Lighting Design: Non-visual impacts and its influence on employees' health and well-being

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Abstract

In the last ten years, findings in medical science reveal that light plays important roles in maintaining optimum regulation of biological rhythms and hormones on a daily basis. Despite the decades of research, it was only in 2002 that David Berson discovered the connection between light and a third type of photoreceptor in the retina and this was the missing link in the description of the mechanism of biological effects controlled by the light and dark cycle. This discovery revolutionized the research on the spectrum, the intensity, the duration and the type of light that affects biological responses. This work addresses this issue of non-visual impacts of human exposure to light, in an attempt to relate the quality of lighting design to health, comfort, and well-being of female retail store employees. The sample for the cross-sectional study was randomly established with 30 female volunteers in street retail stores (possibility of outside visual contact) and shopping mall retail stores (no outside visual contact). Assessment of lighting considered the occurrence of glare, color appearance of light, flexibility, and possibility of lighting control by employees. The tools to assess well-being and health were psychometric scales internationally validated by the psychiatric field to measure depression, anxiety, and stress symptoms. Assessment of sleep conditions and analysis of the activity/rest rhythm was carried by a wrist monitor with attached luximeter and the analysis of the body temperature rhythm was made by a temperature sensor, to which each participant was submitted for five consecutive days. The lighting pattern's influence on the circadian system was verified by measuring saliva melatonin and cortisol levels. The degree of satisfaction of employees and their preferences regarding work environment lighting were surveyed by applying questionnaires. Data were analyzed using Pearson correlations, ANOVA, and stepwise regression.

Keywords

lighting design; health; circadian rhythm; cortisol; melatonin; retail stores;

The role of design has become increasingly more complex in daily life, increasing the need for understanding users' desires, needs and priorities and the way they interact with new products and technologies, which include, among others, new lighting design technologies. Studies (Campbell et al., 2007; Margolin, 1997) have systematically pointed out the relevance of incorporating the information provided by the user into the design in order to develop innovative products, spaces and, especially, sales outlets. In the specific case of lighting in retail stores, the previous work by the author (Martau, 2009) shows that there is a significant conflict between a lighting design oriented to product sales and a design oriented to the health and well-being of store employees, which can influence their productivity. In view of these complex challenges, a user-based research approach is an alternative for qualifying answers provided by the design. The Human-Centered Design approach aims at the better understanding of human needs in order to monitor, assess and propose innovations in the field of design having social and financial viability in mind. Desmet and Hekkert (2007) describe the potential of this research approach which encompasses from behavior studies to the affective experience resulting from the interaction between humans and products to define design attributes and parameters (Wellings, Williams & Pitt, 2008). The study of the interaction process between user and retail store lighting system has this goal, since in placing human beings once again as the central object of lighting design new strategies need to be established so as not to fail to address the primary objective of a retail space, namely, advertising a product or brand while at the same time allowing users/workers to be in good health and well-being conditions.

Background

The architectural typology adopted in shopping mall buildings in Brazil and the type of service provided generate many environments without outside contact and work shifts that advance into the night, both potential factors for the alteration of biological rhythms. A major challenge in the past years in the illumination field has been to define how light affects health, not only in aspects related to vision, but also related to metabolic processes (studies of circadian rhythms and tumor development, for instance). A population of special interest for the study of the relationship between light and health conditions is that comprising shopping mall employees, who are subject to artificial lighting in environments without windows during the day and often work until late at night. These individuals seem to be potentially more susceptible to diseases related both to excess lighting and to insufficient lighting. Although literature presents several studies on offices (Galasiu & Veitch, 2006) there are very few works relating commercial space employees to lighting (Heschong Mahone Group, 2003), both in the area of architecture and marketing or behavior, in which only Bitner’s work (1992) stands out for including the employee and not only the consumer. Consequently, many shopping mall buildings have uncomfortable conditions for occupants, who, out of necessity, end up adapting themselves to the environment (Martau e Duro, 2005; Martau, 2009).

The knowledge about the relationship between lighting, man and Architecture can be summarized through several approaches to this topic. Regarding human performance, there are three main routes of analysis: through the visual, perceptive and circadian systems. The two former have some consolidated knowledge demonstrating how to illuminate in order to obtain visual comfort and stimulate perception. However, the knowledge of the relationship between lighting and the so-called human circadian system (24-hour daily rhythms) is still incipient. Exposure to light may have both positive and negative impacts on human health. These impacts may become evident shortly after exposure or only after many years. Understanding how light influences the human body helps describe the impact of lighting on building occupants.

The circadian rhythms can be regulated by a variety of external indicators, but light (light/dark cycle) is the primary and most important variable in the synchronization (or desynchronization) of humans with day or night rhythms (Gronfier, Wright, Kronauer, & Czeisler, 2008). he activity-rest rhythm, the body temperature rhythm and the hormone levels (melatonin and cortisol, see figure 1) are examples of light-regulated biological rhythms in the body that can be measured. When an individual is in a healthy state, all of his/her rhythms have a natural relationship, we say that said individual’s phase is normal (Kaplan, Sadock, & Grebb, 1997). When the system is disturbed (by staying up at night, for instance), some biological rhythms become disarrayed (e.g., cortisol or melatonin rhythms) and are considered to be out of phase. The fact that the biological rhythms are out of phase contributes to the harmful effects experienced by the individuals. Some disorders have phase disturbances among their symptoms.

Melatonin is a very important hormone in the investigation of human biological rhythms regulated by the light/dark cycle (Kaplan,Sadock, & Grebb, 1997). The relationship between melatonin inhibition and light is direct, and melatonin responds to lighting only. Its rhythm is considered an excellent phase marker for the endogenous biological clock (Arendt, 2005), and it may also be a great indicator for the quality of lighting in relation to employees’ health.

Cortisol is another hormone that takes part in the so-called adrenal axis. Cortisol shows a clear circadian rhythm, with its peak around the time the individual wakes up (Kudielka & Kirschbaum, 2003). Cortisol plasma concentrations are higher in the early morning (around 6 a.m.) and their values are lower in the afternoon and evening. As cortisol is controlled by the biological clock in the suprachiasmatic nucleous (SCN), cortisol rhythm and concentration are expected to be influenced by light.

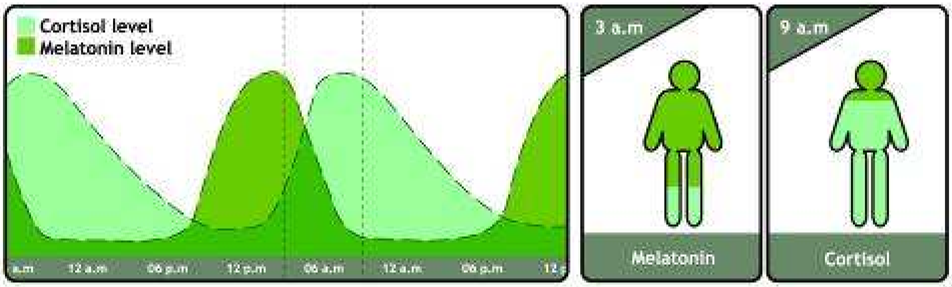

Figure 1: Relationship between melatonin and cortisol rhythms

The body also has an endogenous temperature rhythm called body temperature rhythm, which is considered to be the most stable body rhythm in relation to external variations (Noguera, Riu, Hortensi, & Cucurella, 2007). The hormones cortisol (stress hormone) and melatonin (sleep hormone) play an important role in the sleep/wake regulation, and there are some rhythm relationships between cortisol, melatonin and body temperature. In order to maintain one's health, it is important that these rhythms remain steady. Biologically, the time and duration in which light (or darkness) is received play a crucial role in establishing body temperature (Boyce, 1997).

Studies have shown that stress is also associated with lighting conditions. Stress changes rhythmically with diurnal regulation, as well as with cardiac regulation and neuroendocrine responses, which seem to be responsible for the higher rates of cardiovascular disease found in chronically stressed individuals (Monk, 1983).

Research goals and Methodology

The general goal of this study was to evaluate how lighting conditions interfere with the health and well-being of street retail store and shopping mall retail store employees in Porto Alegre, a city located in south Brazil. For this purpose, specific goals were also defined: to characterize the relationship between lighting conditions and emotional variables such as depression, anxiety and stress; determine if differentiated lighting conditions interfere with the biological rhythm (sleeping conditions, activity/rest rhythm, and body temperature rhythm); determine the levels of the hormones melatonin and cortisol in female employees' saliva in relation to different lighting conditions in stores; and verify female employees' satisfaction and preferences in relation to lighting systems at the workplace. The research was characterized as an exploratory study, with empirical investigation of phenomena in their actual context, with multiple evidence sources (variables).The study sought to assess and relate visual, biological and emotional aspects of lighting in the stores analyzed from the perspective of the individuals who worked therein (figure 2).

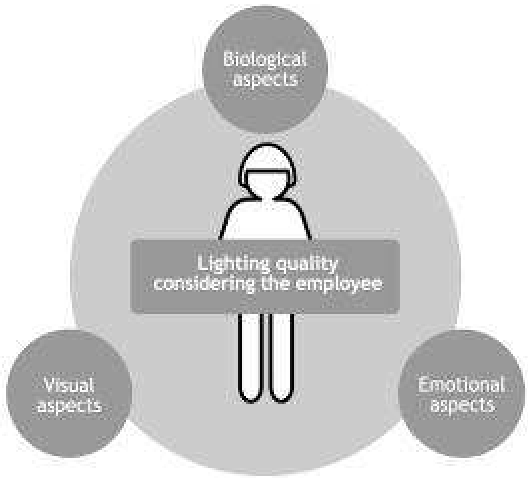

Figure 2: Lighting quality: visual, emotional and biological aspects should be considered

Subjects

Women aged between 18 and 65 years, who lived in the city of Porto Alegre, were selected. All subjects were employees in commercial spaces and must have been working for at least one year at the place and shift under study and could not be working double time. Despite minor variations in entry, lunch, break and exit times, female employees who worked for five to eleven hours on a daily basis were included. All of them volunteered for the study. They were divided in three groups:

- Group A: Ten street retail store employees with presence of daylighting and daytime work (8 a.m. to 6 p.m.).
- Group B: Ten shopping mall retail store employees, without presence of daylighting, and daytime working hours (10 a.m. to 6 p.m.).
- Group C: Ten shopping mall retail store employees, without presence of daylighting, and afternoon and evening working hours (2 p.m. to 10 p.m.).

Procedures and equipment

Evaluation of lighting conditions

Lighting conditions were evaluated by taking photos of the luminous environment and by completing a survey form in which the main aspects of the physical environment and lighting system were recorded: ground plan of the spaces under study, containing the shape and basic dimensions, description of materials and colors, list of light bulbs and luminaries. Items such as color appearance of light bulbs were obtained from the manufacturer's technical specification catalogue. The entrances were marked (if any) and the distance between the employees and the entrance was measured. The general illuminance of the space was measured at four points (to average general illuminance) and at work planes with a portable lux meter. The spaces with day lighting were measured at noon, within the climatic period referred to as spring/summer, on days without rain and at times without direct insulation into the space. All the spaces analyzed had an artificial lighting system activated throughout daytime or at least most of daytime, day lighting in these spaces being, therefore, only quantitatively complementary. The visibility of visual tasks was checked by using the Snelling Chart, which is a standard test to assess visual acuity at preset distances. Undesired reflections were evaluated by moving around the space and placing a reflective surface at different positions to check the presence of it. See synthesis of procedures in figure 3.

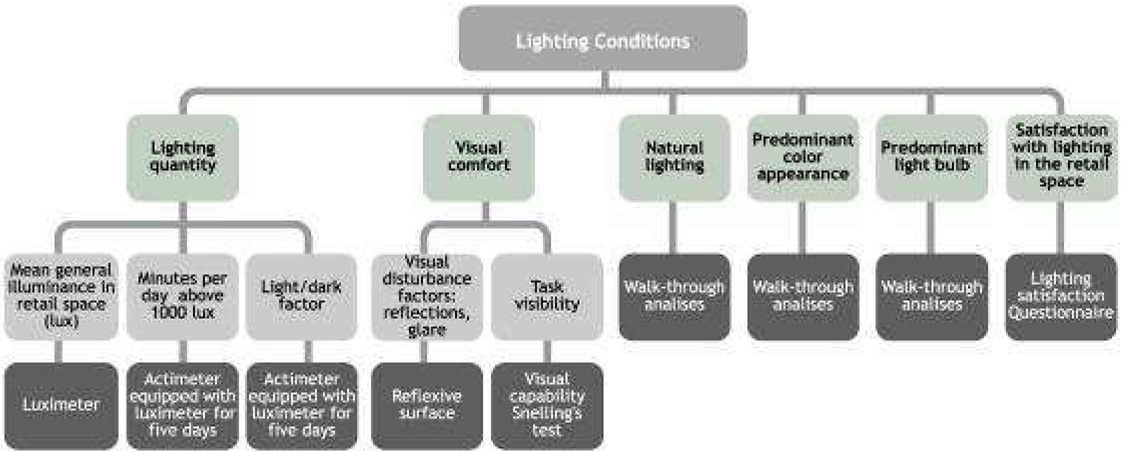

Figure 3: Synthesis of procedures for evaluating lighting conditions

Evaluation of satisfaction with workplace lighting

To evaluate employees' satisfaction with the store lighting, a questionnaire was applied which was developed from other lighting quality evaluation tools (Bean & Bell, 1992; Boyce & Eklund, 1995; Veitch & Newsham,1995; Veitch, 2001), as well as adaptations of part of the guide proposed by the Commission Internationale de l'Éclairage (Commission Internationale de l´Éclairage, 1986 &1972) to evaluate lighting in office environments, with adjustments to the type of existing visual tasks in commercial spaces.

Evaluation of emotional aspects: possibility of mental disorder, depression, anxiety and stress

To evaluate emotional aspects, the so-called psychometric scales were used, validated for Brazilian Portuguese. These are: Self Reporting Questionnaire -SRQ-20 (psychiatric disorder) (Mari & Williams, 1986), Montgomery-Asberg Depression Rating Scale (Dractu, Ribeiro,& Cal,1987), Beck Depression Inventory – BDI (Gorenstein, Andrade, Vieira Filho, & Tung, 1999), Hamilton Depression Scale (Hamilton,1967), State-Trait Anxiety Inventory –STAI (anxiety) (Spielberger,1983) and Lipp's Adult Stress Symptom Inventory (LSSI) (Lipp & Guevara) for stress assessment.

Assessment of sleep conditions

The Pittsburgh Sleep Quality Index questionnaire – PSQI (Buysse, Reynolds, MONK, BERMAN, & KRUPFER, 1999) and the Epworth Sleepiness Scale (Johns,1991) were used to evaluate quality and daytime sleepiness.

Assessment of the timing system: body temperature rhythm and activity/rest rhythm

Body temperature was measured continuously, for five days, by means of a thermistor (Ibutton, 2008) used together with an actigraph (Mini Mitter, 2007) to check if there were changes in the body temperature rhythm between the groups. It was fixed with an adhesive on the internal region of the forearm (figure 5 and 6). The Activity/Rest rhythm was measured by an actigraph with a coupled lux meter (figure 4), for a period of five consecutive days, always including the weekend. The use of an actigraph allowed the illuminance patterns to be analyzed for 24 h in each employee.

Figure 4: Actimeter placement on the wrist of the non-dominant hand.

Figure 5: Thermistor placement on the internal area of the wrist of the non-dominant hand.

Figure 6: Fixation of a thermistor on the internal region of the wrist of the non-dominant hand with skin-colored tape.

Melatonin and cortisol

The melatonin and cortisol levels were analyzed in the saliva, collected by the employee herself (participants were asked to rinse their mouth with water before collecting saliva) directly by expectorating into a collecting tube (12a.m,18 p.m.,12 p.m). After the collections, the saliva was frozen. For melatonin levels, a commercial ELISA kit from APCO Diagnostics® (ELISA kits, Buhlmann Laboratories, AG Swiss) was used. For cortisol levels, a Roche chemiluminescence kit was used. All the procedures for evaluating health and well-being conditions are synthesized in figure 7.

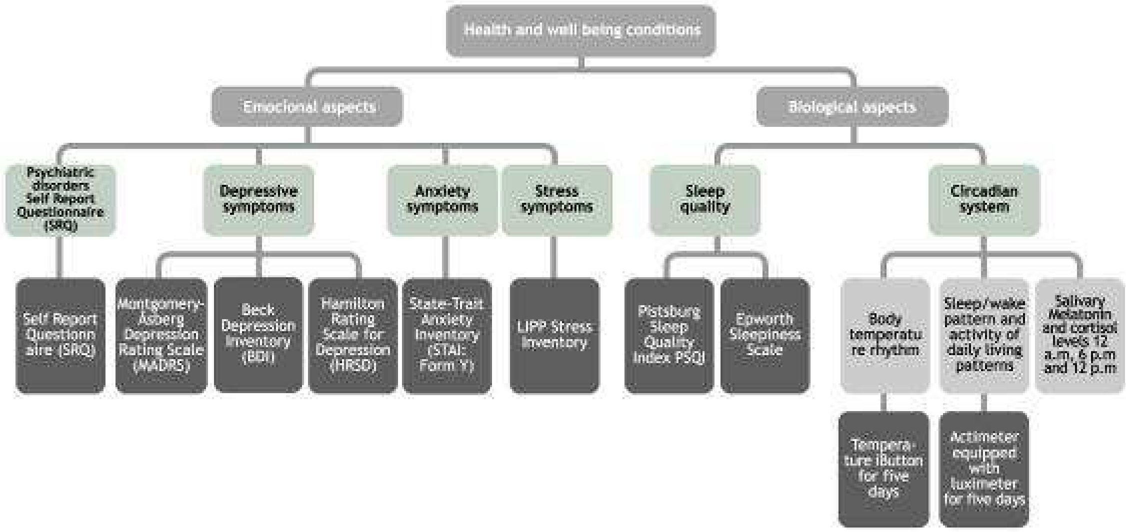

Figure 7: Synthesis of procedures for evaluating health and well-being conditions

Data processing and statistical analysis

Data were organized in a databank using the Excel software (Microsoft). The statistical analysis was carried out with the Statistical Package for Social Science (SPSS) program for Windows, version 13.0. A consistency analysis of the results was performed after the tools were applied by means of the Cronbach's alpha. The distribution of variables was described as mean and standard-deviation or frequency and proportion, when suitable. Stepwise multiple regression analyses were performed. Correlations between variables were analyzed using Pearson's Correlation Coefficient and variance analysis (ANOVA). The potentially confounding variables controlled in the statistical analysis were age, working hours and working shift

Results and Discussion

The results point to a greater dissatisfaction with the workplace lighting in the category shopping malls (groups B and C) than in street stores (group A). This dissatisfaction is highlighted in some aspects assessed, such as possibility of contact with the outside, lighting for the employee to feel relaxed, happy and motivated to work, in which the scores are far lower than in the street store group. The stores of groups B and C, where dissatisfaction with lighting in general is 20% higher than in group A, were the ones in which the employees reported greater dissatisfaction with the absence of visual contact with the outside, which was found to be inversely correlated with depression (Beck) in group C, specifically. The study in the stores demonstrated that the individuals who were more satisfied with the lighting system (independent of the type of lighting to which they are subject) are the ones having a greater light/dark factor and greater satisfaction with the possibility of visual contact with the outside, and these were in group A. In this group, the greater the satisfaction with the possibility of visual contact with the outside was, the lower the depression scores were (Montgomery-Asberg).

The most consist finding, which has a greater impact on the current lighting practice in shopping malls is the inverse correlation found between the average general illuminance of a store and the satisfaction with lighting, as well as the positive correlation of this variable with scores showing a possibility of mental disorder and depression, in group B, and with biological indicators (24-h temperature and melatonin acrophase) in group C. The shopping mall retail store groups presented greater average illuminance in the store (340 lux, group A, 478 group B and 666 lux group C), with predominance of words chosen by the employees describing illuminance as "bright and glaring", who showed a greater need for modifying the amount of lighting in the store, and the main change desired was a reduction in lighting during daytime. These results point to excess lighting for the employee, which may be related to greater stress, anxiety and tendency to cortisol rhythm loss in group B, and, in group C, higher scores indicating a possibility of mental disorder, depression and worse sleep quality, as well as changes in the 12-h melatonin level, with likely phase delay in the production of this hormone.

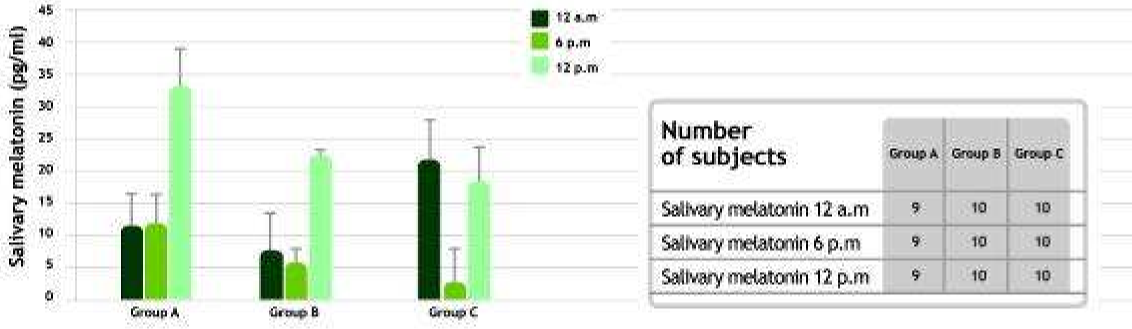

Figure 8: Salivary melatonin levels at 12 a.m, 6 p.m and 12 p.m by groups

The results shown in figure 8 suggest that individuals of group C suffer an alteration in melatonin rhythm, with probable phase delay (its peak is supposed to occur between 3 a.m and 4 a.m and decline significantly between 8a.m -9a.m, since, based on the level found at 12a.m and the relationship with the skin temperature rhythm, the peak must take place later than in the other groups. The observation of the melatonin production behavior in this group reflects directly the influence of the working environment lighting pattern of the store. These data, associated to the dissatisfaction with the average general illuminance of the store, in which the employees indicate a need for reducing daytime lighting, supports the hypothesis that the luminous environment is not suitable to meet the health and well-being requirements of the employees in these stores.

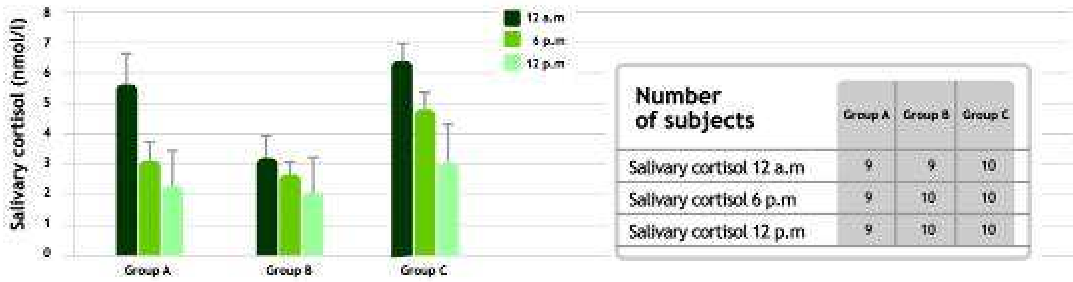

Figure 9: Salivary cortisol levels at 12 a.m, 6 p.m and 12 p.m by groups

Considering the situation of street stores (group A) as the optimal situation among the three groups, especially due to the presence of natural light and visual contact with the outside, groups B and C showed cortisol levels and variation between times different from the optimal ones (figure 9). The results found in the saliva cortisol levels (12 a.m, 6 p.m, 12 p.m) indicate a rhythm change (tendency to loss) in group B, in which a small variation between levels at three different times is observed, when a clear circadian rhythm is almost not perceived, with a peak around the time the individual wakes up (Kudielka & Kirschbaum, 2003). This may be explained by the absence of contact with more intense and natural light during daytime, because they are in a closed environment both in the morning and in the afternoon. Literature indicates that the exposure to intense light (preferably natural) in the morning is responsible for activating cortisol, more than at other times (Leproult, Colecchia, L'Hermite-Baleriaux, & Van Cauter, 2001). The group C employees spend the morning period outside the workplace, which enhances the possibilities of being exposed to higher and different illuminances (natural light). This may be associated to a better performance in relation to cortisol than the group that works in the morning and in the afternoon. Considering that other factors can change the cortisol rhythm, such as stress (Leproult et al., 2005), it is difficult to find a direct relationship between the tendency to cortisol rhythm loss in group B and lighting. Taking into account that in the groups without windows more than half of the employees are found to be stressed and that this percentage is higher in group B (60% stressed), it is necessary to evaluate more thoroughly the relationship between lighting, stress and cortisol rhythm loss detected here. There is a hypothesis that the need to adapt oneself to unsatisfactory lighting may lead to greater stress in this group and, consequently, to an alteration in the cortisol rhythm. The associations (positive correlations) of the cortisol level found with the SRQ, Hamilton and Epworth scores, in group B, support the hypothesis of a loss of cortisol production ability in these individuals due to stress, and the scale scores associate with the average general illuminance of the store positively (SRQ, Beck and Montgomery). As stress and depression are often part of the same disease situation, the hypothesis that the store illuminance is influencing health is suggested by the results found. Nevertheless, the results indicate that the luminous environment of the workplace, despite being influential, must not be studied separately, since workplace illuminance alone cannot explain variations in the circadian phase. The lighting in the workplace certainly influences the circadian effects, but it has to be interpreted in the context of the individual's full 24-h luminous pattern.

In all psychometric scales applied, the results pointed to higher mean scores for symptoms indicating a possibility of psychiatric disorder, depression and anxiety in groups B and C in relation to group A (figure 10). The higher absolute values in all variables analyzed showed that the more severe symptoms indicating a possibility of health alterations were also found in groups B and C, and that the environmental factor, including lighting, may be contributing to these results, which calls for a deeper analysis of these relationships.

	Group A	Group B	Group C
psychiatric disorder	**SRQ lower** No disturbance	No Disturbance	**SRQ higher** Disturbance found
depression	**Hamilton lower** 40% disturbance **Montgomery lower** **Beck lower**	**Hamilton** 50% disturbance **Beck higher**	**Hamilton higher** 40% disturbance **Montgomery higher**
anxiety	**Lower**	**Higher**	
stress	**Lower** 40% stressed	**higher** 60% stressed	50% stressed

Figure 10: Synthesis of psychometric scales

Since circadian rhythm regulation depends on the time and duration of exposure to light, the workers in group C seem to be more influenced by the light in the workplace, perhaps because they are exposed to high illuminances until a later time than the other groups. Group C was the one that differed from the others in the light/dark factor (lighting pattern), activity rhythm, mesor of skin temperature rhythm and acrophase behavior of activity and body temperature rhythm. The latter aspect is directly related with melatonin mechanism, which seemed to be altered in this group. These data, associated to the dissatisfaction with the average general illuminance in the store, through which the employees indicate a need for reducing lighting during daytime, support the hypothesis that the luminous environment is unsuited to meet workers' health and well-being requirements in those places.

The pattern of exposure to light provided by the actigraph lux meter did not find any difference in the amount of time of exposure to lighting between the groups, since the mean exposure time in minutes per day above a 1000-lux illuminance was similar between them, ranging from 62 to 68 min/day. A difference was found in the light/dark factor, which was lower in group C, which also differed from the others in the activity rhythm. This can be explained because, even though the times of exposure to certain illuminance is quantitatively similar, the type of light received is different (as regards spectrum, color temperature, visual access to the outside), which is quite important to people's health, as also shown in literature (Figueiro, Rea & Bullough, 2006; Farley & Veitch, 2001).This is an issue that needs to be discussed, because the regulations pertaining to lighting standards regulate the amount of light only, and not the quality or type.

The issues of uncomfortable noises and heat produced by light sources appeared in different correlations with the psychometric scales (anxiety in groups B and C), demonstrating that the non-visual aspects of lighting also have an influence on employees' well-being. In group A this correlation is not observed to appear, although their lighting systems have a worse quality than in shopping malls. This may be explained by the greater external noise found in street stores, masking the noise from light sources, which may make it more harmful. Similarly, the dissatisfaction with the heat produced by the light sources seems to be correlated with emotional variables in shopping mall groups B and C, in which the greater illuminances account for the greater discomfort with this aspect.

Conclusions

The study demonstrated that the female employees in the retail stores responded differently to lighting conditions in the three groups analyzed. There is a high degree of dissatisfaction with the lighting system in the three groups and satisfaction with lighting design was demonstrated to be associated to emotional and biological factors. By demonstrating this relationship, one can encourage entrepreneurs to invest in female employees' satisfaction with lighting and, indirectly, in their productivity.

The employees in street retail stores (A), where we found lower illuminances (up to 300 lux), showed higher drowsiness during the day and higher dissatisfaction with issues related to task visibility. Probably, it would be necessary to increase general illuminance in the category street stores, since dissatisfaction with lighting and daytime drowsiness may be indirectly associated to low illuminances (likely little circadian stimulation). The presence of windows and visual contact with the outside was an important factor for this group to present better conditions in the assessment of depression and stress, as well as the normal behavior of cortisol and melatonin levels.

The female employees of shopping mall stores working in the morning and afternoon shifts (group B) showed the worst conditions in the assessment of anxiety and stress among the three groups because they had no contact with natural light during the day as a result of their work time. The altered cortisol levels may be related to the high stress in this group and the lack of contact with natural light to stimulate it. Allowing them to have visual contact with the outside and access to natural light, whenever possible, is a precondition for health and well-being, since the results indicate direct and indirect correlations between this factor and higher depression and anxiety scores. This means that the project must prioritize the presence of windows, employing technical resources currently available to deal with issues of potential color fading caused by light, such as placing filters and special films on window panes.

The female employees of shopping mall stores working in the afternoon and night shifts (group C), where the highest average general illuminances were found (up to 700 lux) and the time to which they are subjected is later than the other shifts, showed physiological alterations in melatonin production and worse conditions in the assessment of depression. It is necessary to reduce general illuminance, since the alteration of the hormones melatonin and cortisol and the dissatisfaction in the shopping mall groups are directly and indirectly associated to high illuminances in the workplace. It also seems to be advisable to avoid using only one type of light bulb (same spectrum), reducing, thus, the risk of the existence of only one type of wavelength in the environment that may be harmful to the circadian system, until we learn what kind of spectrum is the most suitable and how these spectra interact with one another in a real environment. We must be careful so as not to use sources that are more suppressive of melatonin at night time and pay attention to new technologies, such as LED sources, until their influence on people is confirmed.

The results for the amount of light in stores indicate a need for adopting lighting techniques that incorporate intense light spotlighting the merchandise – which is the key to the process of attracting customers to buy – and milder general lighting for employees, light sources with reflected or indirect light being the most suitable for this, which is important for their health and well-being. It is crucial to review the international legislation that dictates high general illuminance for this type of stores.

The shopping mall typology must be reviewed since the lack of visual contact of employees with the outside is related to higher depression scores in these groups. In stores without visual contact with the outside, the variation and control of artificial lighting systems by employees or the use of a programmed system should be enabled, varying the amount of light and color appearance, since great dissatisfaction was found with the lack of variability in the luminous environment of stores without openings.

An important question raised by this study was that of the methodology used, which tested the variables to assess the quality of lighting focusing on human needs (visually, biologically and emotionally), as well as the tools brought from the fields of Psychology and Medicine. The methodology was deemed to be appropriate, since countless associations (correlations) were found between the variables under study, and the results were convergent and coherent between the different tools used. However, the methodology was found to be too complex and long for the employees, which resulted in a high number of drop-outs (12 people) after the start of the evaluation.

Lighting design needs to be regarded as a multidisciplinary field of knowledge aiming at developing and applying information on human behavior and physiology to environment lighting. The conceptual-theoretical base that is being established in the field of lighting design allows us to point out that, as human requirements become understood, a new paradigm is needed for contemporary lighting design. The technological solutions of lighting systems will remain of key importance, but it will be necessary to learn how to reorganize design guidelines in order to render them user-centered.

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