ORIGINAL ARTICLE

Sleep Science

Hunger hormone and sleep responses to the built-in blue-light filter on an electronic device: a pilot study

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ABSTRACT

The aim of the current study was to investigate the effect of the blue-light filtering 'Night Shift' function on the Apple iPad at night and leptin production, perceived hunger levels and markers of sleep quality and quantity in healthy young adults. In a randomised, crossover design, 13 young adults (6 male/7 female) performed three experimental trials. Two of the interventions included one hour of night-time electronic device use; reading on an iPad ~30 cm from eyes, either with (iPad+NS) or without (iPad) the 'Night Shift' blue-light filtering feature turned on. The control trial involved reading a hard-copy book for one hour (CON). Leptin and perceived hunger and tiredness levels were assessed at various time points for the three experimental conditions. Objective sleep indices (actigraphy) and subjective ratings of sleep were recorded. There were no significant interactions for any of the measured variables ($p > 0.05$). *Small* to *moderate* effect sizes were found for perceived sleep quality, with CON (7.3 ± 1.7) having the highest value when compared to iPad+NS (6.6 ± 1.8, $d = 0.29$) and iPad (5.6 ± 2.3, $d = 0.66$). *Moderate* effects were associated with iPad+NS when compared to iPad ($d = 0.77$) and for iPad compared to CON ($d = 0.90$) for pre-post change in leptin concentration. Use of electronic devices at night may result in *moderate* suppression of leptin levels and impaired sleep quality, with negligible differences associated with whether or not the 'Night Shift' feature is turned on.

Keywords: leptin; circadian rhythms; electronic device; screen time; obesity.

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1.1 INTRODUCTION

A decline in average sleep duration and quality has been reported over the past few decades[1], contributing to numerous chronic diseases including obesity[2]. Poor sleep can lead to increased feelings of hunger and subsequent increases in food portion sizes[3] as well as poor food choices[4,5]. Indeed, in Western societies, where chronic sleep deprivation has become common and food is widely available, changes in appetite regulatory hormones (leptin and ghrelin) associated with poor sleep may contribute to obesity[6]. One factor strongly implicated in the decline of sleep quality and quantity in modern society is the use of light-emitting electronic devices (televisions, smartphones, computers, etc.) at night and specifically during the hours before sleep[7]. In particular, self-luminous displays that emit high levels of short-wave-length (blue) light seem to cause significant circadian disruptions[7].

A representative survey of 1,508 American adults revealed that 90% of Americans used some type of electronics at least a few nights per week within 1 hour of bedtime[8]. Adolescents (13-18 y) and young adults (19-29 y) were the highest users of smart-phones in the hour before bed, with 72% and 67% of the surveyed population reporting use of these devices, respectively. Exposure to light-emitting devices has been shown to suppress the release of the sleep-facilitating hormone melatonin[7,9,10], which causes a shift to the circadian clock making it difficult to fall asleep and reducing sleep quality and quantity[11,12]. Chang et al. (2015) reported that, compared with reading a printed book, reading on an electronic device in the four hours before bedtime for five consecutive nights suppressed the late evening rise of pineal melatonin secretion, decreased subjective sleepiness, lengthened sleep latency; sleep propensity and impaired morning alertness[12].

Light has an impact on hormone production through stimulation of the suprachiasmatic nuclei. Sensitivity to the light from the retina in our eyes to the suprachiasmatic nuclei are the major circadian synchronizer of human daily biological rhythms. Pilot research has shown that blue-enriched light exposure immediately before and during the evening meal acutely increases hunger and alters metabolism in comparison to dim light[13]. Night time exposures to certain light levels and spectra will reduce or impair the production of melatonin[14]. In humans, nocturnal melatonin suppression is maximally sensitive to short-wavelength (blue) light peaking close to 460 nanometers (nm)[15]. Changes in melatonin have also been linked to perturbations in a hormone related to satiety - leptin[16]. Leptin plays a key role in food intake inhibition, body weight regulation and energy homeostasis[17], where it provides information about the state of fat stores to the brain, and the neurodendocrine systems adapt their function to the current state of energy homeostasis and fat stores[18]. Melatonin is involved in leptin synthesis and release by adipose tissues[19] and its absence is related to metabolic syndrome, diabetes, and increased body weight[20]. While the relationship between melatonin suppression and the use of electronic devices are well understood, the direct link between electronic device use and leptin is yet to be established in healthy, non-sleep-restricted humans.

Recent technological advancements have attempted to reduce the potential negative impact of short-wavelength blue-light by adjusting the spectral composition of self-luminous displays. Apple Inc. released a function called 'Night Shift' on their e-devices in 2016, which proposed to filter the blue-light wavelength emitted by the devices at night, thereby improving sleep. To the authors' knowledge, only one study has investigated the efficacy of the Night Shift feature. Nagare et al. (2017) compared two different Night Shift modes (low and high correlated color temperature) with a dim-light control (wearing orange goggles) and a blue-light intervention for melatonin suppression in 12 participants[17]. The results from their study showed that both Night Shift modes suppressed melatonin significantly more than the control trial, but significantly less than the blue-light trial. The authors also reported no difference between the two Night Shift modes and suggested that future research should investigate the impact that this feature may have on sleep and other factors associated with sleep. The study did not measure sleep and failed to include a condition where the Night Shift feature was turned off.

Therefore, the aim of the current study was to examine the acute effect of 1-hour of night-time iPad use with and without the Night Shift feature turned on, compared to a control trial using a printed hard-copy book. Perceived tiredness, hunger levels, salivary leptin and sleep (via wrist-actigraphy and perceived ratings of sleep duration and quality) were measured in healthy young adults.

2.1 MATERIALS AND METHODS

2.1.1 Participants

Thirteen healthy young adults (6 male/7 female, age; 29 ± 5 y) volunteered to take part in the study. All participants were free of any diagnosed sleep disorders and were required to have a Pittsburg Sleep Quality Index global score of < 7 (mean ± SD; 4.4 ± 1.8). Participants with chronic medical or psychological conditions or sleep disorders and those taking prescription sleep medications were excluded from the study. During the study, participants were also asked to sleep alone (no bed-partners) and parents with children under 2-years of age were excluded from taking part in the study. Ethical approval for the study was obtained through the institution's Human Research Ethics Committee.

2.1.2 Study Design

In a randomized, crossover design, participants performed three experimental trials, each separated by five to seven days. For two of the trials, participants were required to read an e-book on an electronic device (9.7" iPad Pro, Apple Inc. Cupertino, CA, USA) held at a standardised angle ~30 cm from eyes (as enforced by the researchers) either with the Night Shift feature turned on (iPad+NS) or off (iPad), with the same brightness settings (full warmness/brightness). A third trial involved

participants reading the same book as a hard-copy paperback (CON). The order of the trials was counterbalanced between the participants. All trials involved reading the same self-help book ("*How to win friends and influence people*" by Dale Carnegie) for one hour in a dimmed room, with just one table-lamp as the only light source. Reading took place for the hour leading up to each participants habitual bedtime (as identified by the Pittsburg Sleep Quality Index), while participants remained in a seated position. The photopic lux of the room was measured in the same position across the three trials using a Digitech QM1587 light meter. The spectrometry and wave-length of the light emitted by the iPad (with and without Night Shift) is reported using methods and techniques described previously[21] via the online tool found at fluxometer.com. Based on these methods, the spectral power of both the iPad and iPad+NS is further detailed in Table 1 and Figure 1 below.

To control for dietary variables, participants recorded their meals using a 24-hour diet diary for the day of the first testing session and were instructed to replicate their diet for the subsequent testing sessions. Participants were to refrain from any vigorous physical activity and alcohol consumption on the day of testing and caffeine consumption after 12pm. Participants were required to have dinner 3.5 hours before their habitual bedtime. Following dinner, participants were allowed to only drink water until up to 30 minutes before 'reading time' (i.e., one hour before bedtime) in order to guarantee good quality of saliva samples.

2.1.3 Sleep monitoring

Participants were required to wear a wrist actigraphy device (Readiband™, Fatigue Science, Vancouver) on either the dominant or non-dominant wrist[22] for the experimental trials. Participants were instructed to leave the actigraphy devices on at all times during the study. The Readiband has been validated against PSG, with accuracy levels of up to 93% being reported[23,24] and research from our laboratory has also shown that the Readiband results are in acceptable levels of inter-device reliability (ICC = >0.90)[25]. At the conclusion of the recording period, actigraphy data were wirelessly downloaded to a computer, which was then analysed using Fatigue Science software (16Hz sampling rate: Readiband™, Fatigue Science, Vancouver). The raw activity scores were translated to sleep-wake scores based on computerized scoring algorithms. Sleep indices including total sleep time, sleep latency, sleep onset time and wake time were used to assess sleep variables.

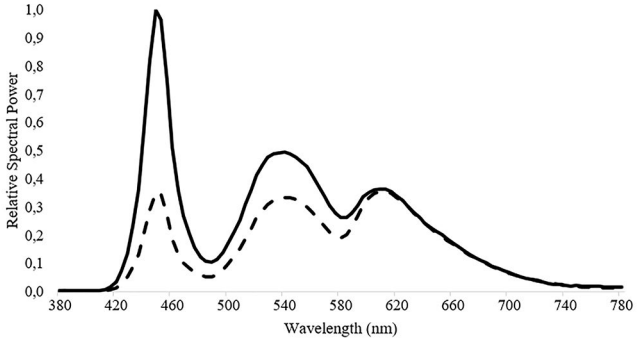

Figure 1. The relative spectral power distributions for the two interventions in the current study as described by Lucas et al.[21] Thick black line represents iPad condition and dashed line represents iPad+NS condition.

2.1.4 Hormonal measures

Whole saliva samples were collected pre and post the 1-hour reading intervention during all three trials (iPad+NS, iPad and CON). Participants expectorated a sample via passive drool into a 50-mL polyethylene tube, which was stored at -20°C until assayed. On the day of testing, saliva samples were thawed to room temperature and centrifuged at 3000 rpm for 15 minutes to remove mucins. Leptin concentrations were determined using saliva from the upper phase of the centrifuged samples in duplicate using commercially available enzyme-linked immunosorbent assay kits (ELH-LEPTIN, RayBio, USA) as per the manufacturer's instructions. Leptin assay sensitivity was 2 Archie11 $pg.mL^{-1}$ with intra-assay variation (calculated from the saliva samples of between 25.8 and 32.0% and an inter-assay CV (calculated from the standards) of between 2.4 and 13.0%. Saliva samples for each participant were analyzed on the same assay plate to eliminate the possibility of inter-assay variance.

2.1.5 Perceived hunger and tiredness measures

At various time points (pre, post and next morning), perceptual measures of hunger and tiredness were given by participants. The perceived hunger scale consisted of one-item (i.e., How hungry are you feeling right now) that was rated on a Likert-style scale ranging from 'so full you feel sick'[1] to 'starving and feeling weak/dizzy'[10]. Similarly, the perceived tiredness scale also consisted of one item (i.e., How tired are you feeling right now) that was rated on a Likert-style scale ranging from 'not at all'[1] to 'extremely'[10].

2.1.6 Pittsburg Sleep Quality Index (PSQI)

The PSQI is a self-rated 19-item instrument intended to assess sleep quality and sleep disturbance in clinical and non-clinical populations[26]. Global scores range from 0 to 21 with higher scores indicating poorer overall sleep quality. The PSQI has been demonstrated to have good internal reliability, validity

Table 1. Calculations of five α-opic irradiances for experimental conditions (iPad+NS and iPad), following the SI-compliant approach recommended by the International Commission on Illumination.

Intervention	Cyanopic irradiance (μWcm^2)	Melanopic irradiance (μWcm^2)	Rhodopic irradiance (μWcm^2)	Chloropic irradiance (μWcm^2)	Erythopic irradiance (μWcm^2)
iPad+NS	3.46	6.04	8.38	11.3	13.1
iPad	9.43	12.2	15.0	17.3	18.0

and is perhaps the most commonly-used subjective sleep measure not only in the research literature, but also in the sleep community[26].

2.1.7 Statistical Analysis

Simple descriptive scores are shown as means ± standard deviations unless stated otherwise. Statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL), with statistical significance set at $p < 0.05$. One-way repeated measures analyses of variance (ANOVA) were performed to determine the effect of different treatments (iPad+NS, iPad, CON) on sleep measures. Two-way repeated measures ANOVAs (treatment x time) were performed on leptin and perceived tiredness and hunger variables. There were no outliers in the data, as assessed by visual inspection of a boxplot and all data was normally distributed, as determined by Shapiro-Wilk's test ($p > 0.05$). There was homogeneity of variances, as assessed by Levene's test for equality of variances. Where significance was found, comparisons were performed using Tukey's post-hoc analysis. When sphericity was violated, Greenhouse-Geisser corrections were used. Magnitudes of the standardized effects between treatments were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for *small, moderate, large and very large* effect sizes, respectively 27. An effect size of < 0.2 was considered to be *trivial* and the effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for both *small* positive and negative effects[28].

3.1 RESULTS

There were no significant differences between trials for photopic lux in the rooms where testing took place ($p > 0.05$).

The results revealed no significant differences between the three experimental trials ($p > 0.05$) for any of the outcome variables (Table 2 and Table 3).

Effect size analysis (Table 3) revealed *small* to *moderate* effects between trials for perceived sleep quality, with CON (7.3 ± 1.7) having the highest value when compared to iPad+NS (6.6 ± 1.8, d = 0.29) and iPad (5.6 ± 2.3, d = 0.66). Although these findings for perceived sleep quality were not statistically significant, the repeated measures ANOVA revealed an interaction effect that approached significance, $F_{2,20} = 3.13$, $p = 0.066$, with participants reporting higher sleep quality after reading a hard-copy book than reading from an iPad ($p = 0.046$). There were *moderate* effects associated with iPad+NS when compared to iPad (d = 0.77) and for iPad compared to CON (d = 0.90) for pre-post change in leptin concentration (Figure 2).

4.1 DISCUSSION

The main findings from the current study indicate that when the blue-light filtering 'Night Shift' feature is turned off, iPad use at night may result in *moderate* but not statistically significant ($p > 0.05$) suppression of leptin levels and impaired sleep quality in healthy young adults when compared to reading a hard-copy book. When the Night Shift feature is turned on, there is a *small* difference in sleep quality and tiredness measures in favour of the control trial and an *unclear* difference in the change in leptin concentration when compared to the control. To the authors' knowledge, this is the first study to evaluate the sleep and hunger responses to the Night Shift feature on the iPad. The findings from this study have established a somewhat novel link between electronic device use at night and trends towards affected leptin and sleep responses that warrant further investigation.

The trends toward decreased leptin levels in the iPad intervention when compared to both the control and the Night Shift interventions indicate that individuals were more likely to feel hungry after higher levels of blue-light exposure. Interestingly, the control and Night Shift trials showed increases in pre to post leptin concentrations, indicating that appetite was further suppressed after the one-hour intervention. This may be in response to the participants consuming food ~2 hours prior to the start of the intervention, which is consistent with previous research showing that circulating leptin levels peak ~4 hours

Table 2. Mean ± SD values for perceived and measured sleep variables, perceived tiredness and measured hormonal and hunger variables for the three interventions (iPad+NS, iPad, CON).

	iPad+NS	iPad	CON
Perceived Sleep Duration (h:mm)	7:19 ± 0:54	6:57 ± 1:14	7:28 ± 0:49
Perceived Sleep Quality (/10)	6.6 ± 1.8	5.6 ± 2.3	7.3 ± 1.7
Pre-Post Δ Tiredness (/10)	1.9 ± 1.2	0.6 ± 1.9	1.5 ± 2.2
Next morning Tiredness (/10)	4.1 ± 1.9	4.5 ± 2.3	3.2 ± 1.7
Total Sleep Time (h:mm)	7:09 ± 0:45	7:31 ± 0:22	7:36 ± 0:26
Sleep Latency (h:mm)	0:35 ± 0:37	0:36 ± 0:39	0:23 ± 0:26
Sleep Onset Time (time of day)	23:12 ± 0:26	23:10 ± 0:37	23:06 ± 0:32
Wake Time (time of day)	6:57 ± 0:22	7:00 ± 0:33	7:00 ± 0:32
Pre-Post Δ Hunger (/10)	0.6 ± 0.7	0.5 ± 1.0	0.3 ± 0.5
Next Morning Hunger (/10)	6.0 ± 0.4	6.2 ± 0.7	6.1 ± 0.8
Leptin Pre ($pg.mL^{-1}$)	2.263 ± 1.113	2.976 ± 2.079	2.584 ± 1.431
Leptin Post ($pg.mL^{-1}$)	3.059 ± 1.450	2.752 ± 1.118	3.446 ± 1.157
Pre-Post Δ Leptin ($pg.mL^{-1}$)	0.796 ± 1.807	-0.224 ± 1.228	0.861 ± 2.008

Table 3. Comparison between interventions (iPad+NS, iPad and CON) for measured sleep and hunger variables. Data presented as raw difference in values (mean ±90% confidence intervals) with effect sizes for comparison between experimental trials.

	iPad+NS - iPad mean ± 90%CI (*effect size*)	iPad+NS - CON mean ± 90%CI (*effect size*)	iPad - CON mean ± 90% CI (*effect size*)
Perceived Sleep Duration (h:mm)	0:22 ± 0:22 0.28 ± 0.28 *Small*	-0:09 ± 0:21 -0.11 ± 0.27 *Trivial*	-0:31 ± 0:26 -0.39 ± 0.33 *Small*
Perceived Sleep Quality (/10)	0.9 ± 1.4 0.37 ± 0.56 *Small*	-0.7 ± 1.1 -0.29 ± 0.45 *Small*	-1.6 ± 1.0 0.66 ± 0.41 *Moderate*
Pre-Post Tiredness (/10)	1.3 ± 1.2 0.73 ± 0.67 *Moderate*	0.5 ± 0.7 0.38 ± 0.57 *Small*	0.8 ± 1.7 0.44 ± 0.88 *Unclear*
Next Morning Tiredness (/10)	-0.5 ± 1.6 -0.19 ± 0.67 *Unclear*	0.8 ± 0.8 0.35 ± 0.33 *Small*	1.3 ± 1.5 0.53 ± 0.61 *Small*
Total Sleep Time (h:mm)	-0:23 ± 0:25 -0.96 ± 1.04 *Moderate*	-0:27 ± 0:27 -1.15 ± 1.15 *Moderate*	-0:05 ± 0:16 -0.19 ± 0.67 *Unclear*
Sleep Latency (mins)	-0:01 0:21 -0.03 ± 0.48 *Unclear*	0:12 ± 18 0.27 ± 0.42 *Small*	0:13 ± 0:23 0.31 ± 0.54 *Unclear*
Pre-Post Δ Hunger (/10)	-0.1 ± 0.6 -0.09 ± 0.67 *Unclear*	-0.3 ± 0.4 -0.43 ± 0.59 *Small*	-0.2 ± 0.6 -0.27 ± 0.68 *Unclear*
Pre-Post Δ Leptin ($pg.mL^{-1}$)	1.020 ± 1.118 0.77 ± 0.85 *Moderate*	-0.065 ± 1.745 -0.05 ± 1.30 *Unclear*	1.086 ± 1.249 0.90 ± 1.03 *Moderate*

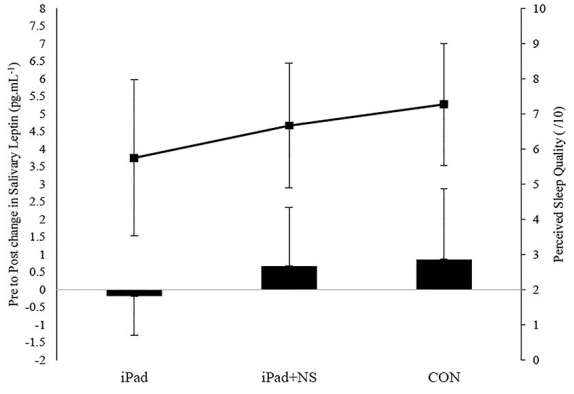

Figure 2. Bar graph represents the pre to post change in salivary leptin concentration (primary axis) across the three interventions (iPad, iPad+NS and CON) and line graph represents the perceived sleep quality (secondary axis) following each intervention. Error bars represent standard deviations.

post feeding[29]. In contrast, there was a slight decrease in pre to post leptin levels for the iPad trial, suggesting that the use of the lit device may have led to suppression of leptin levels, usually meaning an increase in ghrelin levels[5], and therefore, increased hunger. The pathways through which light might modulate leptin concentrations are not known, however, previous research has also shown that light exposure in the morning can influence leptin and ghrelin concentrations in sleep-restricted individuals[15]. As leptin is the key hormone in regulating food intake inhibition, continuous suppression of leptin following electronic device use might have significant long-term consequences on weight control and may contribute to obesity in a chronic setting.

The differences in leptin concentrations between interventions do not necessarily reflect the perceived hunger levels in the current study. There were no significant differences between conditions for perceived hunger at any time point (pre and post intervention and next morning). However, unlike leptin, satiety levels peak soon after feeding (< 1 hour)[30] and it is possible that the length of the light intervention in the current study (1 hour) was not long enough to cause perturbations in perceived hunger levels. Previous pilot research has suggested that blue-light enriched exposure (260 lux for three hours) before the evening meal in 10 healthy adults, resulted in increased feelings of hunger for up to two hours following the meal, when compared to a dim-light control[13].

Night time iPad use had a *moderate* effect on subjective perception of sleep quality, suggesting that after reading from an iPad compared to reading a hard copy book, participants felt that they slept worse. Insufficient or low-quality sleep has been shown to have deleterious effects on mental and physical health and cognitive performance[31]. Notably, poor sleep has also been associated with reduced leptin and increased body mass index[6]. Continuous use of blue-light emitting electronic devices prior to sleep is, therefore, likely to contribute not only to sleep problems but also to a range of different health outcomes[20].

There were no significant differences between groups for any of the sleep measures identified via wrist actigraphy. However, *moderate* differences were found for total sleep time between the iPad+NS intervention and both iPad and control

interventions, with the iPad+NS intervention resulting in the least sleep time. Sleep latency was the lowest in the control trial (26 minutes) compared to both iPad+NS and iPad trials (35 and 36 minutes, respectively), with a *small* effect size between iPad+NS and CON. These results are not surprising, with previous research suggesting longer times to fall asleep following electronic device use[14].

Alongside the minimal differences between trials for any of the objective sleep measures, there were *small* trends towards increased tiredness the following morning after both iPad interventions, when compared to the control. There were also *moderate* differences between iPad interventions for pre to post tiredness ratings, with iPad+NS associated with greater increases in tiredness compared to iPad. This would support previous research, suggesting that blue-light enriched exposure will reduce feelings of tiredness[32], however, interestingly, in the current study there was an *unclear* difference between iPad and control trials for tiredness.

Future research would benefit from monitoring the effect of night time electronic device use on sleep over longer periods of time (e.g. multiple weeks) with longer exposure to the device each night (e.g. > 90 minutes). One study involving 13 young adult participants showed that the night-time (23:00 to 01:00) use of iPad devices suppressed melatonin by 7% and 23% following one-hour and two-hour exposures, respectively[33]. This would suggest that perhaps the one-hour exposure implemented in the current study, on one single occasion, was not long enough to elicit significant responses in any of our measures, despite the trends observed.

Further research is also required comparing blue-light filtering applications on devices and blue-light blocking sunglasses for melatonin and sleep responses. Indeed, orange-tinted, blue-light reducing sunglasses (blue-blockers) have been shown to have a positive impact on preventing melatonin suppression when using lit devices[34], and also subsequent sleep[14]. The current study did not measure melatonin, which is the key sleep-facilitating hormone. As melatonin has been associated with both night time electronic device use[17] and leptin[35], future studies should investigate the potential mediating effect of melatonin on the relationship between night time electronic device use and leptin. While melatonin measures in saliva have been well validated in the literature[36,37], future research should consider the use of blood samples to evaluate leptin levels, for possible issues related to accuracy. It is acknowledged that when using the leptin plate standards in the current study, the inter-assay CV across plates was calculated at between 2 and 13% and, for saliva samples, the intra-assay CV was somewhat higher, at between 26 and 32%. The relatively high CV indicates that the saliva is a difficult matrix and the ELISA kit was operating near its detection sensitivity threshold. Therefore, it is suggested that interpretation of the leptin data should be treated with caution, and future research should consider using blood-plasma sampling as a more accurate assessment of leptin levels.

In conclusion, based on the current study and previous related research, the use of electronic devices at night may result in trends towards suppression of leptin levels and impaired sleep quality, with negligible differences associated with whether or not the 'Night Shift' feature on the iPad is initiated or not. This research has important implications for the potential link between electronic device use at night and obesity rates in young adults, however further research is required to expand on these findings in a chronic setting, with additional plasma hormonal measures (leptin, ghrelin and melatonin), greater sample sizes and greater exposure durations to blue-light.

Declaration of Interest

There are no conflicts of interest to declare.

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