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Non visual effects of light: an overview and an Italian experience

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Abstract

Since the discovery of non-visual effect of light, consequences on human psychology and physiology have been investigated; however, effects on cognition of exposure to different spectral composition have been partially explored. Aim of this paper is an overview on researches developed in this field to compare general approaches and measurements protocols: the scarce knowledge of the physiological mechanisms, as well as the lack of shared methods, techniques, tools and procedures represent the weak point of this research. The impact of different procedures and experimental settings on results is shown, evidencing the need for scientifically consistent and internationally agreed procedures.

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1. Introduction

The discovery of the role of the intrinsically photosensitive Retinal Ganglion Cells (ipRGC)[1] has confirmed the existence of a non-visual pathway of light in the brain able to influence the human physiology and psychology [2, 3]. Light regulates many human biological functions on a circadian rhythmicity: previous studies demonstrated these non-visual effects on sleep-wake cycle, melatonin and other hormones secretion, core body temperature and heart rate [4]. In the same way light elicits positive effects on psychological states like mood, depression and behavior [5]. The efficacy of these non-visual effects depends on timing and duration of light exposure [4] and also on the quality of lighting. It has been shown that bright light affects both physiological and psychological states and that the blue light is the most effective emission [6, 7] in stimulating the circadian system[8].

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Cognitive processes are directly affected by light for its activating effect on many areas of the brain that produces an increase of the alertness state: electroencephalogram monitoring has shown how light reduces alpha and theta activities (indicators of different states of vigilance-sleepiness) linked to sleeping and neuroimaging studies have demonstrated the activation of brain structures as consequence of lighting [9]. Studies on brightness have confirmed that high illuminance levels enhance brain activity, increasing arousal and alertness [10]; furthermore, the use of white bright light can improve performance and cognitive functions [11]. Nevertheless, a limited number of studies addressed the effect of correlated color temperature, and in particular of blue light, on cognition, and that these works obtained different results.

This field of research will have potentially very important applicative consequences in interior as well as in exterior lighting design; although we are still in the early days of understanding what will constitute a healthful lighting application in any specific installation, this represents a very promising field of activity and research. The aim of this work is to review some of these contributions and then to compare them with the study carried out by the authors, with the intent of analyzing the lack of uniformity and of indicating possible solutions and future directions.

Nomenclature

E	illuminance (lux)
CCT	correlated colour temperature (K)
ipRGC	intrinsically photosensitive retinal ganglion cells
EEG	electroencephalography

2. A brief review on the effects of lighting on mental performance

2.1. The international experience

The studies conducted on the influences of CCT of light on cognitive functions was aimed at analyzing whether the quality of light improves the cognitive performances and which spectral composition can enhance the brain work.

The first investigations compared the effects of different fluorescent lighting producing the same E level, but results have shown that the different spectral compositions did not affected mental performances or they obtained contrasting results. In Deguchi and Sato [12] experiment, 11 subjects executed an attentive task in an shielded and monitored chamber lit with 3000 K, 5000K and 7500 K fluorescent lamps; even though no effect of light was found on reaction times, the EEG recorded a grater cerebral activation with cold than with warm lighting. In a previous study [13] three different fluorescent lighting (3000, 4150, 5000 K) did not produce statistical difference on simple verbal and quantitative tasks, neither on ratings nor on moods, but these results could be imputed to the between-subjects design. More recently Sivaji et al. [14] compared the performances of 10 subjects exposed in separated days to fluorescent warm white (2700 K), cool white (4000 K) and artificial daylight (6200 K) within a test room: it was found that differences in CCT did not affect visual task performance, but subjects typed most quickly with cool light; interestingly, the level of self-reported alertness increased during the experiment with warm light.

Some works investigated the effect of lighting in real settings using blue-enriched white light to understand if high CCT can improve mental performances. In the study of Mills et al. [15] substantial improvements of wellbeing, alertness and work performance have been observed using validated questionnaires in a shift-working call centre with fluorescent lamps of 17000 K compared to the baseline lighting of 2900 K; similarly results of Viola et al. [16] have indicated that the blue-enriched white light experimented within an office has improved the subjective measure of alertness, mood, performance and other indicators of wellbeing assessed with 9 questionnaires, compared to a fluorescent white light of 4000 K.

As consequence of the development and diffusion of the LED technology, research has started to investigate the effects of this new light sources on human vision and performance; using LEDs, Keis et al. [17] have experimented within two classroom a test lighting realized with a mix of direct white light (4000 K) and indirect blue-enriched white light (14000 K), obtaining a CCT of 5500 K, and comparing it with a standard fluorescent lighting: students in the test classroom have showed faster cognitive processing speed and better concentration with respect to students under the standard lighting.

Based on previous literature, Hawes et al. [18] have experimented the effect of four lighting conditions (fluorescent 3300 K, LED 4000 K, LED 5500 K, LED 6000 K) in a controlled setting, using a within-subject design and sensitive tests: 24 subjects executed 3 visual perception and 2 cognitive tasks under each lighting condition, and their mood was measured prior to and following the exposure to different lightings. Results have showed faster performance in one visual task and in both cognitive tests with higher CCT, but no effect on their accuracy; moreover the authors found that higher CCT decreased depression and fatigue and increase vigor and activity.

2.2. The Italian experience

The research developed at Sapienza University [19] is contextualized within the investigations on new LED lamps, with particular focus on the still unknown effects of their radiation on human beings. The study aimed at analyzing the influence of different CCT on cognitive functions, by comparing two lighting conditions with very different spectral compositions: warm CCT halogen lamps (2800 K) and neutral white LED (4000 K). Two specific aspects of the executive functions have been investigated: the inhibitory processes and the visuo-spatial abilities. The research, conducted in collaboration between the ENEA Lighting Laboratory of Ispra and the Faculties of Psychology and Engineering, took place in an experimental cabin where lighting and environmental parameters were carefully controlled. Forty-four healthy university students, were accurately selected among people in the age between 18 and 35 years for participating in the experiment. Participants were randomly subdivided in two groups as request in the specific experimental design: subjects in the ‘experimental group’ performed the cognitive tasks in a baseline session with halogen lamps, then spent a break time and repeated tasks in a test session with LED light; the ‘control group’ performed the same protocol under only halogen lamps, instead.

In each session, participants of both groups performed the same two highly sensitive cognitive tasks, and compiled a validated questionnaire during the break time and at the end of the experiment, in order to self-evaluate their performance. A Task-Switching (TS) paradigm was used to evaluate the inhibitory process, while the visuo-spatial abilities were tested with the Purdue Visualization of Rotations Test (ROT); an accurate description of the two tasks is provided in [19] and an explanation of the experimental protocol is reported in Table 1.

Table 1. The experimental protocol indicating the lighting scenarios and the tasks preformed by the two groups.

Session	Tasks	Experimental lighting	Control lighting
Baseline session	TS and ROT	halogen	halogen
Break	-	LED	halogen
Test session	TS and ROT	LED	halogen

Results have showed that performance on executive functions and visuo-spatial abilities are modulated by exposure to a cooler light. In the ROT, participants have been significantly more accurate (higher number of hits and correct rejections) and faster response times have been registered under LED light than with halogen lamps; performing the Task-Switching paradigm, participants in the experimental group have showed a significantly reduced backward inhibition effect during the test phase than the baseline, whereas participants in the control group showed no difference between the baseline and the test phase.

3. Discussion

Starting from the analysis of previous works investigating the interaction between quality of light (spectral composition and color temperature) and human cognition, discordant findings emerge with a tendency to indicate the positive effect of the cold light on mental performance in the most recent works. Nevertheless, some considerations concerning the reasons of the lack of uniformity of results, can be outlined.

In general, it is necessary to take into account that different brain functions have been investigate in each work (Table 2), from the general level of alertness or fatigue to the most specific executive functions or memory, depending on specific interests of research teams. Light could affect only specific functions or the effect of light could be different depending on the zone of brain: these topics have not been investigated in detail. Moreover, different tests or techniques have been used in each study to measure and monitor brain functions: it is clear that questionnaires, tasks and instrumentation were selected for their reliability in investigating each specific topic, but often different tests with the same validity can be used for examining the same function. The use of multiple techniques for observing the same phenomenon, for instance a cognitive test together with the functional electromagnetic resonance, is advisable because it allows the relative measures to be integrated and more reliable results to be obtained.

Table 2. Main characters of the studies examined.

Object	Deguchi, Sato 1992 [12]	Boray et al. 1989 [13]	Sivaji et al. 2013 [14]	Mills et al. 2007 [15]	Viola et al. 2008 [16]	Keis et al. 2014 [17]	Hawes et al. 2012 [18]	Ferlazzo et al. 2014 [19]
Cognitive performance		X	X	X		X	X	X
Alertness	X		X	X	X			
Mood		X			X		X	
Concentration				X	X	X		
Ratings		X						
Work performance				X	X			
Memory						X		
Comfort			X	X	X			

Another element to be considered is that the above mentioned studies have investigated different light sources (fluorescent, LED and halogen lamps), and this has deeply influenced the findings of the literature, being the light source the principal variable of these studies. The earlier works compared the effect of different CCT in fluorescent lamps, then the diffusion of LEDs moved the interest on these new sources, confronting them at different CCT or with fluorescent and halogen; as these lamps have very different spectral compositions, results of literature should be considered separately, in function of the source type investigated. Independently of the specific typology of lamp examined, it must be also underlined that these studies have investigated very different CTT, and lighting with different intensities: all these variables affect the experiment and human response (Figure 1). To isolate the CTT effect comparing to that derived from light intensities, the Italian study has been developed with a low E level at participants' eyes in both tested lighting conditions.

As a critical analysis has shown [20], the setting in which the experiment has performed has a great influence on results; this is particularly true when lighting is the object of the study: presence of windows, color of walls, furniture, intensity of light and phenomenon like glare or flicker are variables that affect results. Literature reveals that not always studies have been performed using an experimental setting (62% of considered works), but sometimes they have been conducted in a real environment (38%), like a classroom or an office; in this second hypothesis, the control of many variables is very difficult and the findings deriving from the study cannot be completely generalized, as they are strictly limited to the real setting in which the study has been carried out. On the contrary, researches performed using test rooms obtain results describing the absolute effect with a higher scientific relevance, but their application in real environments could result less effective. On this basis, the Italian experiment has been performed in a fully controlled test room, with the further intent to apply it in a real setting, to verify the previous findings.

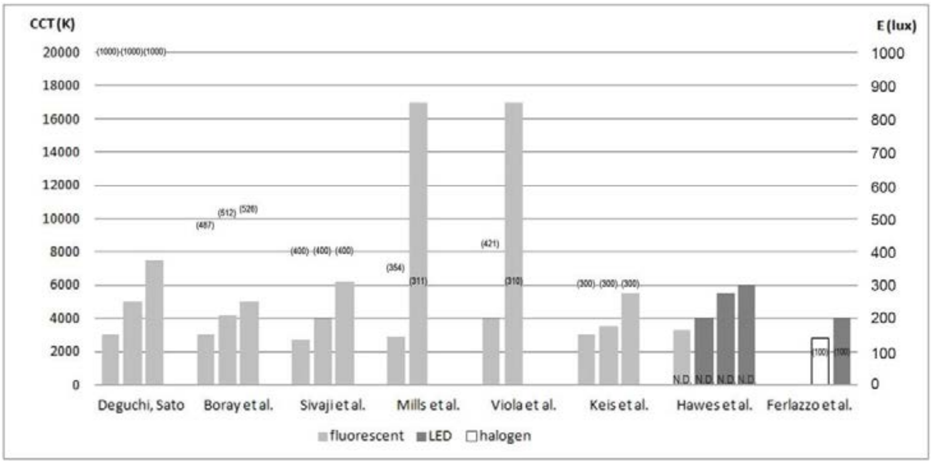

Fig. 1. Diagram of lighting investigated: lamps, CCT, illuminance (in brackets; N.D.=not declared)

The selection of the correct sample of subjects is very important for the validity of results; in addition to the exclusion criterions, that depend on the object under investigation, the age of participants must be taken into account when the studies regard the effect of lighting (Figure 2a). The human visual system undergoes to the aging effects, like yellowing of crystalline, and perception of light changes with years going by: for this reason it is important to include participants' age within a limited range, because testing subjects with a remarkable difference of age, can produce high variability of results. For this reason, subjects younger than 35 years old have been tested in the Italian experiment, this age being characterized by limited changes occurring to the human eye.

Moreover, an inadequate sample size can lead to insignificant finding of light effects (figure 2b); for this reason, a study with few participants should be only considered as a preliminary experiment and its validity should be confirmed through more extensive analyses. The power of the experimental design is not limited to the correct number of participants, but it also concerns the capacity to select the most indicated tests for the study, and to exclude elements that could interfere with the independent variable, or to adopt a between-subject or a within-subjects design.

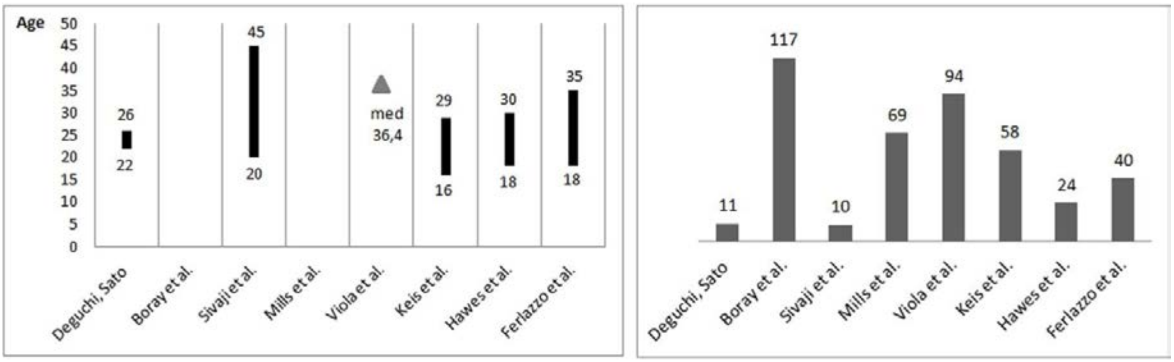

Fig. 2. (a) Age of participants: maximum, minimum, average (b) Number of subjects participant to experimental studies

4. Conclusion

The main aspect emerging in the review analysis here developed is the number of multiple different variables existing in these studies: the most evident are the large variety of brain functions investigated, the high number of tests utilized for their evaluation, and the difference in the spectral composition of the lamps examined. A reason imputable for the discordance in literature findings can be the different experimental settings in which researches were performed, for their explained great capacity to affect the results.

The use of shared methods, techniques, tools and procedures represents a possible solution for obtaining more uniform results; also, the definition of experimental protocols agreed by the scientific community and roadmaps to follow when investigating the effect of lighting on mental functions, could be additional valid instruments to enhance the research.

The future research should improve the consistency of results, by using both controlled and experimental settings, making so possible to quantify the impact of the setting on the light stimulus, and giving a chance to move from theoretical and experimental to real environments where people live.

The results of all the research activities carried out in the field of the non-visual effect of light are opening a new way of interpreting the role of lighting inside buildings and, in the future, they are destined to change the current approach to lighting design. The concept of artificial lighting as a function of the human activity will be in the future enriched taking into account also the physiological and psychological effects of the luminous stimulation.

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