

Influence of Evening Display Light on Melatonin Levels and Autonomic Nervous System Balance

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Abstract

In this study, we compared the effects of light from a high-end LCD TV and an OLED TV on humans by measuring the saliva melatonin levels and the heart rate variability (HRV) during and before/after watching TV in the evening with 40 volunteers. Participants using the LCD TV demonstrated a decreased melatonin secretion by 2.7% after watching TV, whereas those utilizing the OLED TV exhibited an increase of 8.1%. The HRV analysis, which represents the relative activation levels of the sympathetic and parasympathetic nerves, revealed that on average, the OLED TV activated the parasympathetic nerves more than the LCD TV during the entire watching time. This indicates that watching OLED TVs induces relatively comfortable states. Further, a questionnaire was simultaneously conducted to assess eye discomfort and overall eye strain after watching TV, and the results showed a significantly increased eye fatigue after watching the high-end LCD TV compared to the OLED TV.

Author Keywords

OLED TV; LCD TV; Blue light; Melatonin secretion; sleep disorder; Circadian rhythm; Sympathetic; Parasympathetic

1. Introduction

Human beings can perceive light intensity levels and specific wavelengths as colors because of the rods and cone cells in the retina. These two photoreceptor cells are a type of sensor that recognize the visual information. Conversely, a third class of photoreceptors in the retina are the intrinsically photosensitive retinal ganglion cells (ipRGCs), which function in circadian rhythm entrainment rather than the visual function, and these types of light sensing without sight have been known as non-visual or non-image-forming photoreception. [1]. The spectral sensitivity of these non-visual responses to light is maximally sensitive to short wavelengths of visible light, and international standard CIE S 026:2018 provides action spectra of melanopsin-containing ipRGCs with a peak of approximately 480 nm [2]. Therefore, light in this specific region is a powerful time cue of circadian rhythm and a regulator of physiological phenomena. In particular, the human circadian rhythm is a physiological signal with a 24-hour cycle and is synchronized by a non-visual process that responds to the specific wavelength region of blue light [3].

Melatonin secretion is one of the representative biomarkers of circadian rhythm. Melatonin is a hormone that the pineal gland releases during nighttime, and it plays a crucial role in the sleep-wake cycle regulation. Light, especially blue light, acts as a zeitgeber of the circadian rhythm, which suppresses or stimulates melatonin secretion [4]. Generally, this circadian rhythm is an evolutionary result that makes humans adapt to Earth's Day and Night cycles [5]. However, exposure to a lot of lighting [6] and displays [7-8] at nighttime in modern society disturbs the circadian rhythm. White light-emitting diode (LED) lighting,

which is widely used in terms of energy efficiency, and backlight used in LCD displays are based on blue light LEDs. Hence, using these devices at night will directly and adversely affect the circadian rhythm. Failure to entrain the circadian rhythm causes sleep disorders [9] and depression [10].

Recently, as displays such as TVs become larger and larger, they serve as another artificial light in living rooms or offices. Thus, the effects of these display devices on melatonin hormone secretion need to be investigated. Melatonin secretion begins and increases in the evening, and watching TV generally disrupts this physiological process [11-12]. Conversely heart rate variability (HRV) is a variation in the time intervals between heartbeats and is calculated using time or frequency domain analyses of the HR signal. HRV is considered a marker of the autonomic nervous system (ANS) and it is described by the balances between the sympathetic and parasympathetic activity [13]. HRV is represented as the power density in two standard frequency bands of low frequency (LF; 0.04~0.15 Hz) and high frequency (HF; 0.15~0.40 Hz) for frequency domain analysis. The LF:HF ratio may reflect the sympathovagal balance whereas the HF might represent a measure of the parasympathetic modulation of the heart [14]. In the case of time domain analysis, the root mean square of the successive differences (RMSSD) and the percentage of successive NN intervals greater than 50 ms (pNN50) demonstrate the activity of parasympathetic modulation [13]. Therefore, HRV measurement data can be used to determine what state the participant is in while watching TV, that is, whether he or she is relaxed or tense when watching TV.

LCDs generate light from a backlight composed of blue LEDs and phosphors or QDs, while OLEDs generate light from R, G, and B of organic light-emitting materials, indicating the difference in the fundamental principles of light emission. Also high-end LCD TVs outperform OLED TVs in brightness to compete in the premium TV market because LCDs inherently show lower contrast than OLEDs. Therefore, it can be expected that the effects of light from displays on human melatonin hormone secretion and the autonomic nervous system will be different. In this study, we compared and analyzed the effects on sleep rhythm from the data on melatonin levels and the balance of relaxation/tension from HRV.

2. Methods

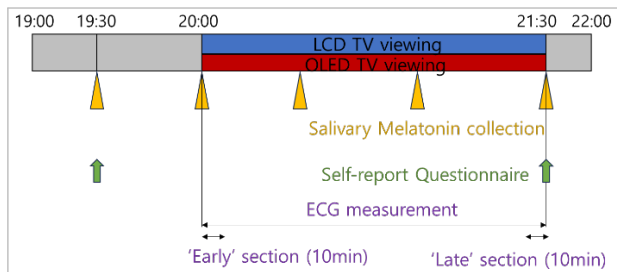
2-1. Experimental protocol

This study was conducted with 40 healthy volunteers (mean age \pm SD: 23.0 \pm 1.8 years) without any medical, neurological or sleep disorders. Additionally, people who were 'definite evening' or 'definite morning' types based on the Morningness-Eveningness Questionnaire (MEQ) score were excluded from the study. The participants visited twice with a one-week interval and

watched LCD TV and OLED TV from 20:00 to 21:30 in random order. Electrocardiogram (ECG) measurements were continuously taken before, after, and while watching TV, and saliva melatonin samples were collected five times at 30-min intervals. No other external light was used to focus on the effect of the light from the TV screen on the human body. Hence, the participants watched the TV in a dark room from 1.5H, where H is the height of the TV screen.



(a)



(b)

Figure 1. Experimental setup (a) and process of the clinical trial (b)

Both TVs were set to the “HDR cinema mode” provided by each manufacturer. HDR movie (Super Mario Bros, 2023) is played back during the test. Figure 1 shows the experimental setup and the process of the clinical trial. Specifications of the TV samples are shown in Table 1. A high-end LCD TV was chosen to compare with OLED TV because it is competing with OLED TV in the premium TV market. They are both 65 inches with the same resolution of 3840*2160. The chromaticity gamut coverage of LCD TV and OLED TV are 97.0% and 98.7%, respectively. The luminance according to the APL (Average Picture Level) are shown in the table below. Considering the average APL of HDR content, we can see that the average luminance of LCD TV is about 3 to 5 times higher than that of OLED TV. Display specifications such as size, resolution, chromaticity gamut coverage are similar except for the luminance. The luminance levels of both TVs were not adjusted to the same because this experiment aims to compare both TVs under actual TV watching scenario with default luminance level. High-end LCD TVs normally feature higher luminance level than OLED TV to compensate their lower contrast ratio.

Table 1. Specifications of the TV samples

Item	Unit	LCD	OLED
Size	inch	65	65
Resolution		4K	4K
Chromaticity gamut coverage (DCI-P3)	%	97.0	98.7
Luminance	APL_10%	2680	794
	APL_25%	2500	522
	APL_100%	791	158
MEDI	lux	93,291	30,066

Figure 2 shows the comparison of LCD TV and OLED TV in terms of cumulative MEDI (Melanopic Equivalent Daylight Illuminance) value, an index proposed in CIE S 026:2018 [2]. The cumulative MEDI value of LCD TV is about 3 times higher than that of OLED TV due to the relatively higher luminance of LCD TV.

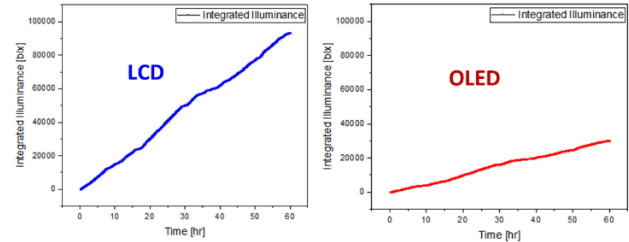


Figure 2. Cumulative MEDI value of the LCD and OLED TVs.

2-2. Melatonin assay

The Melatonin levels of each participant were identified using a saliva sampling method. Salivary samples were collected five times at 30-min intervals, starting at 19:30, 30 min before TV watching, and ending at 21:30 after TV watching, for each TV type. All participants were required to provide approximately 2 mL of saliva samples directly into an individual sterile tube at each time point, and these collected samples were kept frozen at -60°C until assayed. The melatonin was analyzed in duplicate using commercially available salivary melatonin enzyme-linked immunosorbent assay (ELISA) kits (Salimetrics, Inc., USA), and a microplate reader (VersaMaxTM, USA). The lower and upper limits of detection for the ELISA kits were 0.78 pg/mL and 50 pg/mL.

2-3. HRV measurement

An ECG system (BIOPAC MP160, Biopac System Inc., USA) for HRV measurement was utilized to record data from each participant. Three pre-gelled and self-adhesive electrodes were connected to a BIOPAC Bionomadx wireless transmitter. ECG data were collected with a sampling rate of 500 Hz with the AcqKnowledge 5.0 software. The QRS complex is detected in a continuous ECG record, and the interval between adjacent R waves is named the normal-to-normal (NN) or RR interval. The RR tachograms were extracted using open-source MATLAB R2018b software to analyze HRV from the obtained ECG waveform. Time-domain HRV is calculated based on the RR interval, and typical markers are RMSSD and pNN50 as mentioned at introduction session. The frequency-domain HRV is calculated by performing a fast Fourier transform (FFT) on the RR tachogram. In general, pLF or pHF is utilized, which is expressed as a portion of total power after removing the effect of power in a very low frequency (≤ 0.04 Hz) region rather than LF or HF. Additionally, the LF/HF ratio is also one of the frequently used markers that indicates the balance between the sympathetic and parasympathetic contributions to HR regulation [13].

3. Results and Discussion

3-1. Melatonin level

The average saliva melatonin collected at 19:30, 30 minutes before watching TV, was used as a reference value to compare

the changes in melatonin secretion. Figure 3 shows the average melatonin secretion that was relatively decreased or increased at 21:30, immediately after watching TV. Similar to the previous research results [11-12], watching LCD TV was found to disrupt sleep rhythms due to the reduction of melatonin secretion. However, the amount of melatonin secretion increased by 8.1% after watching OLED TV in this study. It does not mean that watching OLED TVs promote melatonin secretion, but rather that watching OLED TVs does not interfere with melatonin secretion, as melatonin secretion begins and increases in the evening. These clinical results are consistent with the previously measured MEDI results. Compared to OLED TVs, the MEDI value of LCD TVs is much higher due to the relatively higher luminance when considering the average APL of HDR content, so it is expected to suppress melatonin secretion more and have a greater impact on sleep rhythm. Therefore, watching OLED TV in the evening does not disturb sleep rhythms compared to LCD TV due to the relatively lower luminance, since OLED has much higher contrast ratio and lower black level down to 10E-6 cd/m², which means that it does not need to have higher luminance compared to LCD TV.

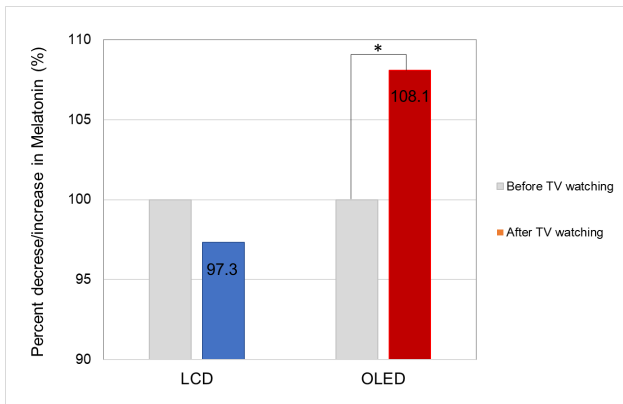


Figure 3. Normalized percent decrease/increase rate in melatonin after watching LCD and OLED TVs. **p*-value < 0.05.

3-2. HRV analysis

Figure 4 shows the average value of the HRV indexes measured while watching TV by comparing LCD TV and OLED TV. RMSSD, pNN50, and pHF indicate parasympathetic nerve activation as the value increases, whereas the LF/HF ratio denotes sympathetic nerve activation. All indexes exhibit that watching OLED TV relatively activates the parasympathetic nerve. This indicates that OLED TV maintains a more comfortable watching state than LCD TV. In particular, the RMSSD index demonstrates that watching OLED TVs is, approximately 30% more comfortable than watching LCD TVs.

We also analyzed the relative changes in the average values of HRV indexes during the 10 min after starting TV viewing (“Early” section) and the 10 min before finishing watching TV (“Late” section), in addition to the average of the entire TV watching time, and the results are shown in Figure 5. Tension was confirmed to increase after watching LCD TV, except for pNN50, whereas tension decreased after watching OLED TV, indicating a comfortable state. Especially, according to the LF/HF ratio index, it was found that tension increased by more than 30% after watching LCD TV.

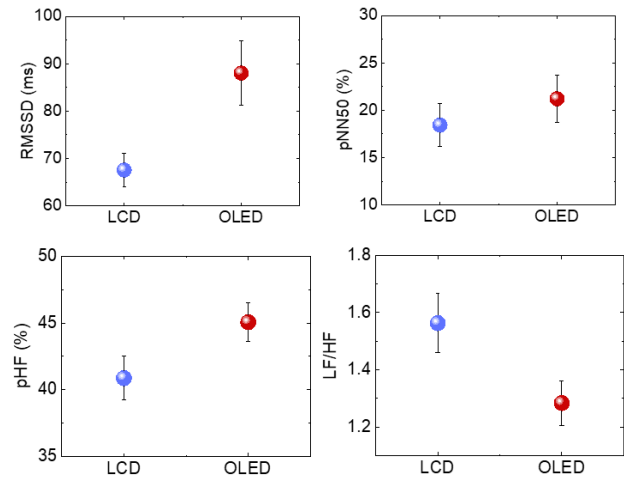


Figure 4. Average HRV indexes within total TV watching time, between 20:00 and 21:30.

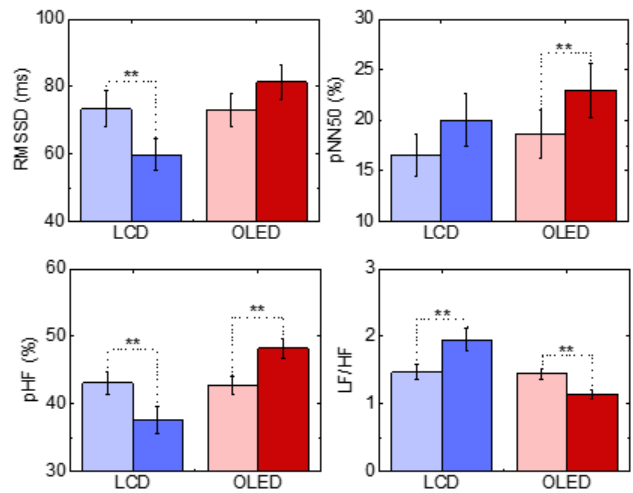


Figure 5. Comparisons of the difference in HRV indexes between “Early” section (during 10 min. after starting) and “Late” section (during 10 min. before finishing). **p*-value < 0.05, ***p*-value < 0.01.

Table 2. Results of the questionnaire scores on the four types of eye discomfort and overall eye strain after watching LCD and OLED TVs

	Eye discomfort				Eye strain
	Glare	Sore eyes	Dry eyes	Blurred vision	
LCD	58.7 %	53.5 %	33.3 %	30.6 %	40.1 %
OLED	47.2 %	30.1 %	17.9 %	12.9 %	29.3 %

3-3. Questionnaire result

Before and after watching TV, a questionnaire was administered to participants who had watched TV to evaluate their eye fatigue level on a 9-point scale. Table 2 shows evaluated eye discomforts that were divided into four subcategories and overall eye strain. The result indicates that eye fatigue increased after watching both

OLED and LCD TVs, but LCD TV exhibited a relatively larger increase compared to OLED TV. This experiment was conducted in a dark room, thus increase in the “Glare” item was large for both TVs, and the “Sore Eyes” item increased more in the LCD TV than in the other items, which can be expected to be due to the relatively high brightness.

4. Conclusion

In this study, we investigated the effect of light from a high-end LCD TV and an OLED TV on sleep rhythm, sympathetic-parasympathetic balance, and eye fatigue through the clinical trials. It was conducted in a real TV-watching scenario (HDR cinema mode and default brightness) to offer more practical information to consumers. In the case of melatonin secretion experiment, it was confirmed that watching the high-end LCD TV in the evening disturbs the circadian rhythm and causes sleep disturbance, whereas OLED TV shows less interference with sleep. Secondly, for the HRV analysis, parasympathetic nerve activity was relatively greater when watching OLED TV, enabling viewers to watch in a more comfortable state. Third, the results of the questionnaire analysis showed that watching OLED TV causes relatively less eye fatigue than watching the high-end LCD TV. In other words, OLED TVs have been shown to have better health effect while maintaining the best image quality compared to high-end LCD TVs. However, it should be also noted that this result does not support general comparison between OLED TV and all types of LCD TVs.

5. Acknowledgements

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