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Considerations on the effects of automotive lighting to enhance alert and avoid sleepiness in night time drivers via melatonin inhibition

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Abstract

The effects of light on circadian rhythms have been known for a long time. It is well known that shift workers, transoceanic travellers and other people being exposed to light during their sleep hours have remarkable disorders in their biological clocks that can last just some days with few important effects or become really serious with higher incidence of serious diseases. One of the reasons for circadian clock to be altered is the melatonin inhibition, due to the exposure to intense and/or bluer lights during sleep hours. The inhibition of the secretion of this neurohormone has been proven to be an effective measure to enhance alert and avoid sleepiness. However, although this sleepiness avoidance is widely used in indoor illumination to achieve better productivities or higher concentration in mental tasks, nothing has been done in order to ensure that night time drivers will keep awake during long journeys via melatonin inhibition. In this sense, the lighting of the own vehicle could be the most reasonable candidate to avoid sleepiness on this collective with the consequent impact on safety. This work uses the theoretical models of dependence between light intensity and wavelength and melatonin inhibition to analyze the potential influence of car headlamps on sleepiness in people driving during long periods at night-time. The results of this research show that cars equipped with headlamps using xenon and halogen light sources, which are the most common with a still wide advantage on LEDs cause no melatonin inhibition on people driving during long periods at night and thus, the current automotive lighting technology cannot avoid distraction and sleepiness in drivers with this strategy. However, a new lighting pattern that theoretically would cause melatonin inhibition and hence, an enhanced road safety, is proposed. We conclude that the incorporation of headlighting systems providing this pattern would be extremely positive for road safety and one important step for the automotive industry.

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1. Introduction

Nowadays, it is widely accepted that illumination has biological influence on the human body through the inhibition of melatonin (a neuro-hormone produced in the pineal gland). This inhibition results in changes of the cyclic processes called circadian rhythms (sleeping time, body temperature and pressure fluctuations, heart frequency changes, etc) [1-8]. The explanation to this inhibition is due to the role of the so called "intrinsically photosensitive Retinal Ganglion Cells" (ipRGC) which act as photoreceptors and start a non visual path that finishes in the pineal gland [9].

In the past it was shown that melatonin secretion helps us to fall asleep whereas melatonin inhibition keeps us awake but the influential factors on this process were not well known. Recent investigations have determined that the most influential factors involved in the melatonin inhibition process by light are: wavelength, intensity and time of exposition [10-14]. The role of each factor according to these studies is as follows:

- The maximum of melatonin inhibition is reached for wavelengths within the blue.
- The higher the intensity of the light, the higher the inhibition.
- The higher the time of exposition to the light, the higher the inhibition.
- There exist threshold values of intensity and time of exposition under which the melatonin inhibition does not take place.

Due to the important role of melatonin on the sleeping processes, the investigation of how headlighting affects the circadian system in night drivers is necessary. Moreover, the quick development of new technologies in automotive lighting [15] is another reason to investigate this subject. In this sense, the massive introduction of more powerful light sources such as xenon bulbs in cars all around the world is a very relevant fact. This is because, as mentioned previously, short wavelengths in the electromagnetic spectrum (much more abundant in xenon sources), have a higher impact in melatonin suppression.

The main purposes of the presents work are:

- To perform a theoretical analysis of the impact of vehicles lighting on melatonin suppression during long night travels.
- To make some proposals in order to optimize melatonin inhibition to avoid sleep in night time drivers, and therefore, to increase road safety during the night.

Before going into details, a brief summary with some considerations on night driving and the light sources usually incorporated by cars will be presented.

In night driving, drivers receive light from different sites: interior boards of the car, public lighting, other vehicles, and light of their own headlamps partially reflected back by the road.

The retro-reflected light coming from our own vehicles is the most important in absence of public lighting [16]. This stimulus and that due to the interior boards of the car are present at any moment during the night driving, however it has been shown that the light coming from the control panels inside the car have no influence on melatonin inhibition [17]. Finally, other stimuli are present only during very short periods of time (the ones from the incoming drivers) and thus will not be considered in this study.

The only stimulus considered to calculate melatonin inhibition in the present study was the light reaching the driver's eye due to the reflection in the road surface.

Two types of lighting sources were considered in order to develop calculations:

- Halogen bulbs: with a colour temperature T_c= 3200 K (typical for this kind of lamps)
- Xenon bulbs: the spectrum of this lamps was treated as continuous with a colour temperature T_c= 4100 K. This approach is possible because the last generation of theses bulbs incorporate different types of

salts that enrich their chromaticity providing an almost continuous spectrum. In fact, the commercial catalogues and datasheets from bulb manufacturers consider similar correlated colour temperatures.

For the sake of simplicity, it was considered that the spectral composition of light reaching the driver's eye after reflection on the road is the same that the one emitted by the bulb, but with lower intensity. It is to say, the spectral irradiance reaching the eye (E_e), and the exitance of the headlamp (E_h), are related by one attenuation coefficient of the road surface. The mathematical expression is as follows:

$$E_e = \alpha E_h \tag{1}$$

where α is a factor between 0 and 1.

2. Results

The spectral irradiance reaching the eye (E_e), was measured using a fully cosine corrected digital radiometer. To calculate the melatonin suppression due to the vehicle lighting, the Irradiance Response Curves (IRC) for such lights, were considered. These curves provide the relationship between melatonin suppression and light intensity for a given wavelength. The IRC curves used in the present study were obtained from the work of Thapan et al [11]. They are shown in Fig. 1.

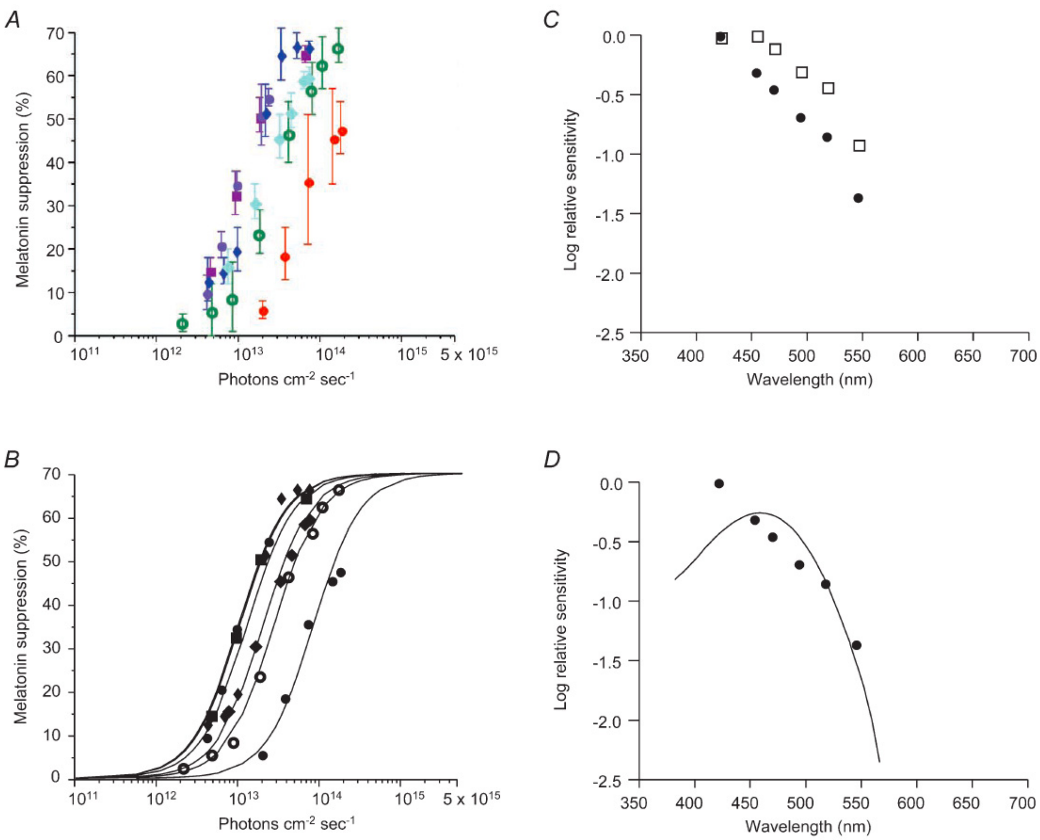

Fig. 1. A) Inhibition data for different irradiances and wavelengths. B) Adjustment of the experimental data in A). C) Experimental data of sensitivity to inhibition for different wavelengths. D) Adjustment of the experimental data in C). Figure taken from [11].

Once the irradiance E_e is known, its values in the visible spectrum have been determined by means of the black body curve for each colour temperature.

The irradiances reaching the driver's eye in the visible (380 to 780nm) were within the interval [136 to 1623] W/m^2 for halogen bulbs and [260 to 833] W/m^2 for xenon bulbs; or in equivalent form, within [2.6×10^8 to 6.4×10^9] photons $cm^{-2} \cdot s^{-1}$and [5.0×10^8 to 6.4×10^9] photons $cm^{-2} \cdot s^{-1}$ respectively.

From the IRC curves for the wavelengths under consideration, we find that there is no inhibition at all because, as shown in Fig. 1, irradiance must be higher than 10^{12}photons $cm^{-2} \cdot s^{-1}$. Indeed, a suppression of 35% is reached in the interval between 10^{13}and10^{14} photons $cm^{-2} \cdot s^{-1}$. However, the irradiance values reaching the driver's eye obtained for both type of light sources (halogen and xenon) are lower or equal to 10^9photons $cm^{-2} \cdot s^{-1}$.

The values of irradiance for the wavelength of 460 nm, for which melatonin suppression is maximum according to the IRC curves, were 9.5×10^8 for halogen bulbs and 1.2×10^9 for xenon bulbs. Therefore, these values are far away from those necessary to start melatonin suppression.

Thus, much more intense light sources should be necessary to produce melatonin inhibition in order to diminish the risk of falling asleep in night drivers.

Although the intensity of headlamps cannot be arbitrarily increased because it would cause glare, the results of this work highlight the necessity of designing optical systems that concentrate light on those zones of the road that are visible only by the driver of the concerned vehicle but not for incoming drivers, that is, below the cut-off of the beam pattern. The recent development of much more intense lighting sources in automotive lighting such as laser beams, may be an accurate solution in order to enhance the illumination in the necessary parts of the road thus increasing the luminance perceived by the own driver and increase melatonin inhibition. Future research will be focused on the design of the optical systems to perform such lighting pattern.

3. Conclusions

The results obtained in this theoretical study show the following conclusions:

- Classical halogen headlamps do not inhibit melatonin secretion trough retro-reflection during night driving.
- This research answers the following question: Can xenon headlamps cause more melatonin inhibition than the classical halogen headlamps due to the spectral composition of the light they emit? The answer is no with the current technology.
- Since the risk of falling asleep during night driving would decrease if melatonin inhibition was reached, this should be used to design new headlighting systems.
- A new AFS (Adaptive Frontlighting Systems) that concentrates light on those zones of the road that are visible only by the driver of the concerned vehicle is proposed in order to produce melatonin inhibition during long periods of night driving. It is proposed to be performed with laser or similar new sources with high intensity.

As resume, we believe that future headlighting systems in vehicles must consider, not only efficiency, but also the influence of light on melatonin inhibition to increase safety. In addition, the proposed methodology used can be very useful, in our opinion, for future calculations of melatonin suppression in more complex situations.

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