

Spectral properties of phototherapy for seasonal affective disorder: a meta-analysis

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The general therapeutic effect of light on seasonal affective disorder (SAD) has been widely acknowledged. However, the antidepressant effect of light does not seem to be the same for different spectra of light. In this study, the authors attempted to study the spectral properties of phototherapy for SAD using a meta-analytical procedure. The findings suggested that light of short to medium wavelengths (blue/green/yellow) seem to be essential for the therapeutic effect of light on SAD. Red wavelengths were relatively ineffective. It was then postulated that SAD may be predisposed and/or precipitated by the inefficiency of the S and M cones in the retina. Furthermore, ultraviolet (UV) waves did not seem to be essential for SAD symptom alleviation by artificial light. Therefore, these potentially harmful UV waves should be blocked in any clinical application of phototherapy for SAD.

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Introduction

The general therapeutic effect of light on seasonal affective disorder (SAD) has been widely demonstrated (1). The original study design of phototherapy for SAD used a bank of full-spectrum fluorescent bulbs behind a plastic diffusing screen within a rectangular box (1). Since then, there has been speculation that full-spectrum light may not be essential for treating SAD.

The treatment efficacy of different light spectra has been studied, including full-spectrum light with or without the ultraviolet waves, cool-white, red-wave, green-wave and incandescent light. Cool-white light is fluorescent light with a large output of power in the green and yellow wave bands and a small amount of ultraviolet (UV) emission. Incandescent light consists primarily of yellow waves with negligible UV emission (2).

Bielski et al. (3) compared the treatment effects of full-spectrum and cool-white fluorescent light and found that they were equally effective for the treatment of SAD. Brainard et al. (4) conducted a study to investigate the efficacy of white, red and blue light for treatment of SAD. They found that white light was of greater therapeutic benefit than red or blue light. None the less, the authors realized that the sample size used was too small ($n=18$), so

that generalizing the findings of their study to other populations might be risky.

Oren et al. (5) studied the treatment efficacy of green and red light, and concluded that green light was as effective as white light, and that both of them had a superior antidepressant effect to that of red light. They further reported that UV light was not critical for the treatment effect of phototherapy for SAD. Their report supported the hypothesis that the UV light band can be eliminated completely without reducing the antidepressant effect of phototherapy for SAD (6). On the contrary, Teicha et al. (7) concluded in their study that red and white light produced no significant difference in therapeutic response of SAD patients.

Lam et al. (2) compared the antidepressant effect of 2500 lux full-spectrum fluorescent light with and without the UV spectrum. They found that UV light was more effective for the typical depressive symptoms, e.g. insomnia, appetite loss, weight loss, etc. The UV-block condition, on the other hand, produced significant improvement of the atypical symptoms that characterize SAD. Nevertheless, in another study by Lam et al. (8) of the treatment efficacy of the UV-A and UV-block treatment

conditions, it was found that both conditions were effective in reducing typical and atypical symptoms.

Despite the vigorous research effort, the spectral properties of phototherapy for SAD are not yet known. In the present study the authors employed a meta-analytical methodology to identify a more unifying conclusion about the spectral properties of phototherapy for SAD. Identification of the optimum light spectrum for treating SAD is important for two reasons. First, it will provide an essential guideline for excluding or including the potentially toxic UV light in therapy for SAD. Secondly, it will allow the identification of photopigments and photoreceptors involved in the transduction of light into nerve impulses in the retina, which may offer insights into the pathophysiology of SAD.

Material and methods

The meta-analytical methodology based on the model of meta-analysis proposed by Cooper and Hedges (9) was adopted in order to identify the spectral properties of phototherapy for SAD. The entire research procedure was divided into four stages as follows.

Stage I — problem formulation

The a priori hypothesis was formulated that full-spectrum light is more effective in treating SAD than any selected spectrum of light.

Stage II — data collection: searching the literature

Published and non-published studies of phototherapy for SAD were collected. Two inclusion criteria were employed. The first criterion was that parameters of light therapy were experimentally manipulated under between-subjects design or within-subjects design. The second criterion was that measurement tools used for the dependent variable, i.e. the severity of the SAD symptoms, had to be versions of the Hamilton Depression Rating Scale (HDRS) (10, 11) and/or measures of atypical symptoms (AS) proposed by William (12) or Rosenthal and Heffernan (13), or versions of these.

Representativeness of the studies selected. Both published and unpublished data were solicited in order to ensure the representativeness of the sample. In this meta-analysis, published articles were located via a thorough literature search of the following sources:

- (i) reference database systems, including PSYLIT

and MEDLINE, available in the libraries of the University of Alberta;

- (ii) an indexed bibliography published by the Society for Light Treatment and Biological Rhythm, which provided about 3000 references covering the areas of light therapy, biological rhythm and seasonal affective disorder;
- (iii) relevant chapters in published books, which discussed the medical applications of light, biological rhythm and seasonal affective disorder;
- (iv) bibliography lists of books and journal articles located in sources (i) to (iii);
- (v) personal communications with prominent researchers and colleagues in the area.

Unpublished data were solicited from clinicians and researchers in the field, listed in Norman Rosenthal's book on SAD (14).

The 'file drawer problem' (15) is believed to be minimal for the present meta-analysis for at least two reasons, both of which are related to the short history of phototherapy and SAD. Unlike some other fields, where research is driven by well-established theory, thereby creating a tendency to publish findings in support of the well-received theory in that field, the theoretical constructs of phototherapy and SAD are far from being established. This suggests that clinicians and researchers are less inhibited about publishing significant or insignificant research findings, because either direction might be a true explanation of the phenomena. Moreover, the short history of this newly identified research area should prevent the stockpiling of significant numbers of insignificant data sets, thereby avoiding a sample bias that would jeopardize the validity of the findings of the present meta-analysis.

Stage III — data evaluation and coding

Data evaluation. The collected published and unpublished studies were screened for study quality by a threats-to-validity method (16). This method provided a numerical rating of the degree to which a specific study design controlled for the seven threats to internal validity proposed by Cook and Campbell (17). For each study, the degree of control of each of the seven threats to internal validity was rated on a 3-point Likert scale, where 0 represented no control, 1 represented partial control and 2 denoted full control of that threat. Two raters were employed to rate the studies collected.

Coding. Based on the model proposed by Stock (18), seven categories of information, namely identification, research design, sampling, subject characteristics, independent variable characteristics,

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dependent variable characteristics and statistical data for calculating the effect size, are coded. Two coders, who were not the same individuals as the two raters employed to evaluate the internal validity of the studies, were responsible for coding all of the data sets that passed the data evaluation stage. The inter-rater reliability index of the coding process was expressed as the percentage of agreement between the two coders.

Validity. In order to ensure a high degree of validity of measurements, definitions of specific terms, such as the seven threats to internal validity, were provided. Specific questions were clarified in the training session conducted for the two raters and the two coders involved in this process.

Reliability. The reliability index was the inter-rater reliability expressed as the percentage of agreement between (i) the two raters who rated the degree of control of the seven threats to internal validity of each study and (ii) the two coders who coded data other than the seven threats to internal validity from each study.

The use of two different indices to reflect the reliability of the present analysis is considered to be more meaningful because some items, such as the publication date (Index 2), should yield a much higher level of inter-rater agreement than other items, such as internal validity (Index 1) (19). Therefore, the use of only one of the two inter-rater reliability indices could produce misleading information about the reliability of the data evaluation and coding in the present analysis. Because of the different expectations concerning the level of agreement of the two indices, a percentage agreement of 70% for Index 1 and 90% for Index 2 is considered to be satisfactory. Orwin commented that agreement between individual variables could range from 0.24 to 1.00 (19).

Stage IV — analysis

The fixed-effects model for analysis of variance (20) was adopted to guide data analysis. Following the procedures suggested by Hedges and Olkin (21), data analysis included effect sizes estimation, testing of the homogeneity of the data set, and testing of publication bias by funnel graph plots (22) and an estimation of the Fail-safe N (23). In order to verify the hypothesis formulated in stage 1, studies of median light intensity (1700 to 3500 lux) were selected for analysis. They were then divided into four groups of different wavelengths as follows:

- (i) group 1 — full-spectrum light with the UV component;

- (ii) group 2 — cool-white or full-spectrum light without the UV component;
- (iii) group 3 — red wavelengths;
- (iv) group 4 — green/blue/yellow wavelengths.

The differences in treatment efficacy between these groups were compared. Two analyses were conducted on the available data. The first analysis compared the treatment-effect size, measured by the HDRS, of groups 1 to 4. The second analysis compared the results of the AS obtained for groups 1, 2 and 4.

Results

Data collection ended in August 1994. A total of 40 articles, consisting of 37 published (92.5%) and three unpublished (7.5%) papers, were coded for analysis and hypothesis testing. The funnel graph plots and the Fail-Safe N value provided reassuring evidence that publication bias was not a serious concern in this study (24). With regard to the reliability indices, Index 1 (percentage agreement of the two raters for each of the seven threats) ranged from 70% to 85%, and Index 2 (percentage agreement of the two coders) was about 98%. The results were acceptable according to the criterion set for this meta-analysis (24).

The treatment-effect sizes, measured by the HDRS, of the four treatment groups using different spectra of light were as follows:

- (i) group 1 — full-spectrum light with the UV component (range of effect sizes=0.00–3.22);
- (ii) group 2 — cool-white or full-spectrum light without the UV component (range of effect sizes=0.71–2.96);
- (iii) group 3 — red wavelengths (range of effect sizes=0.31–1.52);
- (iv) group 4 — green/yellow wavelengths (range of effect sizes=0.32–2.93).

Group 1 was further divided into three subgroups according to the timing of phototherapy administration. The results are presented in Table 1.

Group 3, (i.e. red wavelengths) appeared to produce the smallest effect size for treating the typical symptoms of SAD. The different treatment efficacy of groups 1, 2 and 4 was difficult to delineate by merely comparing their respective estimated effect sizes, because of the degree of overlap of their respective confidence interval (CI). Analysis-of-variance (ANOVA) procedures following a fixed-effect model (20) were performed in order to examine this hypothesis further.

The findings of the modified ANOVA showed a statistically significant difference in treatment-

Table 1. Treatment effectiveness of different spectra of light as measured by the HDRS

Group	Effect size (d)	95% confidence interval
1		
Morning	1.71	1.48–1.94
Evening	1.59	1.30–1.89
Morning-Evening	2.09	1.81–2.38
2	1.98	1.70–2.26
3	0.79	0.20–1.39
4	1.59	1.24–1.93

effect sizes between the four groups. These results are presented in Tables 2, 3 and 4.

Table 5 shows that the wavelengths used in group 4 appeared to be more effective than those used in group 2 and group 1 for alleviating the atypical symptoms of SAD, but the degree of overlap of the CI of their respective estimated effect sizes suggests that their relationships may not be as simple as depicted here. Therefore, ANOVA procedures following a fixed-effect model were performed in order to examine this hypothesis further. The findings of the modified ANOVA showed a statistically significant difference in the weighted mean effect sizes between the three groups ($\chi^2=7.21$, $df=1$, $P<0.05$). The effect size produced by group 1 was significantly smaller than that produced by groups 2 ($\chi^2=4.61$, $df=1$, $P<0.05$) and 4 ($\chi^2=4.39$, $df=1$, $P<0.05$). There was no statistically significant difference in treatment-effect size between groups 2 and 4 ($\chi^2=0.79$, $df=1$, $P>0.05$).

Discussion

In the present meta-analysis, the spectra of light used in phototherapy studies were categorized into four different groups according to their wavelengths in the visible spectrum of light (25). The effectiveness of individual wavelengths could not be ascertained due to insufficient data. The first

Table 3. Results of the contrast of ANOVA (evening light subgroup)

Group contrast				
1	2	3	4	χ^2 value (df = 1)
X	X	—	—	2.37
X	—	X	—	5.97*
X	—	—	X	0.01
—	X	X	—	11.85*
—	X	—	X	1.83
—	—	X	X	5.74*

* $P<0.05$.

group consists of full-spectrum light with the UV component, the second group consists of cool-white or full-spectrum light without the UV component, the third group consists of light of red wavelengths, and the fourth group consists of light of blue, green or yellow wavelengths.

The optimum wavelengths of light for treatment of SAD were examined in two separate analyses. The first analysis compared the treatment efficacy of groups 1 to 4 as measured by the HDRS, while the second analysis examined the different treatment effects of groups 1, 2 and 4 as measured by the AS. The findings of the first analysis showed that red wavelengths were significantly ineffective in treating the typical depressive symptoms of SAD measured by the HDRS. No difference in the treatment efficacy of the other groups was identified. In the second analysis, the results showed that light without the UV component, as well as the blue/green/yellow wavelengths, was more effective in alleviating the atypical symptoms of SAD measured by the AS.

The present findings indicate that red wavelengths are relatively ineffective in the treatment of SAD, whereas light of short to medium wavelengths (i.e. the blue and green wavelengths of the spectrum) is necessary for the antidepressant effect of phototherapy. None the less, these findings may have been significantly confounded by the fact that

Table 2. Results of the contrast of ANOVA (morning light subgroup)

Group contrast				
1	2	3	4	χ^2 value (df = 1)
X	X	—	—	1.56
X	—	X	—	8.05*
X	—	—	X	0.13
—	X	X	—	11.85*
—	X	—	X	1.83
—	—	X	X	5.74*

* $P<0.05$.

Table 4. Results of the contrast of ANOVA (morning-evening light subgroup)

Group contrast				
1	2	3	4	χ^2 value (df = 1)
X	X	—	—	0.51
X	—	X	—	15.00*
X	—	—	X	3.93*
—	X	X	—	11.85*
—	X	—	X	1.83
—	—	X	X	5.74*

* $P<0.05$.

Table 5. Treatment effectiveness of different spectra of light as measured by the AS

Group	Effect size (d)	95% confidence interval
1	1.14	0.93–1.35
2	1.51	1.27–1.74
4	1.61	1.15–2.08

phototherapy studies employing red wavelengths used dim-intensity light (≤ 600 lux), whereas light of other wavelengths was of medium to strong intensity. The observed non-significant antidepressant effect of red light may be compromised by the dim intensity used in the respective phototherapy studies.

Assuming that light intensity was not a significant confounding factor, the present findings suggest that an insufficient number of functioning M and S cones may be one of the predisposing/precipitating factors for SAD. This speculation appears to be consistent with the proposal of Lam et al. (26) that subtle retinal abnormalities at the level of the photoreceptor/retinal pigment epithelium complex, consistent with sub-sensitivity to light, may be linked to the aetiology of SAD.

With regard to the UV wavelengths, the present findings suggest that they are not necessary for the antidepressant effect on SAD, either for alleviating the typical or the atypical symptoms. Due to the potentially harmful effects of the UV wavelengths, they should not be used in phototherapy for SAD.

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