of the distance to the source, although the situation can be much more complex close to the source. In addition to potential inaccuracies in reporting hours per day of mobile phone use, radiofrequency exposure depends on characteristics that were not collected, such as brand and generation of the mobile phone, applications on the phone, network quality, distance to base stations, and use of earpieces and protective covers (46, 47). With technical development, the output power of mobile phones has decreased as 3G phones emit, on average, 100–500 times lower levels than 2G phones. In contrast, modern smartphones are much more active in standby mode compared with previous bar phones (48). Therefore, the number of applications on the phone and whether the person is stationary or not may play an important role. During traveling, for example, mobile phones are connecting more frequently and with higher output power on average (49). Such limitations, together with random errors in self-reported use, cause nondifferential exposure misclassification, which would attenuate our estimates and should be considered when interpreting the data.

An association between mobile phone use and sperm concentration was found to be more pronounced in the first period of the study (2005 and 2007) and decreased progressively over the subsequent time periods (2008–2011 and 2012–2018). This pattern is in line with the transition to new technologies, mainly from 2G to 3G and 4G, and the corresponding decrease in the phone's output power. Furthermore, the increase in phone network coverage is expected to significantly decrease the RF-EMF output power of mobile phones in the future (49, 50). In fact, given the rapid evolution of mobile phone use and technology, our study represents a snapshot of their impact during the period between 2005 and 2018. With the advent of new phone technologies in recent years, more contemporary prospective observational studies are needed to better understand the impact of RF-EMF on male reproductive health and fertility potential.

Our association study, suggesting a negative effect of RF-EMF exposure and mobile phone use on sperm concentration and TSC, raises 2 important issues: the potential consequences on fertility and the mechanism of action by which sperm count is affected. To our knowledge, only one study has examined the association between mobile phone exposure, semen quality, and fecundability, defined as the probability of being pregnant in a single menstrual cycle (31). On the basis of 2 preconception cohorts with men in Denmark (n = 751) and in North America (n = 2349), the investigators did not find a consistent link between carrying one's phone in the front pants pocket and either fecundability or semen quality, which is in line with our study (31). In addition to self-reported use of mobile phones, participants had to analyze their semen quality themselves using a home-based semen testing kit, which constitutes a technical limitation to a certain extent (51). Although practical, reliable, and Food and Drug Administration-approved, these measurements are not as accurate as those performed by trained technicians using CASA, especially when evaluating sperm motility (52, 53). However, various confounders were considered.

The mode of action by which mobile phone use and RF-EMFs may adversely affect the male reproductive system remains unclear. Radiofrequency electromagnetic fields from mobile phones emitting at maximum output power result in a maximum local tissue heating of 0.5 °C (54). The increased temperature of the testes caused by the heat generated by the handset located in the pants pocket may thus hamper spermatogenesis and sperm production (55). An association with the position of the phone on the body would thus have

supported a direct effect of RF-EMF exposure on spermatogenesis and sperm function, which is not the case. Alternatively, RF-EMF could act indirectly on semen quality by altering the hypothalamic-pituitary-gonadal axis and the secretion of the gonadotropic hormones, luteinizing hormone, follicle-stimulating hormone, and the sex steroid testosterone (18, 20, 23, 41, 56–59). Several mechanisms of action have been proposed previously to explain the adverse effects of RF-EMFs on semen parameters, but none has been validated robustly to date. These include the role of kinases in cellular metabolism (21, 60), DNA damage, oxidative stress (24, 26, 30, 61, 62), thermal action, as well as changes in the activity of magnetite particles influencing cellular processes (63). Nevertheless, most of these studies have been conducted either on rodents or on human semen in vitro, which questions their relevance in determining whether mobile phone use has adverse effects on human reproduction and the precise mode of action. Indeed, human spermatogenesis differs from that of other species, and the 2 are difficult to compare directly. In addition, humans generally produce lower-quality semen, making their spermatogenesis inherently more susceptible to disruption by external factors (8). Experimental studies on human semen in vitro have primarily reported a significant increase in DNA fragmentation and reduced motility (26, 27, 33). However, the in vitro exposure is only marginally comparable to that in everyday life.

## CONCLUSION

The lack of clear evidence for a negative association between mobile phone use and male fertility, as well as the dramatic increase in cell phone use over the past decade, underscores the need for further research in this area. From this perspective, it is important to conduct prospective observational studies with men from the general population and to accurately measure the RF-EMF exposure to the testicles and the hypothalamic-pituitary-gonadal axis. This would allow us to examine the association between cell phone use, RF-EMF exposure, and semen quality and to better understand the mode of action of RF-EMF on the male reproductive system.

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**Asociación entre el uso de teléfonos móviles autodeclarados y la calidad del semen de los hombres jóvenes**

**Objetivos:** Investigar la asociación entre la exposición al teléfono móvil y los parámetros seminales.

**Diseño:** Estudio transversal a nivel nacional.

**Entorno:** Laboratorios de andrología en las proximidades de 6 centros de reclutamiento del ejército.

**Pacientes:** En total, 2886 hombres de la población general suiza, de entre 18 y 22 años, fueron reclutados entre 2005 y 2018 durante el servicio militar obligatorio.

**Intervención:** Los participantes entregaron una muestra de semen y completaron un cuestionario sobre salud y estilo de vida, incluyendo el número de horas que pasaron usando sus teléfonos móviles y dónde los colocaron cuando no los usaron.

**Principales medidas de resultados:** Utilizando modelos logísticos y de regresión lineal múltiple, se determinaron los odds ratios ajustados y los coeficientes beta, respectivamente. A continuación, se evaluó la asociación entre la exposición al teléfono móvil y parámetros seminales como el volumen, la concentración de espermatozoides, el recuento total de espermatozoides (RTE), la motilidad y la morfología.

**Resultados:** Un total de 2759 hombres respondieron a la pregunta sobre el uso de su teléfono móvil, y 2764 dieron detalles sobre la posición de su teléfono móvil cuando no lo utilizan. En el modelo lineal ajustado, una mayor frecuencia de uso del teléfono móvil (>20 veces al día) se asoció con una menor concentración de espermatozoides (beta ajustada: −0,152; intervalo de confianza del 95%: −0,316; 0,011) y un menor RTE (beta ajustado: −0,271; intervalo de confianza del 95%: −0,515; −0,027). En el modelo de regresión logística ajustada, esto se traduce en un aumento del 30% y del 21% en el riesgo de que la concentración de espermatozoides y el RTE estén por debajo de los valores de referencia de la Organización Mundial de la Salud para los hombres fértiles, respectivamente. Se encontró que esta asociación inversa era más pronunciada en el primer período de estudio (2005-2007) y disminuyó gradualmente con el tiempo (2008-2011 y 2012-2018). No se observaron asociaciones consistentes entre el uso del teléfono móvil y la motilidad o morfología de los espermatozoides. No se encontró que mantener un teléfono móvil en el bolsillo del pantalón se asociara con parámetros seminales más bajos.

**Conclusión:** Este gran estudio poblacional sugiere que un mayor uso del teléfono móvil se asocia con una menor concentración de espermatozoides y RTE. La tendencia temporal observada de asociación decreciente está en consonancia con la transición a las nuevas tecnologías y la correspondiente disminución de la potencia de salida de los teléfonos móviles. Se necesitan estudios prospectivos con una mejor evaluación de la exposición para confirmar si las asociaciones observadas son causales.