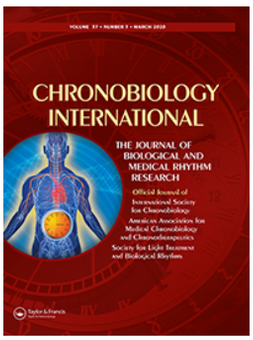

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Exposure by males to light emitted from media devices at night is linked with decline of sperm quality and correlated with sleep quality measures

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ABSTRACT

The last several decades have been characterized by the widespread usage of digital devices, especially smartphones. At the same time, there have been reports of both decline in sleep duration and quality and male fertility decline. The aim of this study was to assess the relationship between evening exposure to the light-emitting screens of digital media devices and measures of both sleep and sperm quality. Semen samples were obtained from 116 men undergoing fertility evaluation for the following sperm variables: volume (mL), pH, sperm concentration (million/mL), motility percentage (progressive% + non-progressive motility%), and total sperm count. Exposure to the screens of electronic devices and sleep habits was obtained by means of a questionnaire. Smartphone and tablet usage in the evening and after bedtime was negatively correlated with sperm motility (−0.392; −0.369; $p < .05$), sperm progressive motility (−0.322; −0.299; $p < .05$), and sperm concentration (−0.169; $p < .05$), and positively correlated with the percentage of immotile sperm (0.382; 0.344; $p < .05$). In addition, sleep duration was positively correlated with sperm total and progressive motility (0.249; 0.233; $p < .05$) and negatively correlated with semen pH (−0.349; $p < .05$). A significant negative correlation was observed between subjective sleepiness and total and progressive motility (−0.264; $p < .05$) as well as total motile sperm number (−0.173; $p < .05$). The results of this study support a link between evening and post-bedtime exposure to light-emitting digital media screens and sperm quality. Further research is required to establish the proposed causative link and may lead to the future development of relevant therapeutic and lifestyle interventions.

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Sleep; sleepiness; digital device; light; melatonin; sperm quality; male fertility; ALAN

Introduction

Significant sperm concentration decline has been reported over the last decades in Western and industrialized countries, while studies from non-Western countries showed no such trend (Levine et al. 2017). Various factors have been attributed to this sperm quality decline, such as obesity, environmental toxins (e.g. pesticides, air pollution, etc.), mobile phone radiation, and stress (Adams et al. 2014; Chiu et al. 2015; Jurewicz et al. 2009; Krausz 2011; Lafuente et al. 2016; Macdonald et al. 2013; Nordkap et al. 2016, 2012; Sharma et al. 2013). Concomitant with this decline in sperm quality is the increased availability of digital media devices, namely televisions, desktop and laptop computers, tablets, and smartphones. Tablets and smartphones, in particular, are electronic media devices that are developed to be portable, multi-functional, and useful for various everyday tasks, such as communication, work, games, entertainment, and social media.

Exposure to bright light has increased exponentially especially in the western countries of the world due to unintentional exposure to illumination from electronic screens that emit light directly into the eyes. Millions of computers, tablets, televisions, and especially smartphones are bought worldwide each month, and the usage time of these devices is constantly increasing, including in the evening and at night shortly prior to sleep onset. Nine out of ten subjects (90%) reported using a digital media device within 1 h before sleep in the "2011 Sleep in America" survey (Gradisar et al. 2013). Several studies reported negative physiological outcomes related to digital media screen artificial light at night (ALAN) exposure. Short wavelength light (SWL) emitted from the screens of electronic devices can inhibit melatonin (MLT) secretion

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(Chang et al. 2015; Higuchi et al. 2005; Wood et al. 2013) and disturb thermoregulation (Green et al. 2017; Higuchi et al. 2005). It can also have negative impact on sleep physiology and sleepiness measures (Custers and Van den Bulck 2012; Figueiro et al. 2011; Green et al. 2017; Nathan and Zeitzer 2013; Wood et al. 2013), cognitive performance (Cajochen et al. 2011), and mood (Sroykham and Wongsawat 2013).

The relationship between exposure to SWL light emitted from digital screens and sperm quality has not been previously explored, and only a few studies have evaluated the relationship between sleep disorders and semen quality. Two recent studies assessing young men from the general population reported an inverse U-shaped association between self-reported sleep disturbances and semen quality (Chen et al. 2016; Jensen et al. 2013), indicating that sleep duration may play a role in the regulation of the male reproductive process.

The aim of this study is to assess the relationship between exposure to digital media device screens and measures of sleep and sperm quality. The major hypothesis is; explored herein is exposure to ALAN from digital media devices in the evening and night is negatively correlated/with sperm quality.

Methods

Participants

One hundred and thirty Men referred to the IVF unit in Assuta Medical Center, between September 2018 and August 2019, were recruited to this study and provided written informed consent to participate. As part of the routine standard of care, they were sent to semen evaluation in the andrology lab. Fourteen participants reported working night shifts and were excluded from the study. A total of 116 male adults aged between 21 and 59 (35.2 ± 7.2) were included in the study. 71% percent of participants were married, 19% single, 4% divorced, and 6% in a relationship. All participants were normally diurnally active Hebrew-speaking residents of the state of Israel. Participants completed the questionnaires in the presence of a research assistant. The study was approved by the Assuta Medical Center institutional ethical review board. The experimental protocol of the study confirms all ethical standards of biological rhythms research (Portaluppi et al. 2010).

Procedure

A single semen sample was collected from each participant after an abstinence period of 2–7 days. Semen samples were collected by masturbation into 120-ml sterile polystyrene wide-mouth cup in a room adjacent to the Andrology laboratory. Participants were instructed to capture the first part of the ejaculate in the process of sample collection and to avoid any collection of spilled semen. Samples were analyzed within 1 h of ejaculation. Semen analysis was performed according to World Health Organization criteria (WHO) in adherence to the Laboratory Manual for the Examination and Processing of Human Semen (2010).

The Semen analysis was viewed under a microscope (Olympus BX-41) at a magnification of 20x using a Makler counting chamber. The sperm morphology was viewed under a microscope (Olympus BX-41) at a magnification of 100x. Semen volume was measured by serological pipette, and sperm concentration was assessed using a Makler counting chamber. The Makler chamber was designed specifically for the determination of sperm concentration and motility in undiluted semen. It has a reported depth of 0.01 mm. The grid area in the center of the coverslip is 1 mm × 1 mm and is divided into 100 smaller squares, each of which is 0.1 mm × 0.1 mm. A 10 µL volume of semen or sperm suspension was loaded into the chamber, and, in order to ensure consistent counting, a minimum of 100 sperms were counted in each chamber.

Measured variables

Sperm variables

The following variables were taken into consideration: complete liquification, color, viscosity, volume (mL), sperm concentration (million/mL), and motility (%). Sperm motility was graded into total (progressive + non-progressive motility) and progressive motility. Total sperm count (volume × sperm concentration) was also calculated. Reference values from the WHO semen analysis manual were used to assess sperm concentration and motility as described, in accordance with the most recent guidelines from the World Health Organization (2010). Sperm morphology was evaluated using Kruger's strict criteria and ESHRE monographs. An external quality control

program, created by the College of American Pathologists (CAP), was established in the laboratory in order to control for random and systematic errors and interlaboratory differences.

Demographic, health status, and sleep variables: Self-reporting questionnaires were utilized to obtain demographic, general health, sleep patterning and difficulties, and prevalence of and exposure patterns to digital media screen information. This questionnaire was validated in Green et al. (2018).

(1) **Demographic**: age, gender, family status, education, and employment status, including shift work.
(2) **General health**: chronic diseases, prescription and non-prescription medications, height, and weight. The morning level of Concentration and attention of participants was evaluated by a 9-point Likert scale in response to the statement "Please rate your level of concentration in the morning." All of the numbers have valid point values, but only the odd numbers have descriptions: 1 = "extremely poor concentration"; 3 = "not able to concentrate"; 5 = "neutral, neither unable to concentrate or concentrate"; 7 = "able to concentrate"; and 9 = "extremely good concentration." (Green et al. 2018).
(3) **Sleep**: The Pittsburgh Sleep Quality Index (PSQI) was applied to evaluate sleep timing, sleep onset latency, sleep duration, sleep difficulties, and sleep quality. The PSQI is a self-reporting questionnaire that assesses sleep quality over a 1-month time interval. The PSQI consists of 19 individual items, comprising seven components that produce a single global score. The PSQI is a standardized sleep questionnaire for clinicians and researchers to use with ease and for multiple populations, and is used in many research and clinical settings to diagnose (Buysse et al. 1989). We used the Karolinska Sleepiness Scale (KSS) to assess sleepiness and tiredness. It is a 9-point Likert scale, in which all of the numbers have valid point values, but only the odd numbers have descriptions: 1 = "extremely alert"; 3 = "alert"; 5 = "neither alert nor sleepy"; 7 = "sleepy"; and 9 = "extremely sleepy" (Åkerstedt and Gillberg 1990).
(4) **Exposure to screens of digital media devices**: We asked the participants about the presence and usage habits of digital media devices equipped with a screen (television, computer, tablet, smartphone) and whether they had a television, computer, tablet, and/or smartphone in their homes and bedrooms. They reported the duration of their exposure to digital screens of any digital media device at different times of day, from the morning until after bedtime, both during weekdays and on weekends. Participants were asked to report their exposure time to screens of digital devices, giving the mean time in minutes for each time of day, to enable calculation of the exposure summation (sum) for the different periods of the day: early morning, during work or study time, evening time until bedtime, and after bedtime. Digital media usage for all devices (televisions, computers, smartphones, and tablets) was derived through the summation (sum in minutes) of each of the four afore-defined periods of the day. We also derived an additional "sum-total," a summation of the "sum-evening" and "sum-night" variables.

Statistical analysis

The paired *t*-test was applied to assess differences in usage time of digital media devices between weekdays and weekends. Pearson/Spearman correlations were calculated between the variables in the study in order to identify significant variables to test for confounders. We calculated partial correlation between the variables in the study using the confounder-variables (days of abstinence, age, marital status, and BMI), and we reported only those correlation coefficients that were significant under the partial correlation test. We performed all statistical analyses using SPSS, version 25 (SPSS Inc., Chicago, IL, USA).

Results

Exposure to screens of digital devices and usage patterns

Fifty-eight participants (51%) reported that they had televisions in their bedrooms, and 28 (24%)

had computers in their bedrooms. Almost the entire sample, 115 participants (99%), had smartphones, and 23 (20%) owned tablets. Television was the digital media device most used in the evening, followed by smartphones, computers, and tablets (Table 1). By contrast, after bedtime, smartphones were the most used, followed by television, computers, and tablets. This pattern of digital devices uses in the evening and after bedtime was similar between weekdays and weekends. We did not detect significant differences in usage time of digital devices between weekdays and weekends.

Sleep

Based on information obtained the PSQI, mean bedtime was 00:07 h (±11.0 min), mean time taken to fall asleep was 20.5 min (±16.6 min), mean wakeup hour was 08:03 h (±11.4 min), and mean sleep duration was 6.5 h (±61.1 min). Table 2 presents the percentage frequency distribution of the sleep complaints and sleep evaluation based on data of the PSQI questionnaire. The most frequent complaints were "Wake up in the middle of the night or early morning," "Cannot get to sleep within 30 minutes," and "others." The majority of the participants reported that they sleep well (86.1%), while the rest complained that they sleep badly (13.9%).

Semen

Table 3 contains the mean (std) and CI-95% of the semen analysis variables: volume, pH, total motility percentage, progressive percentage, non-progressive percentage, immotile percentage, total motile sperm number, total sperm number, and sperm concentration.

Associations between exposure time to screens of digital media devices and sperm quality variables

Total motility percentage was found to be negatively correlated with smartphone use in the evening and after bedtime, tablet use after bedtime, the sum of

Table 1. The mean exposure time in minutes and (±SD) to screens of digital media devices (televisions, smartphones, computers, and tablets) on weekdays and weekends in the evening and after bedtime, as well as sum-evening and sum-after bedtime.

	Weekdays		Weekend	
	Evening	After Bedtime	Evening	After Bedtime
Television	76 (± 61.2)	13 (± 27.8)	77 (± 68.3)	12 (± 24.0)
Smartphone	67 (± 54.2)	22 (± 31.1)	58 (± 58.2)	15 (± 22.4)
Computer	46 (± 70.0)	8 (± 30.2)	35 (± 62.8)	8 (± 25.6)
Tablet	3 (± 12.5)	0.6 (± 3.1)	3 (± 14.4)	0.3 (± 2.4)
Sum	192 (± 123.6)	44 (± 60.5)	173 (± 129.7)	35 (± 46.3)

Table 2. Frequency distribution (in percentages) of each complaint in the PSQI questionnaire.

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
Cannot get to sleep within 30 min	54.4	18.4	15.8	11.4
Wake up in the middle of the night or early morning	44.9	18.1	19.0	18.0
Have to get up to use the bathroom	57.0	14.9	13.2	14.9
Cannot breathe comfortably	76.3	7.9	6.1	9.6
Cough or snore loudly	73.7	7.0	7.9	11.4
Feel too cool	84.8	8.9	1.8	4.5
Feel too hot	72.6	12.4	12.4	2.7
Had bad dream	73.2	17.9	7.1	1.8
Have pain	78.4	9.9	5.4	6.3
Other reasons	62.5	7.5	10.6	19.4
During the past month, how often have you taken medicine to help your sleep?	95.5	0	3.6	0.9
During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	75.9	18.8	4.5	0.9
During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	49.1	26.8	19.6	4.5
	Very good	Fairly good	Fairly bad	Very bad
During the past month, how would you rate your sleep quality overall?	32.2	53.9	11.3	2.6

Table 3. The mean (±SD) and confidence-interval 95% of semen samples.

	Mean (±SD)	CI-95%
Volume (ml)	3.3 (1.4)	3.0–3.6
pH	8.4 (0.4)	8.3–8.5
Total motility (%)	51.9 (16.1)	49.1–55.2
Progressive (%)	34.3 (14.1)	31.9–37.2
Non-progressive (%)	18.1 (10.2)	15.9–19.3
Immotile (%)	46.7 (16.0)	43.6–49.8
Sperm concentration	38.9 (28.7)	34.0–45.0
Total sperm number	122.7 (113.1)	103.1–14.7
Total motile sperm number	71.6 (76.7)	57.5–8.9

exposure to screens after bedtime, and the sum of use of portable screens (tablet and smartphone) in the evening and after bedtime. The *percentage of progressive sperm* was found to be negatively correlated with smartphone use in the evening and after bedtime, tablet use after bedtime, and the sum of use of portable screens (tablet and smartphone) in the evening and after bedtime. The *immotile percentage of sperm* correlated positively with smartphone use in the evening and after bedtime, the sum of use of portable screens (tablet and smartphone) in the evening and after bedtime, and the sum of exposure to screens after bedtime. The *total motile sperm number* correlated negatively with smartphone use in the evening, tablet use after bedtime, and the sum of use of portable screens (tablet and smartphone) in the evening and after bedtime. *Sperm concentration* was also found to be negatively correlated with smartphone use in the evening, tablet use after bedtime, and television use in the evening. All correlation coefficients are presented in Table 4. Significant correlations are marked * = $p < .05$.

Associations between sleep duration, subjective sleepiness, cognitive concentration ability, and sperm quality variables

Figures 1 and 2 present the frequency distributions of subjective sleepiness evaluations and levels of concentration in the morning for the sample. Two-thirds (65%) of the participants reported some level of concentration disability in the morning, while one-third (32%) reported subjective sleepiness. Correlation analysis (Table 4) revealed a significant positive correlation between *sleep duration* and percentage of total motility and percentage of progressive sperm, and a negative correlation with pH. We observed significant negative correlation between *subjective sleepiness* measured by the KSS and percentage of total motility, percentage of progressive sperm, total sperm number, total motile sperm number, and age, as well as positive correlation with pH and percentage of immotile. In addition, we found that the *concentration level* is negatively correlated with the percentage of total motility and percentage of progressive sperm, and positively correlated with pH and immotile percentage. We did not observe significant correlation between BMI and any of the sperm variables.

Associations between exposure time to screens of digital media devices and sleep complaints, sleep quality, and subjective sleepiness

Correlation analysis revealed significant positive correlation between the complaint "Wake up in the middle of the night" in the PSQI questionnaire and use of

Table 4. Coefficient correlation between sperm parameters quality and exposure to digital media devices in the evening and after bedtime (night).

	Volume (ml)	ph	Total motility (%)	Progressive (%)	Non progressive (%)	Immotile (%)	Sperm concentration	Total motile sperm number
Smartphone evening	0.025	0.036	**−0.392***	**−0.322***	−0.003	**0.382***	**−0.169***	**−0.173***
Smartphone night	0.005	0.026	**−0.369***	**−0.299***	−0.064	**0.344***	−0.137	0.074
Tablet evening	0.046	0.031	−0.132	0.159	−0.100	0.036	0.070	−0.017
Tablet night	−0.013	−0.139	**−0.167***	**−0.312***	−0.102	−0.138	**−0.204***	**−0.168***
Tv evening	−0.022	0.021	0.012	−0.265	−0.097	0.226	**−0.199***	−0.147
Tv night	−0.039	0.114	−0.200	−0.027	−0.157	0.016	−0.137	−0.001
Computer evening	0.072	0.056	−0.131	0.008	−0.054	0.015	0.003	0.101
Computer night	0.047	0.042	−0.095	−0.116	−0.176	0.112	0.043	0.025
Sum evening	0.020	0.085	**−0.161***	−0.027	0.065	**0.200***	0.053	0.060
Sum night	0.03	0.135	−0.100	0.04	0.112	−0.128	−0.017	0.046
Sum portables evening-night	0.029	0.039	**−0.346***	**−0.345***	−0.137	**0.421***	0.037	**−0.184***
Sleep duration	0.016	**−0.349***	**0.249***	**0.233***	0.059	−0.100	0.050	0.119
Sleepiness (KSS)	−0.030	**0.254***	**−0.251***	**−0.264***	−0.037	**0.238***	−.137	**−0.173***
Concentration level	−0.137	**0.254***	**−0.250***	**−0.264***	−0.018	**0.230***	0.038	0.048

*$p < .05$.

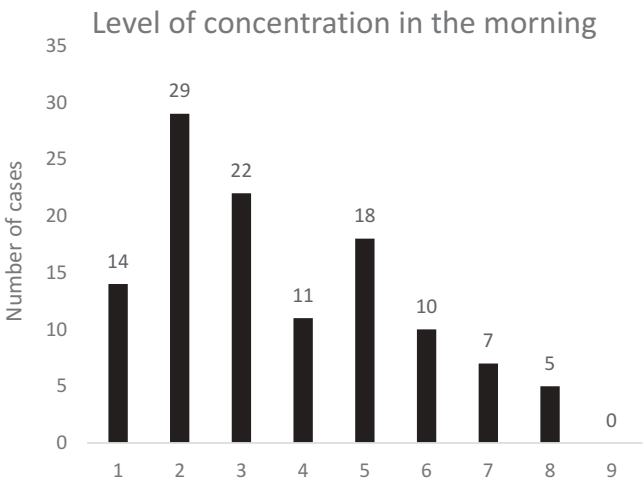

Figure 1. Frequency distribution of level of concentration in the morning (n = 116).

Frequency distribution of level of concentration in the morning. 1 – "extremely poor concentration," 3 – "not able to concentrate," 5 – "neutral, neither unable to concentrate or concentrate," 7 – "able to concentrate," and 9 – "extremely good concentration."

television in the evening, as well as use of smartphones in the evening and after bedtime. We observed positive correlation between the sleep complaint "Have bad dreams" and the use of computers in the evening and after bedtime; this complaint was also positively correlated with the sum of all exposure to screens in the evening and after bedtime. In addition, we observed positive correlation between the answer to the question "how often have you taken medicine?" and the sum exposure to screens in the evening and at night. We did not detect significant correlations between any other sleep complaint in the PSQI questionnaire and exposure to screens of any other digital media device. The *sleep quality* rating was negatively associated with smartphone usage in the evening and computers at night, meaning that extensive use of smartphones and computers in the evening and after bedtime is correlated with bad sleep quality reports. We noted significant positive correlation between *subjective sleepiness* by means of the KSS and the following variables: computer usage in the evening, computer usage after bedtime, smartphone use in the evening, and tablet use after bedtime. All correlation coefficients are presented in Table 5. A significant correlation is marked * = $p < .05$.

Discussion

In line with the major tested hypothesis, smartphone and tablet use in the evening and after bedtime was correlated with decline in sperm quality (motility and sperm progressive motility), and were positively correlated with the percentage of immotile sperm. Furthermore, smartphone use in the evening, tablet use after bedtime, and television use in the evening were all correlated with the decline of sperm concentration. To the best of our knowledge, this is the first study to report these types of correlations between sperm quality and exposure time to SWL emitted from digital

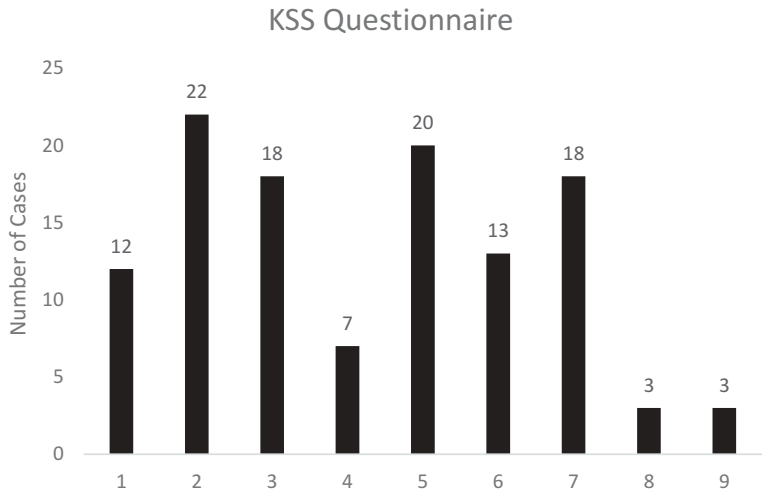

Figure 2. Frequency distribution of subjective sleepiness in the KSS questionnaire (n = 116).

Frequency distribution of subjective sleepiness in the KSS questionnaire. 1 – "extremely alert," 3 – "alert," 5 – "neither alert nor sleepy," 7 – "sleepy," and 9 – "extremely sleepy."

Table 5. Coefficient correlation between complaints in the PSQI questionnaire, subjective sleepiness, and exposure to digital media devices in the evening and after bedtime (night).

	Wake up in the middle of the night	Have bad dreams	How often have you taken medicine?	Sleep quality	Sleepiness (KSS)
Smartphone, evening	**0.210***	0.087	0.113	**−0.168***	**0.199***
Smartphone, night	**0.204***	0.111	0.098	**−0.176***	0.115
Tablet, evening	0.113	0.054	0.059	0.100	0.118
Tablet, night	0.072	0.115	**0.206***	−0.020	**0.191***
Television, evening	**0.197***	0.032	−0.023	0.011	0.088
Television, night	0.062	−0.09	0.008	−0.009	0.04
Computer, evening	0.058	**0.161***	0.114	0.115	**0.166***
Computer, night	0.142	**0.194***	0.099	0.038	**0.157***
Sum, evening	0.111	**0.231***	**0.196***	0.119	0.099
Sum, night	0.092	0.117	0.11	0.058	0.101
Sum, portables evening-night	0.049	0.088	0.074	0.117	0.065

*p < .05.

media, especially smartphones and tablets, in the evening and after bedtime.

Recent comprehensive systematic review and meta-regression analysis of 185 studies demonstrated significant sperm concentration decline over the past several decades. Declines were shown to be significant in studies from Western and industrial countries, while studies from non-Western countries showed no such significance (Levine et al. 2017). Various factors, such as elevated body mass index (BMI), endocrine disruption, stress, nutrition, infections, elevated ambient temperature, and air pollution have been cited as explanations for the observed decline in sperm concentration (Adams et al. 2014; Chiu et al. 2015; Jurewicz et al. 2009; Krausz 2011; Lafuente et al. 2016; Macdonald et al. 2013; Nordkap et al. 2012, 2016; Sharma et al. 2013). Our results suggest this decline in sperm quality is also associated with exposure to SWL light emitted from digital media screens in the evening and at night.

Over the past two decades, the use of electronic media devices has significantly increased in Western societies. Specifically, the use of light-emitting devices in close to sleep time has become extremely popular, and the usage time has also increased rapidly (Adam et al. 2007; Brunborg et al. 2011; Cain and Gradisar 2010; Mesquita and Reimao 2007; Shochat et al. 2010). Users are increasingly exposed to ongoing SWL light emitted from digital screens in the evening and at night, while SWL lighting is a major environmental time cue affecting the human biological clock. Several studies reported negative physiological outcomes related to the "Circadian disruption" caused by exposure to digital media screens at night. It is well known that light emitted from electronic screen devices suppresses melatonin secretion (Chang et al. 2015; Green et al. 2017; Grønli et al. 2016; Higuchi et al. 2005). Exposure to SWL light emitted from digital screens is associated with the decline of sleep quality and quantity, and disturbance of biological rhythms. Such effects rely on the characteristics of the light source, specifically the brightness of the light and the duration of the exposure to ALAN. Even light that is not particularly bright can have a robust impact if the light is characterized by SWL and the exposure occurs in the evening or before bedtime.

Melatonin is a neurohormone secreted by the pineal gland whose secretion is regulated both by dark-light and seasonal cycles. Circadian dysfunction caused by chronic ALAN exposure has been shown to affect cardiovascular, metabolic, and immune system functions, and pose a risk for the development of cancer (Haim and Portnov 2013; Stevens et al. 2014). Melatonin's "reproductive" role in seasonal breeding animals is well-established (Hazlerigg and Simonneaux 2014; Malpaux et al. 1996). However, a growing body of evidence suggests melatonin might have a significant effect on human male reproduction as well.

Spermatogenesis is regulated by a complex network of signaling processes involving the hypothalamic-pituitary-testicular axis. Both Leydig and Sertoli cells (the main testicular somatic cells) are targets of LH and FSH produced by the pituitary gland. Several studies suggest melatonin also plays

an important role in regulating spermatogenesis. Melatonin receptors have been detected in the human hypothalamus and pituitary, suggesting melatonin may regulate the production of gonadotropin-releasing hormone (GnRH), FSH, and LH (Weaver et al. 1993). Melatonin may likewise regulate testicular development directly by binding to specific receptors expressed in the testis (Izzo et al. 2010; Rossi et al. 2014). Melatonin is considered a powerful antioxidant and has been shown to be more effective than Vitamin E in removing free radicals (Pieri et al. 1994, 1995). In a rat model with an artificially induced varicocele, melatonin treatment reduced the severity of the damage sustained by the epithelium and seminiferous tubules while also increasing antioxidant enzyme activity and reducing the level of nitric oxide (NO), which might impair sperm function (Semercioz et al. 2003).

In men, abnormal levels of melatonin in the semen were shown to be associated with infertility (Awad et al. 2006). In vitro studies demonstrated the use of a melatonin-containing incubation medium increased the percentage of motile, progressive, and rapid sperm cells, increased mitochondrial activity, and decreased endogenous NO levels relative to those observed in sperm cultivated in melatonin-free media (Du Plessis et al. 2010). These effects were attributed to melatonin's antioxidant properties.

The results of the current study support a negative correlation between evening and post-bedtime exposure to digital media screens and various parameters of semen quality, specifically sperm concentration, and motility. Based on melatonin's suggested involvement in spermatogenesis, and because the light emitted from electronic screen devices may suppress melatonin secretion (Higuchi et al. 2005; Wood et al. 2013), such disruption may compromise sperm concentration and quality. Given its antioxidant effect, alterations in melatonin secretion may also cause an intra-testicular oxidative imbalance, thus increasing susceptibility to sperm DNA damage (Wang et al. 2018).

The current study also assessed the relationships between sleep (duration-pattern-quality) and sperm quality. We demonstrated a positive correlation between sleep duration and sperm total and progressive motility. A significant negative correlation was observed between subjective sleepiness and total and progressive motility, as well as total motile sperm number. Recently, two studies have suggested the association between sleep quality and/or duration and male reproductive health. A cross-sectional study of 953 young Danish men from the general population detected an inverse U-shaped association between self-reported sleep disturbances and sperm concentration, total sperm count, sperm morphology, and testes size. Men in the highest category of sleep disturbances had an approximately 25% lower total sperm count than men with less disturbed sleep. Men who reported no sleep disturbances also had a trend toward lower semen quality (Jensen et al. 2013). Chen et al. (2016) report a similar U-shaped association between sleep duration and sperm quality in a cohort of 796 Chinese college students. In each of the studies, either restricted or excessive sleep was associated with decline in sperm quality in a dose-response manner.

There are several limitations to our study. The study cohort was rather small. Moreover, the effects of other sources of artificial light at night besides media devices, e.g. room lighting, were not assessed. Additionally, we did sample melatonin levels of the subjects to confirm suppressed levels, but rather we accepted the findings suggesting exposure to SWL light emitted from digital screens results in such and, therefore, is associated with the observed decline in sperm quality. Therefore, future studies should measure the levels of melatonin in order to evaluate the effect of melatonin secretion on sperm quality. Additionally, we have no way to differentiate between the effects of the suppression of melatonin secretion caused by SWL emitted from digital media devices and the effects of sleep deprivation/sleep quality on sperm quality. Future studies should be designed to respond to this query, in order to evaluate whether the decline in sperm quality is linked to sleep deprivation resulting from overexposure to SWL light or whether it is caused by the suppression of melatonin secretions caused by SWL (with no connection to sleep). Further research aiming to establish this proposed causative link may lead to the development of relevant therapeutic interventions. Furthermore, our data on the duration and timing of exposure to SWL from media devices are based on self-reports. The characteristics of the light emitted from these devices could not be measured due to the nature of this study.

Finally, due to the almost universal use of light-emitting devices in everyday life today, the study was unable to incorporate a control group that was devoid of no exposure to them.

The results of our study support the hypothesis that exposure to SWL emitted from screens of media devices is associated with a decline in semen quality. Given the role of melatonin in spermatogenesis, we propose that disruption of melatonin secretion and production by emitted light from screens of media devices at nighttime may be a major "linkage" to decline in sperm concentration and quality.

Compliance with ethical standards

The study was approved by the institutional ethical review board at Assuta Medical Center.

Conflict of interest

Dr. Amit Green, Dr. Shlomi Barak, Mr. Lior Shine, Dr. Arik Kahane, and Prof. Yaron Dagan declare that they have no conflict of interest.

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