Turkish Archives of Pediatrics

ORIGINAL ARTICLE
DOI: 10.5152/TurkArchPediatr.2020.20138

The possible effects of maternal electronic media device usage during pregnancy on children's sleep patterns

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What is already known on this topic?

- *Electromagnetic field exposure in the prenatal period can affect fetal anatomy, viability, and neurological development of the fetus because of the rapid development of organ systems.*
- *Electronic media device usage in children and adolescents is associated with sleep disturbances, low sleep quality, and short sleep duration.*

What this study adds on this topic?

- *Maternal electromagnetic field exposure (e.g., base station, television, computer, mobile phone, wi-fi, microwave oven) during pregnancy was associated with sleep disturbances in children aged between 1 month and 5 years.*
- *The presence of electronic media devices in children's sleeping environments at night (even if not using it) may lead to sleep disorders.*

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Received: 12.06.2020
Accepted: 23.10.2020
Available Online Date: 06.01.2021
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ABSTRACT

Objective: In recent years, there has been increasing scientific evidence about potential health risks caused by electromagnetic fields because of electronic media devices. Therefore, this study aimed to examine the possible association between electronic media device usage during pregnancy and sleep patterns in children and the possible role of electronic media device presence in the sleeping environment on children's sleep disturbances.

Material and Methods: The study was carried out with 400 healthy children aged between 1 month and 5 years whose parents agreed to complete the questionnaire form. The questionnaire form consisted of questions about the history of prenatal and postnatal electromagnetic field exposure caused by electronic media devices and the presence of sleep disturbances in children. Data were analyzed with SPSS for Windows program. P-values <0.05 were considered statistically significant.

Results: Sleep problems were more prevalent in children whose mothers lived near a base station during pregnancy ($p<0.05$). Sleep disorders were more frequent and sleep duration was shorter in children whose mothers used electronic devices (television, computer, mobile phone, wi-fi, microwave oven) during pregnancy ($p<0.05$). Sleep problems were also more common in children with electronic media devices in the sleeping environment during the night ($p<0.05$). Sleep disturbances were not associated with maternal consumption of tobacco or alcohol or history of disease during pregnancy ($p>0.05$).

Conclusion: Our results highlight that exposure to electromagnetic fields caused by electronic media devices during the prenatal or postnatal period could be associated with sleep patterns in childhood. Considering the widespread use of electronic media devices, it may be an important public health problem given the long-term consequences of sleep disorders in childhood.

Keywords: Children, electronic media device, pregnancy, sleep pattern

Introduction

In recent years, there has been increasing scientific evidence about potential health risks caused by electromagnetic fields (EMFs), which are a special area of energy that surrounds electrical devices in everyday life (1). Typical EMF sources are power lines, base stations, radars, microwave ovens, and electronic media devices (EMDs) (wi-fi communication services, radio/television (TV), computers, cordless phones, mobile phones, Bluetooth) (1, 2). The most widely accepted mechanism of EMFs is the thermal effect that can lead to acute health problems (tissue necrosis, cardiac stress) by causing increased tissue temperatures because of the absorption of electromagnetic energy. However, the biological and health-related effects of EMFs known as non-thermal biological effects can also be generated without tissue

Cite this article as: Çöl N, Kömürcü Karuserci Ö, Demirel C. The possible effects of maternal electronic media device usage during pregnancy on children's sleep patterns. Turk Arch Pediatr 06 January 2020. 10.5152/TurkArchPediatr.2020.20138. [Epub Ahead of Print]

heating (1-3). Health risks associated with long-term non-thermal biological effects of EMFs are oncologic, neurodegenerative, or cardiovascular diseases; genotoxic effects; allergic and inflammatory responses; and impairment of the immune system (1, 2).

Sleep disorders are one of the most common health complaints and can be affected by exposure to EMFs originating from EMDs (1, 2). Sleep plays an important role in the physical and psychological development of children. Sleep disturbances affect human health in the short and long term and cause diseases such as obesity, metabolic syndrome, and diabetes mellitus. It is also associated with anxiety, depression, fatigue, dysesthesia, concentration, attention, and memory dysfunction, irritability, low school success, and behavioral problems (3-5). Sleep pattern is associated with the neurohormone melatonin (MT) predominantly secreted from the pineal gland that regulates the circadian rhythm and sleep cycles (6). Neuroendocrine changes and decreased MT synthesis have been reported with exposure to EMFs (2, 3). Furthermore, non-thermal effects of EMFs have been shown to affect brain physiology (7).

Children and fetuses are more sensitive to EMF exposure because of the rapid development of organ systems (8, 9). Prenatal exposure to EMF may cause some adverse effects on the fetus through increased oxidative stress or uterine damage, may affect fetal anatomy and viability, and may also lead to behavioral problems in children (8, 9). Exposure to EMF in the prenatal period or early childhood may affect the neurological development of the newborn (10-12).

Health problems regarding EMF exposure have been researched, but exact underlying mechanisms are not clearly defined (8). The World Health Organization and the National Academy of Sciences high-priority support prenatal and postnatal EMF exposure studies that investigate possible health effects in children and in the fetus (13, 14).

The short-term effects of prenatal exposure to EMF caused by EMDs are being investigated, but studies on long-term outcomes are limited. Moreover, according to present knowledge, data are lacking on the effect that maternal EMD usage during pregnancy might have on children's sleep patterns. Therefore, the aim of this study was to examine the possible association between maternal EMD usage during pregnancy and sleep problems in children aged between 1 month and 5 years in southeastern Turkey. It also aimed to investigate the possible role of EMD presence in the sleeping environment on children's sleep disturbances.

Material and Methods

The study was carried out with 400 healthy children (203 female, 197 male) admitted to Gaziantep University Faculty of Medicine pediatric outpatient clinics. Children were included in the study if their parents agreed to complete the questionnaire and give informed consent. The study was conducted in accordance with the Helsinki Declaration and approved by the local Ethical Committee of Gaziantep University Faculty of Medicine (IRB No: 07/2011-11). The sample size was estimated using a power calculation based on previous study (15). The minimum sample size was determined as 169 at the 80% power level within α error of 5% with MedCalc (version 11.5.1) (15, 16). Because the number of cases we obtained within the specified date range reached 400, we included all of the cases in the study to make the manuscript more valuable.

The questionnaire form was prepared by researchers based on the review of the previous literature on this topic (8, 10, 12, 15-18). The comprehensibility of the questions was reviewed by a pilot study. After participants were informed regarding the aim of the study, each parent completed the questionnaire form.

The questionnaire form consisted of four parts. The first part included questions on sociodemographic features of families. The second part consisted of questions about the history of pregnancy (consumption of tobacco and/or alcohol; history of disease and/or drug usage; existence of a base station near the residential area; duration of TV, computer, wi-fi, mobile phone, and microwave oven usage). Additionally gestational age, birthweight, height, head circumference at birth, and the presence of chronic disease in the children was questioned. The third part included questions about the presence of EMDs in the children's sleeping environment and duration of their open time. In addition, the use of EMDs by parents during the day near the children was questioned. The final part included questions about the presence of sleep disorders (e.g., bedtime resistance, nighttime waking, waking up crying, difficulties in falling asleep, and mean sleep duration at nighttime and daytime) in children. The regular fulfillment of bedtime ceremonies was also questioned.

Statistical analysis

All data were analyzed by using the computer software IBM Statistical Package for the Social Sciences for Windows version 22.0; (IBM SPSS Corp.; Armonk, NY, USA). The numeric values were given as mean±standard deviation or percentage (%). The chi-square test was used to determine the relationship between categorical variables. Mann Whitney U test, independent samples t-test, or Bonferroni-corrected analysis of variance analysis were used when appropriate to compare differences between groups for continuous variables. Logistic regression analysis was used to demonstrate the factors that affect sleep disturbances. The variables that were influencing sleep problems in children were selected from our study. A logistic regression model estimated the odds ratio (OR) and 95% confidence intervals (95% CIs) for the development of sleep disorders, and adjustment included covariates controlling for potential confounders. Statistical significance was determined as $p<0.05$.

Results

The study was carried out with 400 children aged between 1 month and 5 years (2.14±1.58 years). The gestational age ranged between 27 and 41 weeks (37.81±2.47 weeks), and the mean birthweight, height, and head circumference were 3.039±0.681 g (0.900–5.000 g), 49.09±3.18 cm (32.0–55.0 cm), and 35.93±2.77 cm (28.0–37.0 cm), respectively. The preterm birth rate (<37 week) was 14.2% (55/387), whereas the low birthweight rate (<2.500 g) was 22.0% (83/377).

The mean sleep duration at night was 9.27±1.54 hours (5–13 hours). Overall, 81.8% (320/391) of children slept during the day at least once a week. The mean daytime sleep duration was

Table 1. Associations between maternal exposure to electromagnetic devices during pregnancy (e.g., base station, television, mobile phone, computer, wi-fi, microwave oven) and sleep disturbances in children

Existence of a base station near the residential area	N/Total[a] (%) No	N/Total[a] (%) Yes	OR	95% CI	p
Difficulty in falling asleep	69/196 (35.2)	64/112 (57.1)	2.454	1.526–3.948	<0.001
Bedtime resistance	77/193 (39.3)	67/112 (60.4)	2.353	1.462–3.789	<0.001
Night waking	106/196 (54.1)	76/112 (67.9)	1.792	1.103–2.914	0.018
Waking up crying	98/198 (49.5)	77/112 (68.8)	2.245	1.379–3.654	0.001
Television viewing	**No**	**Yes (≥ 1 hour /day)**			
Night waking	11/29 (37.9)	223/359 (62.1)	2.683	1.230–5.852	0.010
Waking up crying	11/29 (37.9)	215/361 (59.6)	2.410	1.11–5.251	0.023
Mobile phone usage	**No**	**Yes (≥30 minute/day)**			
Difficulty in falling asleep	9/34 (26.5)	167/352 (47.4)	2.508	1.138–5.526	0.019
Bedtime resistance	10/34 (29.4)	175/352 (49.7)	2.373	1.102–5.108	0.024
Night waking	9/34 (26.5)	224/353 (63.5)	4.823	2.185–10.650	<0.001
Computer usage	**No**	**Yes (≥1 hour/day)**			
Difficulty in falling asleep	75/197 (38.1)	101/187 (54.0)	1.910	1.272–2.869	0.002
Bedtime resistance	79/197 (40.1)	106/187 (56.7)	1.955	1.302–2.934	0.001
Night waking	103/197 (52.3)	129/188 (68.6)	2.000	1.316–3.025	0.001
Waking up crying	95/199 (47.7)	129/188 (68.6)	2.394	1.581–3.625	<0.001
Wi-fi usage	**No**	**Yes (≥1 hour/day)**			
Difficulty in falling asleep	63/188 (33.5%)	114/198 (57.6)	2.693	1.780–4.072	<0.001
Bedtime resistance	74/186 (39.8)	112/200 (56.0)	1.926	1.285–2.889	0.001
Night waking	100/187 (53.5)	134/200 (67.0)	1.766	1.170–2.666	0.007
Waking up crying	89/188 (47.3)	137/201 (68.2)	2.381	1.577–3.596	<0.001
Microwave oven use	**No**	**Yes (≥1 times/day)**			
Night waking	149/266 (56.0)	83/119 (69.7)	1.810	1.143–2.868	0.011
Waking up crying	141/268 (52.6)	83/119 (69.7)	2.080	1.313–3.286	0.002
Multiple mobile phone usage (≥2)	**No**	**Yes**			
Difficulty in falling asleep	151/348 (43.4)	25/37 (67.6)	2.720	1.323–5.585	0.005
Night waking	204/350 (58.3)	29/36 (80.6)	2.965	1.264–6.953	0.009
Wake up crying	196/351 (55.8)	29/37 (78.4)	2.800	1.275–6.448	0.008

CI, confidence interval; OR, odds ratio. [a]Totals are different from each other because they are taken according to the number of participants who respond to each question.

Table 2. Evaluation of the relationship between the presence of an electronic media device in the children's sleeping environment and sleep disturbances

Wi-fi is open in the children's sleeping room	N/Total[a] (%) No	N/Total[a] (%) Yes	OR	95% CI	p
Difficulty in falling asleep	150/346 (43.4)	27/42 (64.3)	2.500	1.210–4.580	0.010
Bedtime resistance	155/343 (45.2)	29/43 (67.4)	2.512	1.283–4.922	0.006
Waking up crying	192/346 (55.5)	32/43 (74.4)	2.333	1.139–4.780	0.018
Mobile phone is open in the children's sleeping room	**No**	**Yes**			
Night waking	154/275 (56.0)	80/113 (70.8)	1.905	1.190–3.048	0.007
Waking up crying	149/275 (54.2)	77/115 (67.0)	1.714	1.090–2.701	0.020

CI, confidence interval; OR, odds ratio. [a]Totals are different from each other because they are taken according to the number of participants who respond to each question.

2.35±1.19 hours (1–8 hours). A total of 45.4% (178/392) of children experienced difficulty in falling asleep at least once a week, 47.4% (186/392) demonstrated bedtime resistance at least one night per week, and 60.1% (236/393) experienced a night waking problem at least once a week. Overall, 57.5% (227/395) of children woke up crying at least one night per week.

A total of 36.0% (112/312) of mothers lived near a base station during pregnancy. Other maternal EMF exposure from EMDs during pregnancy included TV, mobile phone, computer, wi-fi, and microwave oven (data not shown). Overall, 48% (192/400) of children were sleeping in a room where at least one of the EMDs was open (data not shown). Sleep disturbances were more prevalent in children whose mothers lived near a base station during pregnancy ($p<0.05$) (Table 1). Similarly, sleep problems were more frequent in children whose mothers used electronic devices during pregnancy (TV, computer, mobile phone, wi-fi, microwave oven) ($p<0.05$) (Table 1).

Table 3. The most effective factors to influence the development of sleep problems in children determined by logistic regression analysis

	OR	95% CI	p
Difficulty in falling asleep			
Maternal wi-fi usage during pregnancy (≥1 hour /day)	4.948	2.003–12.223	0.001
Wi-fi is open in the children's sleeping room	5.704	1.162–27.998	0.032
Bedtime resistance			
Presence of base station near the living area during pregnancy	1.902	1.044–3.465	0.036
Wi-fi is open in the children's sleeping room	5.465	1.440–20.750	0.013
Night waking			
Maternal mobile phone usage during pregnancy (≥30 minutes/day)	7.480	1.732–32.308	0.007
Maternal multiple mobile phone usage during pregnancy (≥2)	3.691	1.117–12.125	0.032
Wi-fi is open in the children's sleeping room	2.633	1.117–6.207	0.027
Waking up crying			
Maternal mobile phone usage during pregnancy (≥30 minutes/day)	9.888	1.868–52.346	0.007
Wi-fi is open in the children's sleeping room	13.730	2.281–82.623	0.004

CI, confidence interval; OR, odds ratio

Duration of daytime sleep was shorter in the children of mothers who used a computer for at least one hour per day during pregnancy (no, 2.50±1.35 hours [1–8 hours]; yes, 2.22±1.08 hours [1–8 hours]; p=0.034; 95% CI = 0.021–0.545). Duration of daytime sleep was shorter in the children of mothers who used wi-fi for at least one hour a day during pregnancy (no, 2.55±1.35 hours [1–8 hours]; yes, 2.21±1.03 [1–8 hours]; p=0.011; 95% CI=0.077–0.602). The nocturnal sleep duration was shorter in the children of mothers who used a microwave oven at least once during pregnancy (no, 9.44±1.49 hours [6–13 hours]; yes, 8.89±1.60 hours [5–12 hours]; p=0.002; 95% CI=0.209–0.901).

Sleep disturbances were more prevalent in children with the presence of an EMD in the sleeping environment (p<0.05) (Table 2). There was no significant relationship between maternal consumption of tobacco or alcohol and history of disease or drug use during pregnancy and sleep disorders (p>0.05). Night waking was more common in children born at <37 weeks (<37 weeks, 59/83, 71.1%; ≥37 weeks, 165/288, 57.3%; OR=1.833; 95% CI=1.080–3.110; p=0.024). Similarly, waking up crying was more common in children born at <37 weeks (<37 weeks, 59/83, 71.1%; ≥37 weeks, 155/290, 53.4%; OR=2.141, 95% CI=1.263–3.269; p=0.004). Birthweight and gender were not associated with sleep problems (p>0.05). Sleep disturbances were not associated with the usage of EMDs near the children during daytime (p>0.05).

A logistic regression model estimated the OR for the development of sleep disorders, adjusted for potential confounders (age, gender, gestational age, birthweight, and bedtime ceremonies). The most effective factors that were determined to influence the development of sleep disturbances in children are summarized in Table 3. The presence of a base station near the residential area during pregnancy; maternal use of mobile phone, multiple mobile phones, or wi-fi during pregnancy; and the presence of wi-fi in the children's sleeping room were identified as the most effective factors on the development of sleep problems (Table 3).

Discussion

In recent years, increasing rates of exposure to EMF caused by EMDs has been linked to a variety of adverse health effects (1). The most common symptoms are sleep disturbances, headache, nervousness, fatigue, and concentration difficulties (1–5). The most often reported sources of EMFs were mobile phone base stations (74%), mobile phones (36%), cordless phones (29%), and power lines (27%) (19). The individuals attributed their symptoms to personal computers (51%) or mobile phones (47%), and reduction and/or prevention of exposure to EMF helped in recovery for 76% of them (20).

Exposure to EMF in the prenatal period may cause some adverse effects on the fetus through influencing the oxidative state and intracellular Ca^{2+} signaling patterns at the cellular level. The imbalance between plasma and vascular cell Ca^{2+} causes changes in placental vascular function through nitric oxide synthase and nitric oxide, leading to adverse birth consequences (21, 22). However, some studies did not find any relationship between prenatal EMF exposure and fetal growth or signs of teratology (23, 24). There are many studies related to EMF exposure in pregnancy, but the majority of these studies are related to the neurobiological development of the children (10, 12, 25). Divan et al. (12) did not find any relationship between maternal mobile phone use during pregnancy and neuromotor developmental delay in 6- to 18-month-old children. Choi et al. (25) reported that the psychomotor and mental development index of children was not associated with maternal mobile phone use during pregnancy. However, a large prospective cohort study from Denmark demonstrated that mothers who more often used mobile phones during pregnancy were more likely to have children with behavioral problems at age 7 (10). Our study demonstrated that maternal EMF exposure during pregnancy because of electronic devices was significantly associated with sleep disturbances in children at age 5 years. These results are unexpected and should be carefully reviewed. According to our present knowledge, this is the first study of its kind. We do not have any information about the mechanism to explain this relationship. Multiple biological mechanisms are proposed for effects in infants exposed to EMF in the prenatal period. First, in response to environmental factors like EMF exposure, the fetus makes physiological adaptations to prepare itself for the postnatal period, resulting in epigenetic modifications that may have possible long-term health implications (26, 27). Second, exposure to EMF may affect the

neurological development of the fetus by thermal effect, causing elevated tissue temperature (9). The EMF creates an energy transfer, which increases the permeability of the immature fetal blood-brain barrier that may render the fetal brain more sensitive to environmental factors (2, 9, 23, 25, 26). Intrauterine exposure to EMF interacts with DNA to stimulate protein synthesis, and high concentrations of these proteins cause DNA damage (1). Third, histological changes occur in the fetal nervous system with non-thermal effect of the EMF (3). The most affected organs are the hypothalamus and pituitary gland that show similar neuroendocrine activity patterns. Initially, neuroendocrine activity is increased and then decreased by "exhaustion of neuroendocrine activity" (3). Finally, exposure to EMF reduces the MT hormone levels secreted from the pineal gland that affects circadian rhythm, metabolism, and healthy fetal development (1, 11, 28). Various changes in maternal metabolism may affect sleep patterns in childhood by affecting fetal brain development (11). Development of a regular sleep-wakefulness cycle is an important indicator of brain maturation (27). It has been known that, as early as 32 gestational weeks, quiet sleep (non–rapid eye movement) and active sleep (rapid eye movement [REM]) periods regulated by MT are differentiated in the fetus (27). Because pineal gland maturation occurs in the postnatal period, the fetus is dependent on maternal MT (28). Based on this information and according to our own findings, we hypothesized that decreased maternal MT levels because of the exposure of EMF caused by EMDs during pregnancy may lead to fetal and neonatal REM deprivation. In the neonatal period, REM sleep–deprived animals showed increased anxiety and alcohol consumption, reduced sexual activity, and disturbed sleep in the adulthood period (27). Taken together, at present we can only speculate that maternal EMD usage during pregnancy may be related to later sleep disturbances in childhood. However, this is just a preliminary study; there is a need for experimental animal research to determine the possible long-term effects of exposure to EMF originating from EMDs in the prenatal period.

In recent decades, the use of EMDs by children and adolescents is increasingly growing. The American Academy of Pediatrics recommends limiting the time of EMD usage (screen time) to a maximum of 2 hours a day to avoid potentially harmful health effects (29). Most studies have examined the relationship between screen time and sleep disturbances (30-34). Overall, 72% of children and 89% of adolescents have at least one device in their sleeping environment, and most are used near bedtime (4). Using a video device near bedtime in childhood was associated with short sleep duration (30). Higher levels of screen time were also associated with higher levels of sleep disorders in youth (31). It has been shown by the subjective questionnaire method that mobile phone use in adolescents is associated with sleep disturbances, low sleep quality, and short sleep duration (32, 33). Two studies carried out with electroencephalography (EEG) recording did not show any significant association between human sleep and EMF exposure near bedtime (17, 35). The EMFs originating from mobile phones are absorbed by fluid of any biologic tissue and cause an increase in temperature with thermal effect. It has been shown that a temperature increase of <1.08 K is not harmful to any biological tissue. Thus, they conclude that new generation mobile phones do not increase the tissue temperature by 0.18 K (17, 35). Nevertheless, another sleep EEG analysis showed that REM sleep is more sensitive to EMF effects (7, 16). The observed sensitivity of REM sleep could be associated with innervation of cholinergic neurons, which plays an important role in the initiation and maintenance of REM sleep. This finding provides evidence about how the non-thermal effects of EMFs adversely affect brain physiology (7, 16). In a meta-analysis of 20 studies included involving 125,198 children, a strong relationship has been demonstrated between bedtime EMD use and inadequate sleep quantity, poor sleep quality, and excessive daytime sleepiness. A similar association has also been observed in children who had access to (but did not use) EMDs at night near bedtime (4). Consistent with the literature, we found that sleep disturbances were more common in children under 5 years old who were exposed to EMF caused by EMDs in the sleeping environment during nighttime. We also observed that exposure to EMDs in the daytime was not related to sleep problems. The EMF exposure caused by EMDs can negatively affect sleep through various pathways. The first mechanism is a negative effect that directly alters, delays, or interrupts sleep duration. The second one is related to media content, which can be psychologically stimulating. The last one is associated with screen light emitted from EMDs, which can impact circadian rhythm and sleep physiology by suppressing MT levels (4, 36). Our study demonstrated that being in the same environment with EMDs during nighttime (even when not using it) may lead to sleep disturbances. Clinicians should be aware that the presence of an EMD near children's environment may have a potentially harmful effect owing to EMF exposure.

There are some limitations of our study. The main limitations of this study are that only parental reports have been used, the dose of EMF exposure caused by EMDs has not been measured, and objective sleep assessment has not been made by polysomnography. However, making a dose measurement of EMF exposure originating from EMDs and making a polysomnographic evaluation is not realistic for a prospective cohort. Data, as collected by a well-designed questionnaire, is the only practical way of obtaining EMD exposure information in a cohort study. Additionally, we did not have any information about other possible confounding factors that could be effective in the development of sleep disturbances, such as soothing strategies of parents, breastfeeding, bottle-feeding, and sleeping in the same room with the parents. Confounding by various unmeasured factors could affect our findings.

However, the main strength of our study is that it is the first study to investigate the relationship between maternal EMF exposure caused by EMDs during pregnancy and sleep patterns in children. Another strength is that it provides additional data about the adverse effects of the presence of an EMD (not using it) in the sleeping environment in childhood. To confirm our hypothesis, further studies are needed in which the dose of exposure to EMF originating from EMDs is determined and polysomnography-based sleep evaluations are performed in a large sample size.

Conclusion

We observed that maternal exposure to EMF caused by EMDs during pregnancy is associated with sleep disturbances in chil-

dren. Obstetricians should be aware that pregnant women's EMD usage may affect sleep patterns in children. Clinicians, parents, teachers, and children should be educated about the harmful effects of the presence of EMDs (even when not using them) in the sleeping environment at nighttime. These relationships may be noncausal and may be affected by unmeasured confounding factors. However, this is just a preliminary study; if our findings are true, considering the widespread use of EMDs, it is a very important problem for public health given the long-term consequences of sleep disorders in childhood.

Ethical Committee Approval: Ethics committee approval was received for this study from the ethics committee of Gaziantep University Faculty of Medicine (IRB No: 07/2011-11).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – N.Ç.; Design – N.Ç., C.D..; Supervision – N.Ç.; Funding – N.Ç.; Data Collection and/or Processing – N.Ç., Ö.K.K.; Analysis and/or Interpretation – N.Ç., C.D.; Literature Review – N.Ç., Ö.K.K.; Writing – N.Ç.; Critical Review - N.Ç., Ö.K.K., C.D.

Conflict of Interest: The authors declare they have no conflict of interest.

Financial Disclosure: The authors disclose that they don't have any financial and personal relationships with other people or organizations that could inappropriately influence their work.

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