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ORIGINAL ARTICLE

Lack of exposure to natural light in the workspace is associated with physiological, sleep and depressive symptoms

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The diurnal light cycle has a crucial influence on all life on earth. Unfortunately, modern society has modified this life-governing cycle by stressing maximum production and by giving insufficient attention to the ecological balance and homeostasis of the human metabolism. The aim of this study is to evaluate the effects of exposure or lack of exposure to natural light in a rest/activity rhythm on cortisol and melatonin levels, as well as on psychological variables in humans under natural conditions. This is a cross-sectional study. The subjects were allocated split into two groups according to their workspace (10 employees in the "with window" group and 10 in the "without window" group). All participants were women and wore anactigraph (Actiwatch 2, Philips Respironics), which measures activity and ambient light exposure, for seven days. Concentrations of melatonin and cortisol were measured from the saliva samples. Participants were instructed to collect saliva during the last day of use of the actigraph at 08:00 am, 4:00 pm and 10:00 pm. The subjects answered the Self-Reporting Questionnaire-20 (SRQ-20) to measure the presence of minor psychiatric disorders; the Montgomery-Asberg (MA) scale was used to measure depression symptoms, and the Pittsburgh Sleep Quality Index questionnaire (PSQI) was used to evaluate the quality of sleep. The Rayleigh analysis indicates that the two groups, "with window" an d "without window", exhibited similar activities and light acrophases. In relation to light exposure, the mesor was significantly higher ($t = -2.651$, $p = 0.023$) in t he "with window" group (191.04 ± 133.36) than in the "without window" group (73.8 ± 42.05). Additionally, the "with window" group presented the highest amplitude of light exposure (298.07 ± 222.97). Cortisol levels were significantly different between the groups at 10:00 pm ($t = 3.009$, $p = 0.008$; "without window" (4.01 ± 0.91) "with window" (3.10 ± 0.30)). In terms of the melatonin levels, the groups differed at two different times of day: 08:00 am ($t = 2.593$, $p = 0.018$) and 10:00 pm ($t = -2.939$, $p = 0.009$). The "with window" group had a lower melatonin level at 08:00 am (3.54 ± 0.60) but a higher level at 10:00 pm (24.74 ± 4.22) than the "without window" group. Higher cortisol levels were positively correlated with minor psychiatric disorders and depressive symptoms (MA) at 10:00 pm. Lower melatonin levels at 10:00 pm were correlated with depressive symptoms and poor quality of sleep (PSQI). Our study demonstrated that not only may light pollution affect human physiology but also lack of exposure to natural light is related to high levels of cortisol and lower levels of melatonin at night, and these, in turn, are related to depressive symptoms and poor quality of sleep.

Keywords: Circadian rhythm, cortisol, depression, electrical light, melatonin, mood disorder

INTRODUCTION

The diurnal light cycle has a crucial influence on all life on earth (Qiu, 2006; Shen et al., 2009; Welberg, 2014). All living creatures have had to adapt themselves to the daily cycle of darkness and sunlight; the existence of this rhythm creates ideal moments to procreate, to forage for food and to rest (Amaral et al., 2014). Unfortunately, modern society has modified this life-governing cycle by stressing maximum production and by giving insufficient attention to the ecological balance and homeostasis of the human metabolism. The concept of light pollution is well-known today as the presence of electrical light during a period of natural darkness (Falchi et al., 2011; Riegel, 1973; Settele, 2009).

Periodic exposure to dark periods is necessary to maintain human physiology. For example, the muscarinic receptors that regulate the suprachiasmatic nucleus (SCN) are expressed only at night (Gillette et al., 2001). Appreciable levels of neurohormones,

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such as melatonin, are produced only during periods of complete darkness. Therefore, light pollution may be related to a relevant disturbance of the circadian organization (chronodisruption), which is reflected in metabolic syndromes and animal behavior disorders (Erren & Reiter, 2013). This relationship has been studied in several experiments (Amaral et al., 2014; Karatsoreos et al., 2011; Salgado-Delgado et al., 2010), showing the relationship between the presence of electrical light and physiopathology at night. However, testing this evidence in real-life situations, such as workspaces where electrical lights are exclusively used, is important.

Another example of chronodisruption is night-shift work. Shift workers may sleep sporadically or may completely invert their sleep schedules; either way, they are exposed to electrical light more frequently than non-shift workers. This light pattern has been correlated with an increased prevalence of obesity (Ruger & Scheer, 2009; Suwazono et al., 2008), psychiatric disorders (Healy et al., 1993), cardiovascular disease (Ruger & Scheer, 2009) and breast cancer (Lie et al., 2006; Stevens et al., 2011). In Latin American shift workers, a number of potential complications exist that must be accounted for (Wasserman, 1999): first, most workers hold more than one job, and therefore, the total number of daily working hours may be 16 or more; second, women are usually responsible for house work (child care, cooking, cleaning, etc.) and thus have less free time outside of their employment; third, most employees choose night-shift work because of its higher wages and not because they prefer the chronotype option; fourth, the intensity and stress levels related to each job are relatively broad and independent of the profession, making it difficult to compare the results of heterogeneous samples.

The majority of the literature focuses on shift work as a good model to evaluate chronodisruption. Here we analyze differences in work places, specifically the differences in light exposure in various work environments. Therefore, this study also probes the consequences of the diurnal light cycle on chronodisruption in non-shift workers. Therefore, the aim of this study is to evaluate the effects of exposure or lack of exposure to natural light in a rest/activity rhythm on cortisol and melatonin levels, as well as on psychological variables in humans under natural conditions.

MATERIALS AND METHODS

Sample description

This cross-sectional study comprised 20 employees of Hospital de Clínicas de Porto Alegre, located in southern Brazil. All participants were women. No difference was found in age between the ‘‘with window’’ and ‘‘without window’’ groups (41.3 + 11.5 years and 44.60 + 22.0 years, respectively; Student’s t-tests for independent samples $t = -0.420$ and $p = 0.679$ for ages between 18 and 60 years). The predominant shift was diurnal (between 8:00 am and 6:00 pm) at the same place for at least one year (Table 1). The exclusion criteria for the study were male subjects; workers with a history of stroke; workers with psychiatric comorbidities including primary sleep disorders, unconsciousness, suffering from Alzheimer’s disease, paraplegia or uncontrolled systemic diseases (e.g. hypertension, ischemic heart disease, renal failure, etc.); or workers with movement disorders or who have had emergency surgery. In addition, subjects who did not work at least one year on-site, workers who worked during the day shift and people working double shifts (day and night) were excluded. The use of illicit drugs was queried; those who responded that they had used any of a list of 30 medicines, including corticoids, beta-blockers, hormones and psychostimulants (cocaine, crack, etc.) were excluded from the study.

TABLE 1. Characteristics of demographics and work activities in the ‘‘with window’’ and ‘‘without window’’ groups.

	With window	Without window
Schooling		
Graduate	5 (50%)	5 (50%)
Undergraduate	3 (30%)	2 (20%)
Civil status		
Married	6 (60%)	3 (30%)
Single	2 (20%)	4 (40%)
Profession		
Secretary	2 (20%)	4 (40%)
Administrative agent	3 (30%)	3 (30%)
Nursing assistant	2 (20%)	0 (0%)
Frequent work shift in the last 10 years		
Morning and afternoon	8 (80%)	10 (100%)
Morning	1 (10%)	0 (0%)
Afternoon	1 (10%)	0 (0%)
Number of working days		
Five days	9 (90%)	10 (100%)
Six days	1 (10%)	0 (0%)
Number of hours working per day		
7 to 8 h per day	8 (80%)	7 (70%)
8 to 9 h per day	0 (0%)	2 (20%)
Time working in the current place		
From 1 to 3 years	2 (20%)	3 (30%)
8 years or more	3 (30%)	2 (20%)
At least a year	4 (40%)	1 (10%)
History of surgery	8 (80%)	6 (60%)
History of disease	3 (30%)	4 (40%)
Use of medicine	2 (20%)	6 (60%)
Use of stimulants (coffee, yerba mate, tea)	9 (90%)	9 (90%)

The subjects were allocated into two groups according to their workspace. The ‘‘with window’’ group comprised employees who worked in environments with natural light, i.e. where they received natural light through a window in addition to electrical lighting. Alternatively, the ‘‘without window’’ group comprised employees who worked in environments with only electrical lighting with no visual contact to the outdoors or outdoor light.

The assessment was conducted individually by trained professionals and research participants at the workspace of each subject. The study was approved by the Ethics Committee from Hospital de Clínicas de Porto Alegre (Project 16171 UFRGS/GPPG/HCPA) and all participants signed informed consent forms.

Instruments and measurements

The Brazilian version of the Self-Reporting Questionnaire-20 (SRQ-20) consists of 20 questions and serves as a screening for minor psychiatric disorders, such as somatization, depression, anxious moods and depressive thoughts (Mari & Williams, 1986). Higher scores indicate a greater likelihood of mental disorder. The thresholds for the Brazilian population are scores $\geq$6 for men and $\geq$8 for women.

The Montgomery-Asberg scale was used to measure depression symptoms; its adaptation to Brazilian Portuguese was validated (Dratcu et al., 1987). The instrument defines 10 categories of symptoms and produces a total score ranging from 0 to 60. The ranges are defined as 13–17 for mild depression, 18–26 for moderate depression, 27–36 for marked depression and >36 for severe depression (Muller et al., 2003).

The Brazilian Portuguese version of the Beck Depression Inventory was used to assess primarily cognitive aspects related to depression. This scale consists of 21 items, each rated from 0 to 3, indicating the intensity of each symptom. The score ranges from 0 to 63 (Beck et al., 1988). The threshold for the presence of an at least moderate mood disorder was defined as >10 (Gorenstein & Andrade, 1996).

The Hamilton scale includes 21 items that assess mood symptoms and somatic aspects of depression (Hamilton, 1960). The score ranges from 0 to 62. The cut-off points defined were 8–13 for mild depression, 14–18 for moderate depression, 19–22 for severe depression, and >23 for very severe depression.

The quality of sleep and the presence of sleep disorders over the previous 30 d were evaluated using the Pittsburgh Sleep Quality Index questionnaire (Buysse et al., 1989). This questionnaire contains 19 questions assessing seven components: sleep quality, sleep latency, sleep duration, sense of enough sleep, sleep disorders, medication use and daytime sleepiness. A global score is defined as the sum of the scores of these components; a global score greater than five indicates poor sleep quality.

Assessment of hormonal levels

Concentrations of melatonin and cortisol were measured from saliva samples. Participants were instructed to collect saliva during the last day of use of the actigraph at 08:00 am, 4:00 pm and 10:00 pm. Collector device called sterilized salivettes were used. These tubes were labeled with identifying information and were immediately frozen in 1.5-ml eppendorf-type tubes for further analysis. The samples were subsequently analyzed by radioimmunoassay.

Assessment of activity and light rhythm

The actigraph allows a noninvasive assessment of the activity/rest cycle of a subject in his own habitat. The actigraph device used in this study was an Actiwatch 2 (Philips Respironics), which measures activity and ambient light exposure. The Actiwatch was designed for long-term monitoring of activity in human subjects. The Actiwatch is connected to a computer via a USB port. The epoch length was 1 min. The software used was Actiware software® version 6.0 (Andover, MA). The data were converted into ASCII files and processed with the chronobiology program ''El Temps (Barcelona, Spain)''. The subjects wore wrist actigraphs with light sensors for seven days. Participants were monitored using the device for approximately 10 d, although the use for just 5 d, including a weekend, was sufficient. The subjects were instructed by trained research participants.

Data processing and analysis

Motor activity and light exposure data were first visually inspected by double-plotted graphs. For each participant, data were fitted to a cosinusoidal curve of a 24-h rhythm (cosinor analysis). This analysis provided the amplitude, mesor and acrophase of the adjusted rhythm. The means and standard errors of the daily acrophases were calculated. The stability of the daily phases of each individual's circadian rhythm was calculated using the Rayleigh z-test. The resulting vector angle indicated the mean peak time for each individual rhythm, and the magnitude of the vector (r) indicated the phase coherence. Therefore, a higher value of r was correlated with a more coherent phase of the rhythm. To study the phase tendencies of each group, Rayleigh z-tests were used in relation to the individual vectors, as described above, to obtain the mean vector of each group. The mean daily profiles of the rhythm of each variable and for each patient were calculated. From these profiles, we calculated the mean daily values of motor activity and light, as well as the diurnal and nocturnal mean values of the intensity of activity and light. This methodology has been described in other studies (Refinetti, 1999).

Statistical analysis

Data are expressed as the means ± SD. Means were compared by Student's t-tests for independent samples. The rhythm variables derived from the cosinor analysis, and amplitude (difference between the mesor and peak) and acrophase (clock time of the peak value) (Sokolove & Bushell, 1978) were also evaluated by discriminant analysis to estimate which variable (light and activity rhythm) had higher coefficients to discriminate ''with window'' participants from ''without window'' participants. For all the analyses, the statistical significance was set at $p < 0.05$, with a two-tailed hypothesis. Data were analyzed using SPSS version 16.0 (SPSS, Chicago, IL).

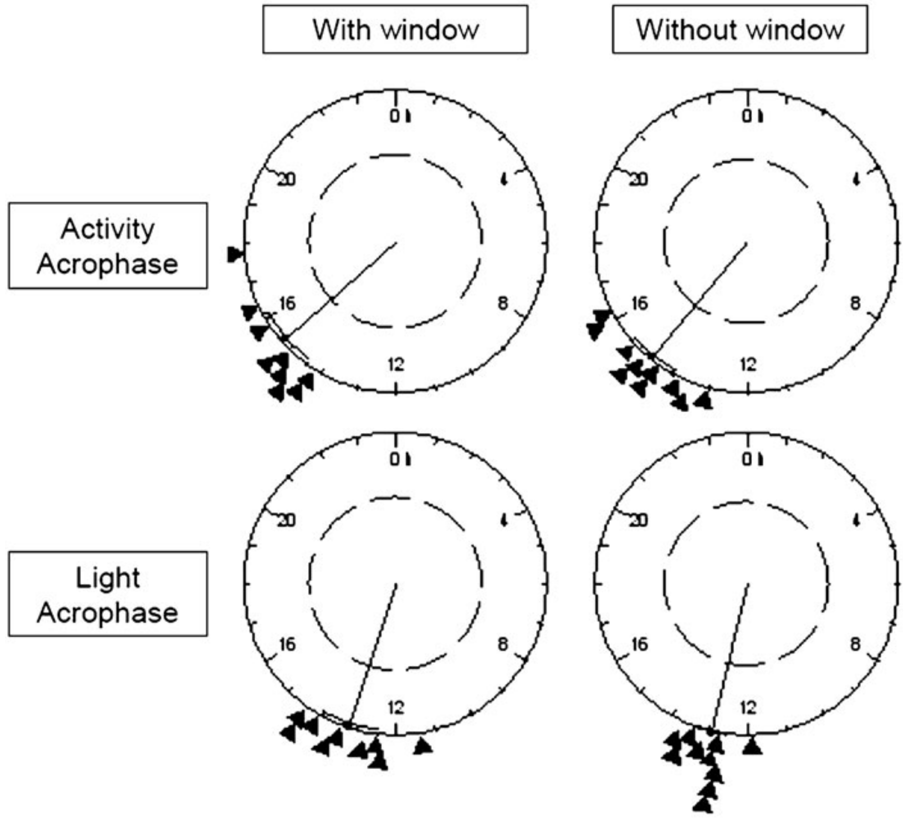

FIGURE 1. Differences in activity and light acrophases between the ''with window'' ?and ''without window'' groups (Rayleigh analysis).

RESULTS

Rayleigh analysis indicates that the two groups, ''with window'' and ''without window'', exhibited similar activity levels and light acrophases (Figure 1). In relation to light exposure, the mesor was significantly higher ($t = -2.651$, $p = 0.023$) in the ''with window'' group (191.04 ± 133.36) than in the ''without window'' group (73.8 ± 42.05). The ''with window'' group presented a higher amplitude of light exposure (298.07 ± 222.97).

The mesor and the amplitude of the general activity level did not differ between the two groups. However, when we separated the mean values of activity and light exposure during nocturnal and diurnal periods, we found statistically significant differences between the nocturnal group ($t = -3.53$, $p = 0.003$) and the diurnal light exposure group ($t = -2.795$, $p = 0.019$). The ''with window'' group had higher nocturnal activity and diurnal light exposure values (Table 2).

The difference in daytime cortisol levels of the two groups was maximized at 10:00 pm (t = 3.009, $p = 0.008$), when the ''without window'' group had higher cortisol levels (4.01±0.91) than the ''with window'' group (3.10 ± 0.30). No statistically significant difference was found in cortisol levels at 08:00 am and 4:00 pm.

In terms of melatonin levels, the groups differed at two times of day: 08:00 am ($t = 2.593$, $p = 0.018$) and 10:00 pm ($t = -2.939$, $p = 0.009$). The ''with window'' group presented a lower melatonin level at 08:00 am (3.54 ± 0.60) but a higher level at 10:00 pm (24.74 ± 4.22) than the ''without window'' group (Figure 2).

Correlations between these hormonal levels and scores for minor psychiatric disorders, depressive symptoms, sleepiness and sleep quality were calculated. SRQ scores were positively correlated with cortisol levels at 10:00 pm and negatively correlated with melatonin levels at 4:00 pm. Similarly, greater Montgomery–Asberg scores were correlated with higher cortisol levels at 4:00 pm and 10:00 pm and with lower melatonin levels at 4:00 pm and 10:00 pm (Table 3).

DISCUSSION

As expected, the group of employees exposed to natural light at the workspace through a window showed higher amplitudes and mesors of light. This is attributable to the work environment because the only one difference in illumination between the groups was the presence or absence of a window in the workspace. Both groups showed similar values of light exposure at night, i.e. outside their workspace. The results of this study underscore the hypothesis relating human health to the amplitude of the diurnal light levels that he or she experiences. That the season and latitude can influence the circadian response of a person is well known. All studies presented in the literature are from north hemisphere countries, but performing local studies

TABLE 2. Mean difference in chronobiological variables between the ''with window'' and ''without window'' groups (cosinor analysis).

	With window Mean ± SD	Without window Mean ± SD	*t* Test	*p* Value
Light mesor	191.04 ± 133.36	73.8 ± 42.05	−2.651	0.023*
Light amplitude	298.07 ± 222.97	116.54 ± 71.9	−2.450	0.032*
Activity mesor	228.61 ± 82.95	177.41 ± 59.13	−1.589	0.129
Activity amplitude	186.025 ± 66.52	149.07 ± 64.06	−1.265	0.222
Average day activity intensity	333.83 ± 84.82	267.14 ± 86.79	−1.69	0.109
Average night Activity intensity	170.46 ± 60.89	92.39 ± 32.93	−3.53	0.003*
Average light in activity period (lux)	372.23 ± 232.45	143.08 ± 84.65	−2.795	0.019*
Average light in rest period (lux)	7.10 ± 4.62	4.36 ± 2.06	−1.64	0.13

$^*p < 0.05$.

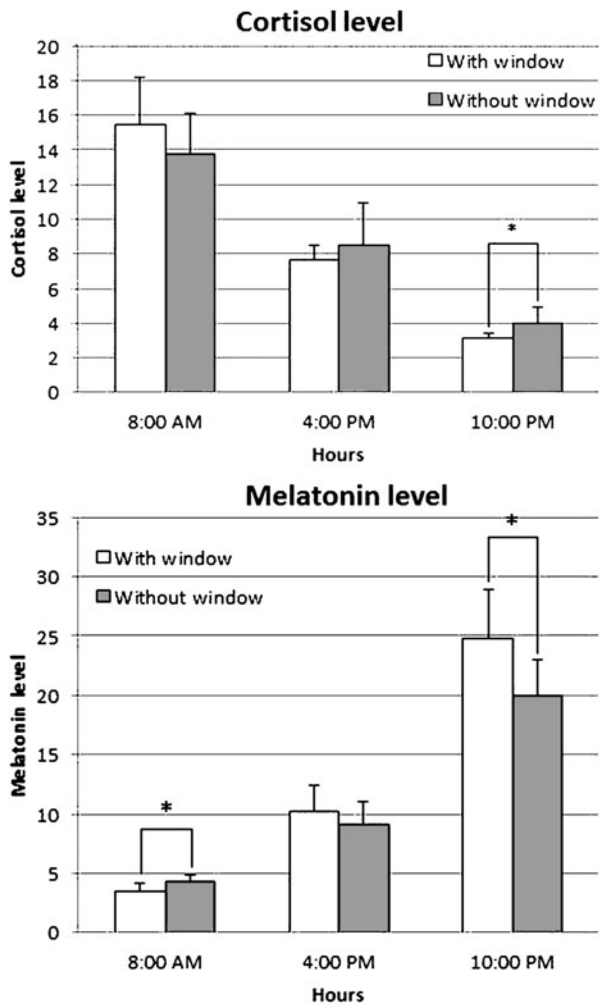

FIGURE 2. Differences between melatonin and cortisol levels in the morning, afternoon and night periods.

that consider the prior history of light of each user, as this study has done, is important (Cole et al., 1995; Herbert et al., 2002; Smith et al., 2004; Vondrasova et al., 1997). Nevertheless, evidence is lacking to propose new interventions and recommendations on the quality and quantity of lighting to increase benefits for labor and workers, even if recommending exposure to natural light for workers is now reasonable (Kramer, 2002; Veitch, 2011; Zonneveldt & Aries, 2002).

Light is known to be the main external *zeitgeber*; it is powerful enough to synchronize endogenous rhythms, ranging from physiological characteristics (hormonal levels) to behavioral characteristics (Hastings et al., 2003). Therefore, subjects who worked most of their time under electrical lighting presented higher levels of melatonin at 08:00 am, lower levels of melatonin at 10:00 pm and higher cortisol levels at 10:00 pm than subjects who work in a place with a window. These results were congruent to a prior study in the same city (Martau et al., 2009).These results may reflect signs of chronodisruption because increased levels of cortisol and lower levels of melatonin are related to several diseases (Amaral et al., 2014). Plasma melatonin peaks (acrophase) occur in the middle of the habitual nocturnal period, which occur 4–6 h before the acrophase of the cortisol rhythm (Hastings et al., 2003; Markus et al., 2013; Selmaoui & Touitou 2003). The primary control of this rhythm is driven by the suprachiasmatic nucleus of the hypothalamus; this structure is extremely sensitive to light exposure, receiving light input from intrinsically photosensitive retinal ganglion cells (Buijs et al., 2013; Hastings et al., 2003). Another possible pathway of regulation is from the immunologic system. Melatonin reduces NF-κB activation and immune-competent cell count. However, the activation of the immune system interrupts melatonin production. The presence of corticosterone increases the synthesis of melatonin induced by stimulation of β- adrenoreceptors (Markus et al., 2013). Therefore, the influence of cortisol and melatonin on mood may be via a complex pathway that includes the immune system.

In our study, depressive symptoms were positively correlated with cortisol levels and negatively correlated with melatonin levels at two times of day, 4:00 pm and 10:00 pm. Many authors have described the links between cortisol, melatonin and light in the built environment and their association with mood disorders (Espiritu et al., 1994; Healy et al. 1993). This may be because depression involves a number of steps before it is fully developed. In this process, only hormonal changes primarily exist that may later trigger clinical features of depression. Therefore, we expect that the subjects with less exposure to natural light during

TABLE 3. Correlation between cortisol and melatonin levels to depressive symptoms and sleep quality.

	Cortisol 8:00 am		Cortisol 4:00 pm		Cortisol 10:00 pm		Melatonin 8:00 am		Melatonin 4:00 pm		Melatonin 10:00 pm	
	Pearson	*p* Value	Pearson	*p* Value	Pearson	*p* Value	Pearson	*p* Value	Pearson	*p* Value	Pearson	*p* Value
SRQ	0.085	0.73	0.404	0.086	0.558	0.013*	0.096	0.695	−0.547	0.015*	−0.52	0.22
MA	0.389	0.169	0.543	0.045*	0.617	0.019*	0.021	0.943	−0.576	0.031*	−0.544	0.044*
BDI	0.391	0.12	0.467	0.059	0.445	0.074	−0.065	0.804	−0.389	0.123	−0.315	0.219
Hamilton	0.022	0.930	0.176	0.484	0.143	0.573	−0.010	0.969	−0.057	0.822	−0.242	0.333
Epworth	−0.305	0.191	−0.079	0.74	−0.239	0.309	−0.244	0.3	0.188	0.428	0.112	0.639
PSQI	0.071	0.771	0.12	0.625	0.247	0.308	0.179	0.463	−0.266	0.271	−0.467	0.044*

SRQ-Self-Reporting Questionnaire-20 assesses minor psychiatric disorders; depression symptoms were assessed by MA (Montgomery–Asberg scale), BDI (Beck Depression Inventory) and Hamilton scale; sleep symptoms were assessed by Epworth (somnolence) and PSQI (Pittsburgh Sleep Quality Index questionnaire). $*p < 0.05$.

working hours should already exhibit physiological changes and may, in the future, be more prone to developing depressive symptoms. In other words, our data suggest that lack of natural light can be associated with chronodisruption that may trigger mental disorders in subjects genetically predisposed to those disorders.

The effect of light on depressive behavior, which can be caused by the actions of melatonin as well as through a direct effect on the SCN, as mentioned above, could also occur through a peripheral effect by L1 expression. Previous studies have already demonstrated a possible relationship between light exposure in night shift workers and genomic instability (deHaro et al., 2014). The hypothesis about the role of environmental lighting on several physiological aspects, especially in the workspace, can be tested with different environment models. Most of these studies have focused on subjective aspects of well-being and have tried to correlate lighting conditions with work performance, satisfaction or emotional responses of user's (Abdou, 1997; Begeman et al., 1996; Boyce, 2003; Edwards & Torcellini, 2002; Galasiu & Veitch, 2006; Heschong Mahone Group, 1999a,b, 2003; Heschong et al., 2002; Houser & Tiller, 2003; Vallenduuk, 1999; Veitch et al., 2011). The presence of windows and possibility of visual contact to the outside has proven to be very important for human well being in indoor environments (Collins, 1975; Cuttle, 1983; Farley & Veitch, 2001; Finnegan & Solomon, 1981). These studies were based on visual pathways of light on humans but not specifically on biological or physiological responses to light. After the photoreceptor in the retina was discovered, some studies began mapping the biological effects of light in the work environment (Aries et al., 2010; Stevens & Rea, 2001; Van Bommel, 2004), but the best way to measure this influence is still being discussed.

No significant difference was found between the groups in rest-activity rhythms (mesor, acrophase or amplitude). Some evidence suggests that not only light exposure but also imposed rest-activity cycles may affect melatonin rhythm (Klerman et al., 1998). To minimize the effects of confounding variables, we controlled the subjects of our study by studying only adult women working under similar work conditions, which partly explains why they had similar general activity rhythms. As the groups were similar in activity, their differences in cortisol and melatonin levels may be attributed to the difference in light exposure. Unfortunately, we did not measure cortisol and melatonin levels over multiple days; therefore, we were not able to calculate the rhythmic parameters of these variables. Nevertheless, previous studies have demonstrated that both hormones are relatively stable and are good tools to measure circadian rhythms (Selmaoui & Touitou, 2003). We were also not able to establish causality between working in an environment with natural light and depressive symptoms, rest/activity rhythms, cortisol levels or melatonin levels due to the cross-sectional design of the study.

The quantity and quality of light that can affect the stimulation of the circadian system, has been extensively studied (Aoki et al., 1998; Dumont & Beaulieu, 2006; Glickman et al., 2003; Leproult et al., 2001; Rea et al., 2006). However, the parameters for the circadian light still have to be defined and this research may help establish recommended practices to the southern hemisphere. The present study demonstrated not only that exposure to light during the night may affect human physiology but also that lack of exposure to natural light is related to a possible disruption of the biological rhythms.

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DECLARATION OF INTEREST

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