Reactivity of heart rate variability after exposure to colored lights in healthy adults with symptoms of anxiety and depression

Chang-Jin Choi a, Kyung-Soo Kim a, Chul-Min Kim a, Se- Hong Kim b, Whan-Seok Choi a,⁎

a Department of Family Medicine, Seoul St. Mary’s Hospital, College of Medicine, The Catholic University of Korea, Seoul, Republic of Korea
b Department of Family Medicine, St. Vincent’s Hospital, College of Medicine, The Catholic University of Korea, Suwon-si, Gyeonggi-do, Republic of Korea

A R T I C L E   I N F O

Article history:
Received 15 January 2010
Received in revised form 9 September 2010
Accepted 10 September 2010
Available online 1 October 2010

Keywords:
Colored light
Depression
Anxiety
Heart rate variability

A B S T R A C T

Studies on human psychological domains associated with color specific light effects have been reported. The heart rate variability (HRV) has been suggested to be a useful tool for the detection of short-term effects of light on the autonomic nervous system (ANS). The emotional state of an individual has an independent effect on the HRV. The purpose of this study was to investigate the acute HRV reactivity after illumination with colored lights and determine the possible interaction between the colored lights and emotional states. Ninety-two healthy adult volunteers underwent short-term measurement of HRV before and after exposures to blue (λmax 420, 380–495 nm, 0.04 lux, 0.41 μW/cm²), red (λmax 765 nm, 620–780 nm, 0.4 lux, 1.62 μW/cm²) and white (49.5 lux, 12.9 μW/cm²) colored fluorescent lights for 5 min during the daytime. A depressed group and an anxious group were identified in 28 (30.4%) and 23 (25.0%) of the subjects, respectively, according to their responses to the Korean version of the hospital anxiety and depression scale (score ≥8). The high frequency (HF) reactivity and the root mean square successive differences (RMSSD) were significantly different in the depressed (p < .05) and anxious groups (p < .05) based on the colored lights. The parasympathetic activity was decreased with red light in the depressed and anxious groups; this activity was further decreased in subjects with both symptoms. However, it was unchanged in the subjects without symptoms of depression and anxiety. The results of this study showed that the emotional state of the subjects was an important modulator of the acute effects of dim colored light on the ANS.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Humans are very sensitive to light (Cajochen et al., 2005; Lockley et al., 2003) and even a light intensity of only 1.5 lux can shift the circadian system (Wright et al., 2001). In addition to regulating circadian rhythms (Aschoff et al., 1969; Lewy et al., 1984), light also elicits acute physiological effects in humans such as, a rapid suppression of melatonin (Brainard et al., 2001, 1997), increased alertness (Cajochen et al., 2000), heart rate (Scheer et al., 2004) and sympathetic nerve tone (Sakakibara et al., 2000). These non-visual effects of light are mediated by a melanopsin-based photoreceptor, which is highly sensitive to the short wavelength of visible light (blue) (Cajochen et al., 2000; Thapan et al., 2001; Warman et al., 2003; Lockley et al., 2003; Yasukouchi and Ishibashi, 2005). Retinal photosensitive ganglion cells project to the suprachiasmatic nucleus (circadian center) through the retino-hypothalamic tract and multisynaptically to the pineal gland as well as to various other brain areas (including brain stem, limbic system, and cerebral cortex) that share inputs from the visual photoreceptor system (Hattar et al., 2006; Vandewalle et al., 2006, 2009). In this manner, light is directed to the brain areas regulating the autonomic nervous system (ANS).

Heart rate variability (HRV) has been used to estimate the modulation of autonomic activity of the heart in response to internal or external stimuli (Pumprla et al., 2002). HRV measurement has been suggested as a useful tool for the evaluation of the short-term effects of light on human physiology (Rechlin et al., 1995; Schäfer and Kratky, 2006). Among patients with seasonal affective disorders, only responders to bright light therapy showed an increase in parasympathetic tone; however, no reaction was observed among non-responders and healthy controls (Rechlin et al., 1995).

The association between psychological abnormalities and low HRV has been extensively studied; the findings of these studies partially explain the increased cardiovascular morbidity in these populations (Carney et al., 2001; Lavoie et al., 2004). Patients with a major depressive disorder (Agelink et al., 2002; Licht et al., 2008) or anxiety disorder (Licht et al., 2009; Thayer et al., 1996), as well as individuals prone to dysphoric emotional states (Bleil et al., 2008; Dishman et al., 2000) have been reported to have low HRV. A decreased HRV response to tasks associated with anxiety and depression has been suggested as a sign of psychological dysfunction (Shinba et al., 2008).
The color specific effects of light on humans have been mainly reported in psychological studies. The effects of light on the psychological domain are very complex and likely involve mechanisms other than melatonin suppression (Rüger et al., 2006). To date, only a few studies have investigated the effects of colored light on HRV. One group found that colored light can influence the HRV within minutes and the effects of individual colors can be differentiated by the HRV (Schafer and Kratky, 2006). Another study reported that the ratio of low frequency to high frequency (LF/HF) was decreased after illumination with cold colors (Chong et al., 2004). However, previous reports did not investigate the possible influence of the individual emotional state. The emotional state reflects the internal environment of an individual and has an independent effect on the HRV. Therefore, a subject’s emotional state is likely an important factor involved in the effects of colored lights on the HRV. In addition, lifestyle behaviors such as alcohol ingestion (Ingjaldsson et al., 2003; Thayer et al., 2006), smoking (Alyan et al., 2008; Cagirci et al., 2009), exercise (Blom et al., 2009; Buchheit et al., 2007) and sleep (Fang et al., 2008) have also been reported to influence the HRV.

The purpose of this study was to investigate the acute HRV reactivity after illumination with three different fluorescent colored lights (red, blue, and white) during the daytime and to evaluate the possible interaction between the colored lights and emotional states or lifestyle behaviors in healthy adults.

2. Materials and methods

2.1. Participants

Ninety-two healthy undergraduate students from The Catholic University, Republic of Korea participated in this study (the mean age was 26.4 years, standard deviation 3.6; 56 men, 36 women). Exclusion criteria included: 1) abnormal color vision, 2) diabetes, 3) hypertension or cardiac disease, 4) psychiatric diseases, 5) sleep disorders, and 6) currently taking any medication potentially affecting the ANS. All participants were non-smokers with the exception of current or past smokers.

2.2. Medical characteristics

The body mass index (BMI) was calculated as the ratio of weight (kilograms) to height (meters) squared (kg/m²). The sitting blood pressure was measured for each participant with a random zero sphygmomanometer after a 5-min rest.

2.2.1. Smoking status

Information on the respondents’ smoking history and current smoking status was obtained. Participants were classified into two groups: never smokers and ever smokers (current and past smokers).

2.2.2. Alcoholic ingestion

Alcohol ingestion was defined as drinking more than 80 g alcohol per week regularly.

2.2.3. Exercise

This group was defined by those that exercised regularly with moderate intensity more than 1 h per week.

2.2.4. Sleep hours

The number of hours of sleep during the week and weekend were surveyed and the daily mean hours of sleep were calculated.

2.2.3.2. Psychological assessment: depression and anxiety traits

The Korean version of the hospital anxiety and depression scale (Korean-HADS) is composed of 14-items divided into the two subscales of anxiety and depression. Item responses were measured on a 4-point Likert type scale of self-report measures. A score of eight or more on either subscale was classified as the depressed or anxious groups. This scale has been previously validated (Oh et al., 1999).

2.2.3.3. Lifestyle behaviors

The subjects completed a questionnaire that provided information about demographic characteristics, lifestyle behaviors and general health status.

2.2.3.1. Smoking status

Information on the respondents’ smoking history and current smoking status was obtained. Participants were classified into two groups: never smokers and ever smokers (current and past smokers).

2.2.2.1. Psychological assessment: depression and anxiety traits

The Korean version of the hospital anxiety and depression scale (Korean-HADS) is composed of 14-items divided into the two subscales of anxiety and depression. Item responses were measured on a 4-point Likert type scale of self-report measures. A score of eight or more on either subscale was classified as the depressed or anxious groups. This scale has been previously validated (Oh et al., 1999).

2.2.3.3. Lifestyle behaviors

The subjects completed a questionnaire that provided information about demographic characteristics, lifestyle behaviors and general health status.

2.2.3.1. Smoking status

Information on the respondents’ smoking history and current smoking status was obtained. Participants were classified into two groups: never smokers and ever smokers (current and past smokers).

2.2.2. Alcohol ingestion

Alcohol ingestion was defined as drinking more than 80 g alcohol per week regularly.

2.2.3. Exercise

This group was defined by those that exercised regularly with moderate intensity more than 1 h per week.

2.2.4. Sleep hours

The number of hours of sleep during the week and weekend were surveyed and the daily mean hours of sleep were calculated.

2.2.3.2. Psychological assessment: depression and anxiety traits

The subjects were seated in a relaxed upright position under conditions of spontaneous breathing. The electrocardiogram (ECG) recordings were carried out under standard conditions after the patient had rested for 5 min. The data collection and HRV analysis were recorded using the SA-2000E (Medicore, Seoul, Korea). The ECG signal was collected at a sampling rate of 500 samples/s for 5 min, and was modified to digitize the signal by analog/digital transformation and transaction. The RR interval was measured by the detection of the QRS complex; several errors during detection of the QRS complex and noise from arrhythmias were not included in the analysis. Time- and frequency-domain indices were chosen for the HRV analysis, and consisted of five components: the standard deviation of the NN intervals (SDNN) and the root mean square successive differences (RMSSD), the high frequency (HF) spectra (0.15–0.40 Hz), the low frequency (LF) spectra (0.04–0.15 Hz), and the low/high frequency (LF/HF) ratio. The HF component and RMSSD served as measures of cardiac parasympathetic activity. LF reflects the fluctuations of sympathetic and parasympathetic activity; an index of sympathovagal influences on the heart was computed by the LF/HF ratio (ESC and NASPE, 1996).

2.3. Procedures

The experiment used a repeated-measures design, with three different light conditions and at least a 4-h washout period between each condition in counter balance order. The experiment took place during the daytime (09:00 to 11:00 h or 14:00 to 16:00 h) between August 2003 and June 2004; each subject finished the experiment within 2 days. All tests were conducted individually in a soundproof, air-conditioned (20°–24°) room. In each experiment, after a period of 10 min of darkness, the subject remained seated and exposed to one of the colored fluorescent lights for 5 min, followed by another 10 min of darkness. Just before and after illumination, with each light, the HRV was recorded for 5 min. Red (λmax 765 nm, 620–780 nm, 0.4 lux, 1.62 µW/cm²) and blue (λmax 420, 380–495 nm, 0.04 lux, 0.41 µW/cm²) lights were presented through a Color Light Stimulator (Model ST900, Medicore, Seoul, Korea) without flickering. The subjects were instructed to gaze at the light source through the light collecting tube, the distance of the light source from the eye was 60 cm. The white light was a full spectrum natural daylight fluorescent desk light (49.5 lux, 12.9 µW/cm²) (3 M, USA); the subjects avoided direct gaze, saw a white paper below the light source, and the distance of paper from the eye was maintained at 60 cm. The spectral characteristics of the lights were measured at the subject’s eye level with a spectroradiometer (Model CAS 140, Instrument Systems, Munich, Germany). After the experiments with the blue and red colored lights, the subjects reported their personal impressions for each colored light. The reports were categorized as negative (uncomfortable, dizzy, anxious, fatigue), neutral (no specific), and positive (comfortable, warm, cool, relaxed).

2.4. Statistical analyses

A natural logarithm (ln) procedure was used to correct for skewed raw score distributions in the spectral data. The general
characteristics and baseline HRV of the participants were compared according to the emotional states of the subjects with respect to the same characteristics using independent t-tests for continuous variables and chi-square tests for categorical variables. To evaluate the effects of each colored light on the HRV indices, a paired t-test analysis was performed. A randomized block design ANOVA was used to analyze the differences in the HRV reactivity among the three colors according to the emotional state or other general characteristics (e.g., gender, exercise, alcohol, smoking, hours of sleep). Post-hoc analyses showed that red light was associated with a decrease in the lnHF and white light with an increase in the lnHF (Fig. 1a) and the anxious group [2, 27] differed in the depressed group [2, 27] and further exposure to the illumination of red light tended to be decreased in the depressed only group and the anxious only group and further exposure to blue light (Fig. 1b).

### Table 2

Means and standard deviations for baseline the HRV indices by emotional status.

<table>
<thead>
<tr>
<th></th>
<th>Depression</th>
<th>No-depression</th>
<th>Anxiety</th>
<th>No-anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln LF</td>
<td>N = 28</td>
<td>N = 64</td>
<td>N = 23</td>
<td>N = 69</td>
</tr>
<tr>
<td>ln HF</td>
<td>5.98 ± 0.85</td>
<td>6.00 ± 0.84</td>
<td>5.92 ± 0.78</td>
<td>6.02 ± 0.86</td>
</tr>
<tr>
<td>LF/HF</td>
<td>1.50 ± 0.97</td>
<td>2.13 ± 2.46</td>
<td>1.32 ± 1.28</td>
<td>2.16 ± 2.35</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>70.0 ± 9.3</td>
<td>70.6 ± 10.2</td>
<td>71.5 ± 10.8</td>
<td>69.7 ± 9.1</td>
</tr>
<tr>
<td>RMSSD, ms</td>
<td>45.6 ± 22.4</td>
<td>38.9 ± 14.9</td>
<td>47.8 ± 23.2</td>
<td>38.5 ± 14.8</td>
</tr>
</tbody>
</table>

In LF = log of low frequency heart rate variability; In HF = log of high frequency heart rate variability; LF/HF = low frequency over high frequency; HR = heart rate; bpm = beats per minute; SDNN = difference of the standard deviation of normal to normal interval; RMSSD = root-mean-square of successive differences.

3. Results

3.1. Descriptive findings

Descriptive statistics and group comparison statistics for the demographic and lifestyle variables are presented in Table 1. There were 28 (30.4%) and 23 (25.0%) subjects with depression and anxiety, respectively. The depressed and anxious groups did not differ from the groups without depression or anxiety by age, BMI, blood pressure, smoking, alcohol ingestion, exercise and hours of sleep. There was no difference in gender between the depressed group and the group without depression. However, for the anxious group, females were more common than in the group without anxiety ($\chi^2 (1) = 6.08, p < .05$). Fifty percent of the subjects in the depressed group were also categorized as anxious and 60.5% of the subjects in the anxious group were also categorized as depressed. The LF/HF was higher in the group without anxiety compared to the anxious group (p < .05). Other HRV indices did not differ based on the emotional states of the subjects (Table 2).

3.2. The effects of colored lights on the HRV indices in all participants

Red light significantly increased the lnLF, $t(89) = 2.53, p < .05$ (M = 5.97, SD = 0.94 pre-illumination; M = 6.17, SD = 0.89 post-illumination), LF/HF ratio, $t(89) = 3.11, p < .005$ (M = 1.65, SD = 1.44 pre-illumination; M = 2.13, SD = 1.67 post-illumination) and reduced the lnHF, $t(89) = -2.05, p < .05$ (M = 5.80, SD = 0.92 pre-illumination; M = 5.69, SD = 0.74 post-illumination). Blue light increased the lnLF, $t(87) = 2.22, p < .05$ (M = 6.04, SD = 0.87 pre-illumination; M = 6.24, SD = 0.90 post-illumination). The SDNN was increased by red light, $t(89) = 2.65, p < .05$ (M = 48.6, SD = 15.8 pre-illumination; M = 53.0, SD = 21.1 post-illumination) and by white light, $t(77) = 2.51, p < .05$ (M = 43.8, SD = 15.4 pre-illumination; M = 47.4, SD = 16.1 post-illumination). The heart rates decreased after exposure to the illumination of colored lights (Table 3).

### Table 1

General characteristics of the study population according to the emotional status.

<table>
<thead>
<tr>
<th></th>
<th>Depression</th>
<th>No-depression</th>
<th>Anxiety</th>
<th>No-anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years M (SD)</td>
<td>26.5 (3.4)</td>
<td>26.4 (3.7)</td>
<td>25.8 (2.6)</td>
<td>26.6 (3.9)</td>
</tr>
<tr>
<td>BMI, kg/m² M (SD)</td>
<td>22.3 (3.6)</td>
<td>22.2 (2.9)</td>
<td>21.7 (3.8)</td>
<td>22.4 (2.8)</td>
</tr>
<tr>
<td>SBP, mmHg M (SD)</td>
<td>117.3 (9.1)</td>
<td>116.7 (12.0)</td>
<td>115.8 (9.4)</td>
<td>117.3 (11.6)</td>
</tr>
<tr>
<td>DBP, mmHg M (SD)</td>
<td>75.1 (10.1)</td>
<td>74.9 (9.7)</td>
<td>73.4 (7.7)</td>
<td>75.5 (10.0)</td>
</tr>
<tr>
<td>HR, bpm M (SD)</td>
<td>70.6 (10.2)</td>
<td>70.0 (9.3)</td>
<td>71.3 (10.8)</td>
<td>69.7 (9.1)</td>
</tr>
<tr>
<td>Sex N (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>17 (60.7)</td>
<td>39 (60.9)</td>
<td>9 (39.1)</td>
<td>47 (68.1)</td>
</tr>
<tr>
<td>Female</td>
<td>11 (39.3)</td>
<td>25 (39.1)</td>
<td>14 (60.9)</td>
<td>22 (31.9)</td>
</tr>
<tr>
<td>Smoking N (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever</td>
<td>3 (9.1)</td>
<td>21 (32.8)</td>
<td>5 (21.7)</td>
<td>25 (36.2)</td>
</tr>
<tr>
<td>Never</td>
<td>19 (67.9)</td>
<td>43 (67.2)</td>
<td>18 (73.8)</td>
<td>44 (63.8)</td>
</tr>
<tr>
<td>Alcohol N (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>17 (60.7)</td>
<td>30 (46.9)</td>
<td>9 (39.1)</td>
<td>32 (46.4)</td>
</tr>
<tr>
<td>No</td>
<td>18 (62.9)</td>
<td>46 (71.9)</td>
<td>18 (73.8)</td>
<td>54 (78.3)</td>
</tr>
<tr>
<td>Exercise N (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (7.1)</td>
<td>18 (28.1)</td>
<td>5 (21.7)</td>
<td>15 (21.7)</td>
</tr>
<tr>
<td>No</td>
<td>28 (92.9)</td>
<td>46 (71.9)</td>
<td>18 (73.8)</td>
<td>54 (78.3)</td>
</tr>
<tr>
<td>Sleep, hours N (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;7</td>
<td>12 (44.4)</td>
<td>25 (39.7)</td>
<td>7 (31.8)</td>
<td>30 (44.1)</td>
</tr>
<tr>
<td>≥7</td>
<td>15 (55.6)</td>
<td>38 (60.3)</td>
<td>15 (68.2)</td>
<td>38 (55.9)</td>
</tr>
</tbody>
</table>

BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; HR = heart rate; bpm = beats per minute.

<sup>*</sup> p < 0.05 by chi-square test.

3.3. The effects of colored lights on HRV indices according to emotional state

The lnHF reactivity after exposure to the illumination of three colored lights differed in the depressed group [F(2, 27) = 4.49, p < .05] (Fig. 1a) and the anxious group [F(2, 22) = 4.97, p < .05] (Fig. 1d). Post-hoc analyses showed that red light was associated with a decrease in the lnHF and white light with an increase in the lnHF (p < .05). The RMSSD reactivity after exposure to illumination with the three colored lights differed in the depressed group [F(2, 27) = 4.64, p < .05] (Fig. 1c) and the anxious group [F(2, 22) = 4.15, p < .05] (Fig. 1f). Post-hoc analyses showed that the red light was associated with a decrease in the RMSSD and the white light with an increase in the RMSSD (p < .05).

For the groups without depression or anxiety, the lnHF and RMSSD reactivity was not significantly changed (Fig. 1a, c, d, f). The LF/HF reactivity differed in the group without depression [F(2, 63) = 3.34, p < .05] and tended to decrease after exposure to blue light (Fig. 1b). Fig. 2 shows the reactivity of the HF and RMSSD in subjects divided into four groups (55 normal, 14 depressed only, 9 anxious only, and 14 both depressed and anxious). The reactivity of the lnHF and RMSSD after exposure to the illumination of red light tended to be decreased in the depressed only group and the anxious only group and further...
decreased in the group with both depression and anxiety. In the group with both depression and anxiety, the reactivity of the lnHF and RMSSD differed according to the colored light \((p < .05)\); the lnHF and RMSSD were decreased with red light, but increased by white light. In the groups without anxiety or depression, the lnHF and RMSSD reactivity did not changed significantly (Fig. 1a, c, d, and f). The LF/HF reactivity was different in the group without depression \((p < .05)\) and tended to decrease after exposure to blue light (Fig. 1b). In HF = log of high frequency heart rate variability; LF/HF = low frequency over high frequency; RMSSD = difference of root-mean-square of successive differences.

4. Discussion

The results of the present study demonstrate that illumination of dim colored light for 5 min during the daytime evoked significant changes of HRV. The HRV reactivity associated with colored light was affected by the emotional state of the participants. The parasympathetic activity (HF and RMSSD) was decreased with exposure to red light in the depressed and anxious groups, and further decreased in the subjects that had both symptoms of depression and anxiety. However, in the subjects without depression or anxiety, the red light had no influence on parasympathetic activity. These results suggest decreased in the group with both depression and anxiety. In the group with both depression and anxiety, the reactivity of the lnHF and RMSSD differed according to the colored light \((p < .05)\); the lnHF and RMSSD were decreased with red light and increased with white light (Fig. 2).

The response rate for describing the subjective impression after exposure to illumination was 85% for blue and 78% for red lights. The impression (positive, neutral, negative) after exposure to illumination of red or blue light did not differ among subjects with different emotional status. Gender and lifestyle behaviors (smoking, alcohol, exercise, sleep) were not associated with different effects of the colored lights.

Fig. 1. Changes in heart rate variability from baseline after illumination by each colored light (means, standard errors) and the emotional status (normal vs. depression or normal vs. anxiety). The lnHF and RMSSD reactivity differed in the depressed \((p < .05)\) and anxious groups \((p < .05)\) based on exposure to three different colored lights. Both the lnHF and RMSSD were decreased by red light, but increased by white light. In the groups without anxiety or depression, the lnHF and RMSSD reactivity did not changed significantly (Fig. 1a, c, d, and f). The LF/HF reactivity was different in the group without depression \((p < .05)\) and tended to decrease after exposure to blue light (Fig. 1b). In HF = log of high frequency heart rate variability; LF/HF = low frequency over high frequency; RMSSD = difference of root-mean-square of successive differences.

Fig. 2. Changes in HF and RMSSD from baseline after illumination by each colored light (means, standard errors) compared to emotional status (normal, depression only, anxiety only and both depression and anxiety). The reactivity of the HF and RMSSD after exposure to illumination with red light tended to be decreased in depressed only or anxious only groups and further decreased in the group with both depression and anxiety symptoms. The reactivity of the lnHF and RMSSD in the group with both depression and anxiety symptoms differed according to the colored light \((p < .05)\). The HF and RMSSD decreased with red light but increased with white light. In HF = log of high frequency heart rate variability; RMSSD = difference of root-mean-square of successive differences.
that symptoms of depression and/or anxiety, in healthy subjects, modulate ANS differently from healthy subjects without symptoms of depression and/or anxiety in response to dim colored lights. In this study, 60.9% of the subjects in the anxious group were also in the depressed group. Anxiety and depression are commonly found together as co-morbidities (Angst, 1997; Mineka et al., 1998). Bleil et al. suggested that with regard to negative effects, there may be unifying and potentially toxic elements linking negative emotions to ANS dysregulation (Bleil et al., 2008). There were no significant associations of the subjective emotional reports, after illumination of the colored lights, and the emotional state of the groups. Therefore, the HRV reactivity in response to colored light might not be associated with perceived emotional changes.

In this study, the subjects were healthy and the baseline HRV indices for the depressed and anxious groups did not show any differences from the groups without depression and anxiety. Previous studies comparing the resting HRV in healthy depressed participants with participants that were not depressed have reported inconsistent results. Some studies have reported no differences (Dishman et al., 2000; Hughes and Stoney, 2000; Shinba et al., 2008; Tulen et al., 1996). However, the most consistent finding is that anxiety and depressed mood are related to low levels of HF during exposure to stress (Hughes and Stoney, 2000; Ledowski et al., 2005; Light et al., 1998; Shinba et al., 2008).

The patterns of HRV provide an early and sensitive indicator of human health. High HRV represents good adaptation through efficient ANS. Low HRV indicates physiological malfunction, requiring further investigation for a specific diagnosis (Pumpria et al., 2002). In a model of neurovisceral integration, low parasympathetic activation has been identified as a marker for prefrontal hypoactivity. Disinhibition leads to failure to recognize safety signals and the activation of the sympathetic nervous system in response to non-threatening stimuli (Thayer and Brosschot, 2005). In the depressed and anxious groups, exposure to illumination of red light reduced the HF and RMSSD; that is, the subjects with depressive or anxious symptoms reacted to only the red light as a stressor but not the blue light. One possible explanation for this finding might be that the red color is a common indicator of danger. This study was conducted with very dim light (<1 lux) and illumination time was relatively short during daytime. Thereby, the HRV reactivity was most likely induced by the color itself rather than the light intensity. Light increases the resting heart rate in a time-of-day dependent manner, with increase at night and no effect during the daytime (Rüger and Scheer, 2009; Scheer et al., 1999).

Color specific effects of light on humans have been reported most frequently in psychological studies. Nocturnal exposure of low intensity blue light (≤1 lux, 2 μW/cm²) and red light (≤1 lux, 0.7 μW/cm²) have an acute alerting effect without melatonin suppression (Phipps-Nelson et al., 2009). Mehta and Zhu reported that red activates avoidance, whereas blue enhances approach (Mehta and Zhu, 2009). The results of another study suggested that color influences cognition and behavior through learned association (Elliot et al., 2007); however, the associated psychological processes have not been fully explored.

This is the first study to demonstrate an interaction between depressive or anxious symptoms and the acute effects of exposure to colored light on the HRV. This study was conducted within the same person during a relatively short period of time, thereby minimizing both within and between subject variability.

There are several potential limitations of this study. For the self-report information used to determine emotional states and lifestyle behaviors, possible response biases are inherent. The depressed and anxious groups were determined based on the information obtained from a questionnaire instead of the standard clinical diagnosis. Another limitation is that the subjects were not instructed to adhere to a fixed sleep–wake schedule prior to the experiment to control for the circadian phase. However, we excluded subjects with sleep disorders. According to their responses to questions about sleep on the questionnaire during the prior two weeks, participants reported a regular sleep–wake cycle in their home environment.

In conclusion, dim colored lights have immediate and varied effects on the cardiac ANS. The results of this study show that these effects were associated with symptoms of anxiety and depression. The parasympathetic activity decreased with red light in subjects in the depressed and anxious groups, and further decreased in the subjects with both depression and anxiety symptoms; however, it was not changed in the subjects without depressive and anxious symptoms. The subjects with depressive or anxious symptoms reacted to red light as a stressor but not to blue light. When investigating the effects of colored light on the ANS in humans, the emotional status of subjects should be considered another important factor. The possible implications of different effects of colored lights as environmental stimuli on human health deserve further study.

Acknowledgements

The authors thank the study participants and Dr. Eun Sook Park for introducing colored light therapy and Koung Mi Lee for technical support.

References


