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THE IMPACT OF MODULATED, COLORED LIGHT ON THE AUTONOMIC NERVOUS SYSTEM • YOGA THERAPY FOR ANXIETY: A CASE REPORT • THE SARATOGA WARHORSE PROJECT: A CASE STUDY OF THE TREATMENT OF PSYCHOLOGICAL DISTRESS IN A VETERAN • VOICES: DANIEL AMEN, MD • EDITORIAL: HEALTH CARE FOR OUR AGING POPULATION

The Impact of Modulated, Colored Light on the Autonomic Nervous System

Mary J. Ross, PhD; Paul Guthrie, PhD; Justin-Claude Dumont, MA

ABSTRACT

Context • Scientists are now finding that light acts on individuals through multiple pathways, most notably the optic nerve that links to the brain's visual cortex, providing a pathway for the visual effects of light. The optic nerve also links to the more recently discovered retinohypothalamic tract, providing a pathway for the nonvisual effects of light. However, specific effects have not yet been widely evaluated clinically, especially in relationship to chromotherapy (ie, therapy based on colored light).

Objective • The purpose of this study was to evaluate the impact of modulated-light projections, perceived through the eyes, on the autonomic nervous system (ANS).

Design • The research team designed a randomized, controlled, partially blinded study with three intervention groups and one control group.

Setting • The study took place in two locations: (1) Midwestern State University, Wichita Falls, Texas, USA (40 participants) and Centre de Santé Satori, Québec, Canada (77 participants).

Participants • The research team recruited 117 individuals, 89 women and 28 men, to participate in the study. Participants were normal healthy individuals who were 19 to 72 y old (average age = 43 y).

Intervention • Three types of light projections, each containing both specific colors and specific modulations in the frequency range of brainwaves, were tested, in addition to a placebo projection consisting of nonmodulated white light.

Outcome Measures • Evaluation was done using a combination of physiological measures—heart rate (HR), heart rate variability (HRV), and skin conductance (SC)—and psychological tests: the Profile of Mood States (POMS) and a subjective evaluation questionnaire.

Results • The research team observed significant differences in the effects of light-modulation projections from baseline to postsession as compared with an equivalent intensity of white light, including decreased HR, increased HRV standard deviations of normalized NN (beat-to-beat) intervals (SDNN), very low (VLF) and low frequency (LF) levels, and decreased POMS total mood disturbance (TMD). Also, the different colors of modulated light were found to result in different ANS effects.

Conclusions • Interest is growing in the therapeutic potential of light. The effects demonstrated in the current study indicate that colored light could significantly enrich the therapeutic potential of light, and further research into chromotherapy is warranted. (*Adv Mind Body Med.* 2013;27(4):7-16.)

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The therapeutic use of light and colors has a long history, originating in ancient cultures such as Egypt, Greece, and India. Newton's discoveries made it clear that the sun's white light is in fact composed of a number of pure colors, as seen in a rainbow or through a prism. In the 19th and early 20th centuries, a few pioneers started developing sophisticated systems of healing with light and colors, with various degrees of success. For example, the first Nobel Prize in medicine was given in 1903 to Finsen, a Danish physician who cured some forms of tuberculosis with light.

The medical use of light was then eclipsed by the chemical development of new drugs, such as antibiotics, and by the 1940s, light was more or less forgotten by modern medicine. Only recently, starting with with the impetus of research institutions such as NASA, has a renewed interest in the therapeutic potential of light occurred throughout the world.[1,2]

It is now becoming clearer that light acts on individuals through multiple pathways, most notably the optic nerve that links to the brain's visual cortex, providing a pathway for the visual effects of light. The optic nerve also links to the more recently discovered retinohypothalamic tract, providing a pathway for the nonvisual effects of light, also referred to as nonimage forming (NIF) effects.[3] This second pathway leads to the suprachiasmatic area of the hypothalamus, mediating circadian rhythms and melatonin secretion and, furthermore, involving the regulation of our autonomic nervous system (ANS). This pathway is implicated in an evolving body of knowledge on light therapy, with clinical applications such as treatment of seasonal affective disorder (SAD) and depression.[1]

Scientists now generally accept that light and color have an impact on the ANS,[4,5] and some studies have occurred on this subject.[6,7,8,9,10] However, specific effects have not yet been widely evaluated clinically, especially in relation to chromotherapy (ie, therapy based on colored light).

Scientists also know that light can have a profound impact on mood through photic brainwaves entrainment, a process in which brainwaves tend to fall in sync naturally with pulsing visual stimuli.[11] This method has been refined with the Light Modulation technique developed by Sensortech, in which arrays of interconnected low-frequency oscillators (LFOs) control, or modulate, the two basic parameters of light: color and intensity.[12,13]

This light modulation system allows full control of both the colors and the brainwave's photic-driving properties (intensity-dependent) of a light projection. Moreover, the system allows the control of cyclic light movements. Through coordinated phase control of the light intensity and/or color parameters, it is possible to generate apparent movement patterns in the light projection. Some patterns—such as a left-to-right linear movement or an outward movement expanding from the center of the visual field toward the edges—are considered to have a subtle tendency to cause arousal and stimulation.[12] Conversely, some patterns—such as a right-to-left linear movement or an inward movement contracting from the edges towards the center of the visual field—are considered to have a subtle tendency to produce pacification and internal focus.

Careful setting of the various control parameters of such a light-modulation system therefore allows the creation of light sessions considered to have specific mood-enhancing or therapeutic effects.[12] This type of light session is currently implemented in the Sensora systems from Sensortech (Sainte-Adèle, Québec, Canada) and also in consumer products such as uVenus and uGalaxy from OSIM (Singapore).

The purpose of the present study was to evaluate the effects of these light projections on the ANS as well as their mood-enhancing effects.

METHOD

Participants

The research team recruited 117 individuals, 89 women and 28 men, to participate in the study, which took place in two locations: (1) Midwestern State University (MSU), Wichita Falls, Texas, USA (40 participants) and Centre de Santé Satori, Québec, Canada (77 participants). Participants at MSU were students recruited by professors who made announcements in class and by flyers in the department, while those in Québec were recruited from patients at the Centre de Santé Satori (a psychology health clinic). Participants were normal healthy individuals who were 19 to 72 years old (average age = 43 y). Prior to the intervention, participants completed an information sheet, an informed-consent form, and an intake questionnaire. The Human Subjects in Research Committee (IRB) of Midwestern State University in Wichita Falls, Texas approved this study (No. 10051301).

Procedures

A participant's ANS state was estimated from two physiological measures—heart rate variability (HRV) and skin conductance (SC)—and two psychological measures—the Profile of Mood States (POMS) standardized psychological test (brief form) and a subjective evaluation questionnaire.

HRV (Physiological). HRV is a measure of the variations in the interheart beat intervals (RR intervals) and is widely used as a medical diagnostic tool for various pathologies, including myocardial infarction, congestive heart failure, and diabetic neuropathy. It has also been proposed as a semiquantitative method of assessing activities in the ANS, which is the way that the research team has used it in this study.[14] For the most part, HRV is caused by variations in input to the sinus node from the ANS. Multiple mechanisms are known to cause the variation in autonomic activity, including respiration, baroreceptor reflexes, and inputs from higher cerebral centers, all of which mediate the flow of neural signals through the efferent and afferent pathways of the sympathetic and parasympathetic branches of the ANS.

In the current study, the research team considered the following time-domain measures yielded from HRV analysis: (1) heart rate (HR), a general indicator of relaxation, with a decrease linked to ANS parasympathetic activation and (2) the standard deviation of normalized NN (beat-to-beat) intervals (SDNN), with an increase broadly linked to better adaptability and health.[15]

The team also examined frequency-domain measures (Figure 1): (1) very low (VLF)—0.003 to 0.04 Hz, related to the vascular tone loop of the baroreflex system, to thermal regulation, and to the activity of the renin-angiotensin system and linked to the sympathetic action of ANS[16,17]; (2) low (LF)—0.04 to 0.15 Hz, related to the baroreflex function (blood-pressure maintenance) and linked to both sympathetic and parasympathetic ANS actions[16,17]; (3) high (HF)—0.15 to 0.4 Hz, related to processes modulating gas-exchange efficiency, respiratory sinus arrhythmia (RSA), and activity from the vagus nerve and linked to parasympathetic ANS

Figure 1. HRV Spectral Bands

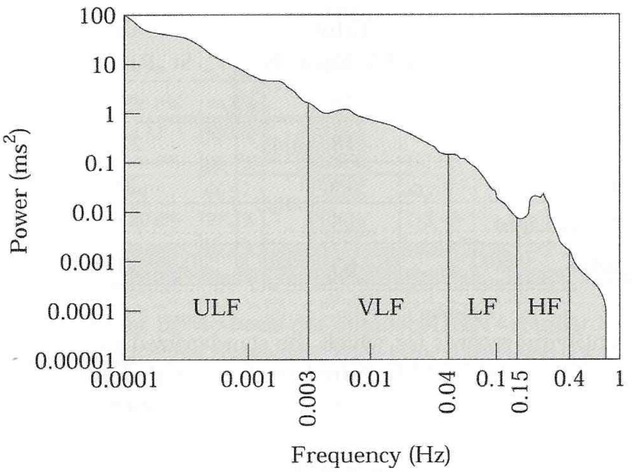
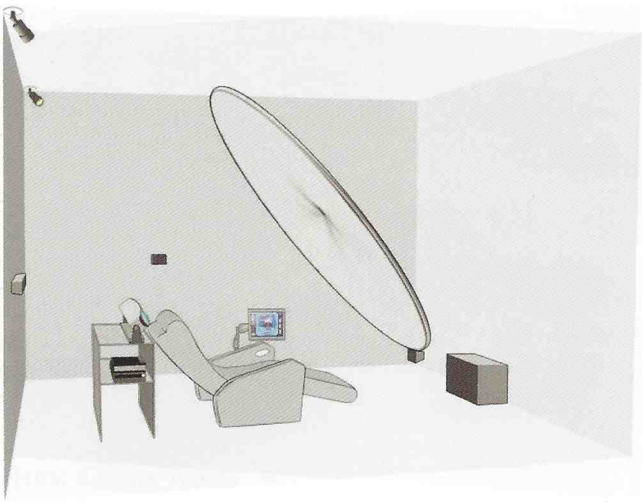


Figure 2. Treatment Room Configuration



action[18]; and (4) LF/HF, often used as a metric of sympathetic and parasympathetic ANS balance.

SC (Physiological). SC is a measure of the electrical conductance of the skin, which varies with its moisture level. Sweat glands are controlled by the sympathetic ANS; so SC is considered to be an indicator of sympathetic arousal.

POMS—Brief Form (Psychological). This questionnaire is an analytically derived inventory with factors that measure six identifiable mood or affective states: (1) tension-anxiety, (2) depression-dejection, (3) anger-hostility, (4) vigor-activity, (5) fatigue-inertia, and (6) confusion-bewilderment.[19] POMS provides a fast, statistically proven method of assessing transient, fluctuating, active mood states. In this study, it was administered twice: (1) before the light session and (2) after the session. It therefore allowed evaluation of the mood impact of the light session.

Subjective Evaluation Questionnaire (Psychological). This simple postsession questionnaire was constructed by the investigators to evaluate (1) if the light session induced changes in the way that the participant felt emotionally, physically, or cognitively (his/her thoughts); (2) if it induced changes in the participant's level of calmness, alertness, tension, energy, or wakefulness; and (3) if the participant fell asleep during the session.

Intervention

At baseline, participants took a first POMS test. During each intervention, participants sat on reclining chairs in a near-supine position in the light-session room. After a 10-minute rest period, a 5-minute, presession recording of each participant's baseline HRV and SC was performed.

Each participant then received a 20-minute light session that was concurrent with 20 minutes of recording of his or her HRV and SC. For the physiological testing, the research team used Thought Technology's (Montréal, Québec, Canada) HRV and SC sensors—the T7400M Procomp 2 Dual Channel System, the SA9306M EKG Sensor, the SA9309M Skin Conductance Sensor, and the SA7700 TT-USB Receiver, with the SA7900 Biograph Infinity Analysis Software. Each participant received a type of light session randomly selected from four types, as follows.

Type 1: Energizing. Developers of the light-modulation technology tested in the study think that these light projections have enhanced energizing and stimulating effects, potentially linked to the sympathetic ANS, that are obtained using various combinations of colors in the warm-color range (red, orange, yellow), with brainwave modulations in the β range (13-20 Hz) and rightward or outward light movements.[12]

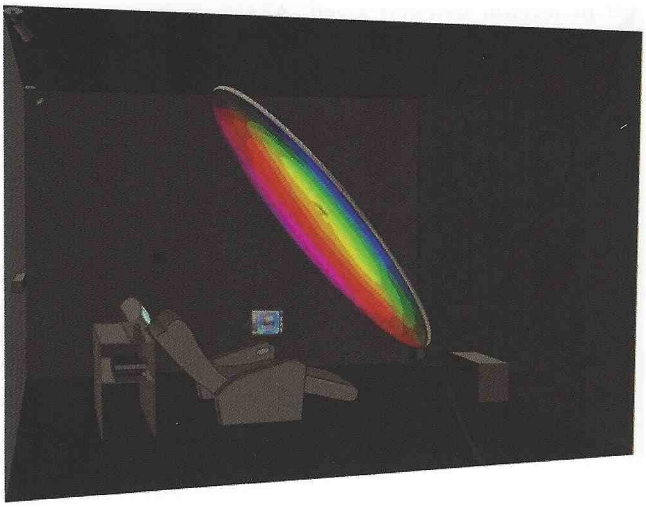
Type 2: Balancing. The developers believe that light projections with enhanced balancing and centering effects are obtained using patterns containing equal proportions of all colors in the spectrum, in combination with brainwave modulations in the higher β range (8-12 Hz), with equal proportions of inward and outward light movements.[12]

Type 3: Relaxing. The developers think that these light projections have enhanced relaxing and pacifying effects, potentially linked to the parasympathetic ANS, and are obtained using various combinations of colors in the cool-color range (green, blue, indigo) with brainwave modulations in the θ/α range (7-8 Hz) and leftward or inward light movements.[12]

Type 4: Placebo (White Light). These light projections consist of static, uniform white light.

The light session was performed on a computer screen, with input data captured directly to digital files. The sessions were administered with standard equipment made by Sensortech. The colored light source was their LED-based, LPA-3 light projection array. The array's integrated light modulation processor projected from behind the participant's head toward Sensortech's PS-Mini, circular, 1.8-m (diameter) screen with a silver surface. The screen was inclined at 45 degrees and located 1.2 m from the participant's head. This configuration was designed to allow the colored-light projection to subtend a significant proportion (75 degrees) of the participant's visual field (Figure 2). The

Figure 3. Treatment Room During Light Session



treatment room was light-proofed and darkened during the light session (Figure 3) to prevent any external, stray light from perturbing the light projection being tested. The research team used a light-level meter, Extech's (Nashua, NH, USA) Model No. 401036 to measure the light level of the projections.

All four types of light session lasted 20 minutes, which the light-modulation developers considered sufficient to realize the session's potential effects on the ANS and mood.[12] To remove light intensity as a variable in the study, all four light sessions were normalized to the same average light level of 63 lx, as measured at the position of the participant's eyes.

Participants were not told which type of light session they would receive nor anything about its potential effects, and prior to a session, the research team did not know which type was to be administered to the particular participant. The type of light session administered to each participant was selected at the beginning of the session by a computerized, pseudo-random algorithm ensuring a similar number of participants per session type. Postsession, participants completed (1) a short, subjective, mood-evaluation questionnaire and (2) the POMS standardized psychological test (brief form) for a second time. The research team also recorded HRV and SC during a 5-minute postsession.

OUTCOME MEASURES

Physiological Measures

HRV values were calculated according to the clinically recommended, short-term, 5-minute recording segmentation.[16] The results were six values per measured HRV/SC parameter: (1) a presession baseline value; (2) four intrasession values—TR1 to TR4 at 5, 10, 15, and 20 minutes, with TR4 being the end-of-session value; and (3) a postsession value. Since the research team was interested in differences induced by the light sessions rather than absolute HRV/SC values, the data sets were standardized by setting individual baseline values at 100%. Data screening was performed by identifying records for which the standardized values were found to have $z > |3.29|$. Paired *t* test, two-tailed probability *P* values were calculated between the baseline (before) and TR4 (after) results for each measured parameter to evaluate their statistical significance, with $P > .05$ considered nonsignificant.

Table 1. Number of HRV and SC Records per Session Type

Session Type	Valid HRV Records	Valid SC Records
Energizing	16	19
Balancing	18	22
Relaxing	16	20
White Light	15	22
Total	65	83

Psychological Measures

To facilitate the interpretation of differences induced by the light sessions, relative trends for the POMS were obtained by standardizing the averaged baseline values to 100%. Variations between the presession and postsession POMS results were then evaluated.

RESULTS

Physiological Measures

Of the 117 HRV records obtained, 33 were invalidated by technical difficulties, which were the result of interference between the PC and the HRV sensors, with the remaining 84 HRV and SC data sets being normalized. After the data screening, 19 HRV cases and one SC case were identified as univariate outliers, departing substantially from the other data points. These cases were eliminated from further analysis, leaving 65 valid HRV and 83 valid SC records (Table 1).

Table 2 summarizes all mean HR and HRV results. Mean HR and HRV SDNN results are shown in Figures 4 and 5. For the three light-modulation sessions, Table 2 shows that HR decreased between 2.5% and 3.8% from baseline to end of the sessions (TR4), all statistically significant results, with the balancing type leading to the greatest and most rapid decrease. In contrast, the placebo white session showed no statistically significant change ($P = .137$). SDNN shows a marginally significant increase from baseline to TR4 for the balancing (21.9%, $P = .041$) and relaxing (18.4%, $P = .054$) sessions. The energizing and white sessions show nonsignificant increases ($P > .05$). The frequency-domain HRV VLF showed clear, statistically significant increases from baseline to TR4 for all three light-modulation sessions. The frequency-domain HRV LF showed statistically significant increases for the energizing and balancing sessions, with the relaxing session moving in the direction of significance with $P = .05$ (Figure 6). The changes for the white session HRV VLF and LF again were not significant. All HRV HF changes from baseline to TR4 were nonsignificant, except for the

Table 2. Results for Average Mean HR—BPM and % relative—and HRV

	Mean HR			HRV SDNN			HRV VLF			HRV LF			HRV HF			HRV LF/HF		
	Baseline	TR4	*P*	Baseline	TR4	*P*	Baseline	TR4	*P*	Baseline	TR4	*P*	Baseline	TR4	*P*	Baseline	TR4	*P*
Energizing	65.84	63.58	.023	58.30	66.42	.105	136.0	273.6	.032	214.4	281.3	.026	138.2	144.6	.198	1.70	1.54	.211
	100.0%	96.6%		100%	115.3%		100%	201.1%		100%	155.1%		100%	119.6%		100%	195.5%	
Balancing	66.33	63.65	.010	60.72	74.69	.041	132.0	292.8	.004	190.8	239.3	.013	156.8	166.7	.159	2.03	3.14	.034
	100.0%	96.2%		100%	121.9%		100%	209.1%		100%	181.3%		100%	119.3%		100%	370.6%	
Relaxing	68.09	66.42	.044	58.41	68.87	.054	136.5	333.2	.019	229.39	262.02	.059	143.28	162.20	.032	1.87	2.43	.109
	100.0%	97.5%		100%	118.4%		100%	244.0%		100%	175.2%		100%	124.6%		100%	184.6%	
White Light	68.46	67.23	.137	53.91	56.39	.088	215.8	169.6	.102	186.9	159.5	.191	82.1	100.9	.076	2.17	2.29	.288
	100.0%	98.3%		100%	109.5%		100%	166.6%		100%	119.2%		100%	121.0%		100%	148.3%	

Abbreviations: BPM = beats per minute; SDNN = standard deviation of normalized NN (beat-to-beat) intervals; VLF = very low frequency; LF = low frequency; HF = high frequency; TR4 = end-of-session value.

Figure 4. HR, Relative Trends

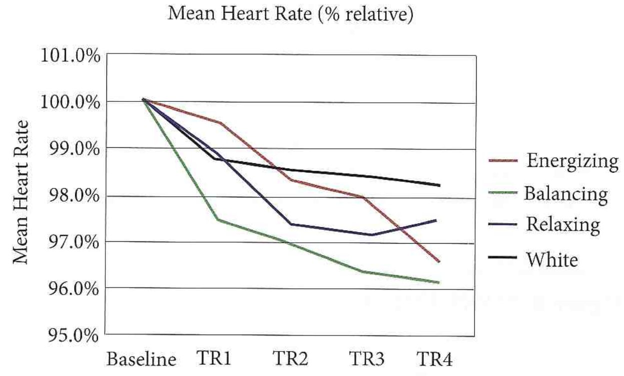


Figure 5. Standard Deviation of Normalized NN (SDNN) HRV, Relative Trends

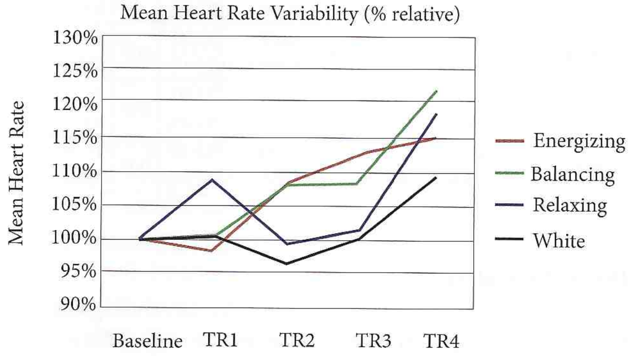


Figure 6. Mean HR, Relative Trends

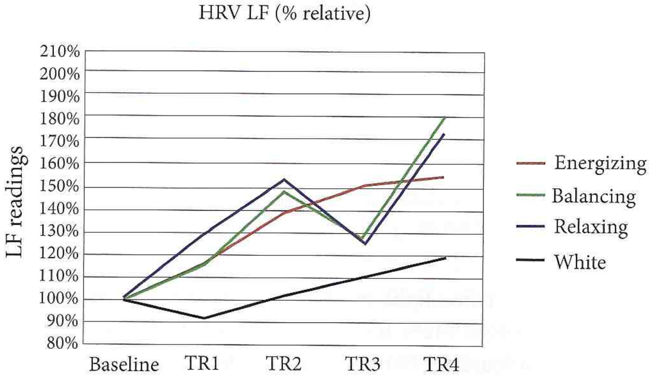
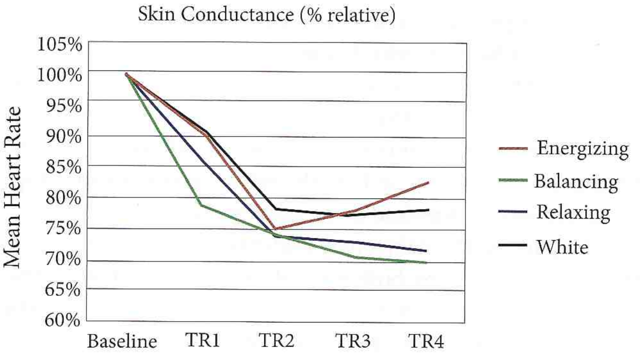


Table 3. Average SC

	Baseline	TR4	*P*
Energizing	2.13	1.60	.045
	100%	82.7%	
Balancing	3.25	2.12	.000
	100%	69.7%	
Relaxing	2.67	1.84	.001
	100%	71.6%	
White	2.93	2.12	.007
	100%	77.9%	

Figure 7. SC, Relative Trends



relaxing session, which showed a 24.6% increase (*P* = .032). As for the HRV LF/HF ratios, only the balancing session showed a significant change (*P* = .034) from baseline to TR4, with a marked increase (× 3.7).

SC results are shown in Table 3 and Figure 7. All session types caused significant decreases in SC from baseline to TR4, with the relaxing (28.4%) and balancing (30.3%) sessions being the most marked and the energizing (17.3%) session being the least. White (22.1%) was intermediate.

Table 4. Number of Participants Responding to Psychological Questionnaires

Session Type	No. of Participants
Energizing	31
Balancing	30
Relaxing	25
White Light	31
Total	117

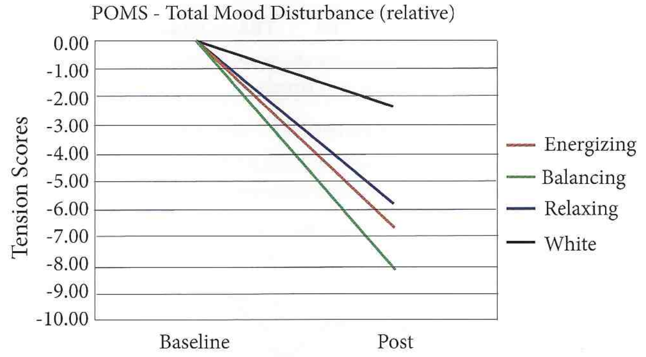
Table 5. Profile of Mood States (POMS) Total Mood Disturbance (TMD) Index

	Baseline	Postsession	Difference	*P*
Energizing	7.48	0.84	-6.64	.004
Balancing	8.31	0.17	-8.14	.003
Relaxing	6.80	0.92	-5.88	.025
White	1.68	-0.74	-2.42	.144

Table 6. Indexes for the Six POMS Moods—Tension, Depression, Anger, Vigor, Fatigue, and Confusion

	Tension			Depression			Anger			Vigor			Fatigue			Confusion		
	Baseline	Post	*P*	Baseline	Post	*P*	Baseline	Post	*P*	Baseline	Post	*P*	Baseline	Post	*P*	Baseline	Post	*P*
Energizing	36.26 100%	31.94 88.1%	.000	35.29 100%	32.68 92.6%	.000	38.45 100%	36.19 94.1%	.007	51.26 100%	47.19 92.5%	.007	41.29 100%	36.77 89.1%	.014	39.35 100%	36.13 91.8%	.000
Balancing	36.70 100%	33.23 90.6%	.003	36.77 100%	32.50 88.4%	.000	39.40 100%	36.20 91.9%	.001	52.23 100%	47.80 91.5%	.010	39.77 100%	34.53 86.8%	.002	41.50 100%	36.03 86.8%	.000
Relaxing	35.40 100%	31.88 90.1%	.001	35.32 100%	33.00 93.4%	.040	38.24 100%	36.40 95.2%	.049	49.64 100%	45.72 92.1%	.005	39.88 100%	35.12 88.1%	.004	39.88 100%	35.80 89.8%	.005
White	34.00 100%	31.03 91.3%	.000	33.84 100%	32.39 95.7%	.005	37.29 100%	36.65 98.3%	.224	55.90 100%	48.74 87.2%	.000	38.32 100%	35.55 92.8%	.047	39.84 100%	36.19 90.9%	.000

Figure 8. POMS TMD, Relative Trends



Psychological Measures

All participants responded to the psychological questionnaires. Table 4 shows the numbers of responding participants for the three light-modulation groups and the placebo group.

The POMS pre- and postquestionnaires allowed an evaluation of the mood changes induced by the light sessions. In addition to its six-mood axis, the POMS provides a composite total mood disturbance (TMD) index, with higher values corresponding to higher mood disturbances. Results for this index showed that all three light-modulation sessions displayed statistically significant TMD decreases, with balancing ($P = .003$) being the most marked. The white session caused no significant TMD change, $P = .144$ (Table 5).

Baseline and postsession results for the six POMS moods are summarized in Table 6. Tension and confusion indexes were significantly reduced (6%-13%) by all four session types. Anger, fatigue, and depression were significantly reduced by all three light-modulation sessions, with the balancing group experiencing the most marked decreases (8.2%-13.2%). The white session had a smaller impact for those factors (1.7%-7.2%) and the results were not significant for anger. Vigor decreased nearly twice as much for the white group (12.8%) than for the three light-modulation sessions (7.5%-8.5%).

The postsession subjective evaluation questionnaire asked participants if they felt any change at the emotional, physical, and thinking levels, with no change, neutral, mixed, pleasant, and unpleasant available as the options for answers. Table 7 summarizes the results, with the first three responses shown in the same column. At both the emotional and thinking levels, the three light-modulation sessions brought more pleasant changes (42%-65%) than the white session (35%), with no unpleasant changes reported for any of the session types. The relaxing group reported the most pleasant physical changes (52%). All three light-modulation sessions brought a few unpleasant physical changes (3%-10%).

Participants were also asked if they perceived feelings in any of eight physical areas. Some notable results included the following: (1) head, legs, and arms were the areas where participants experienced the most feelings (32%-37% average); (2) the energizing group mostly experienced feelings in the head and arms (44%); and (3) the white session mostly triggered feelings in legs and arms (44% each).

As part of the subjective evaluation, participants were asked, “Compared to how you felt prior to the light being administered, do you feel ...” more, less, or no change for the following states: calm, alert, energetic, tense, and sleepy.

Table 7. Feeling Emotional or Physical or Thinking Changes

	Emotional			Physical			Thinking		
	None, Neutral, or Mixed	Pleasant	Unpleasant	None, Neutral, or Mixed	Pleasant	Unpleasant	None, Neutral, or Mixed	Pleasant	Unpleasant
Energizing	35%	65%	0%	77%	19%	3%	58%	42%	0%
Balancing	47%	53%	0%	63%	27%	10%	57%	43%	0%
Relaxing	44%	56%	0%	40%	52%	8%	48%	52%	0%
White	65%	35%	0%	58%	42%	0%	65%	35%	0%

Table 8. Feeling Calm, Feeling Alert, Having Energy, Being Tense, Being Sleepy, or Falling Asleep During Session

	Calm		Alert		Energy		Tense		Sleepy		Did you fall asleep?
Session Type	Less	More	Less	More	Less	More	Less	More	Less	More	Yes
Energizing	0%	77%	10%	42%	10%	35%	58%	13%	26%	55%	30%
Balancing	0%	80%	7%	33%	17%	30%	63%	3%	17%	57%	37%
Relaxing	0%	89%	12%	28%	4%	16%	76%	0%	16%	44%	25%
White	0%	77%	29%	10%	23%	10%	65%	3%	10%	65%	47%

Finally, they were asked if they fell asleep during the session. The most significant results included the following: (1) most participants (77%-89%) felt more calm after the session, with the relaxing group's results being the most marked at 89%—none reported feeling less calm; (2) substantially more participants reported feeling more alert (28%-42%) than less alert (7%-12%) after the light-modulation sessions as compared to the white session (10% more, 29% less)—the energizing session brought the most alertness (42%); (3) substantially more participants reported having more energy (16%-35%) rather than less energy (4%-17%) after the light-modulation sessions compared to the white group (10% more, 23% less); the energizing group experienced the most improvement in energy (35%); (4) most participants reported feeling less tense after all session types (58%-76%), with the relaxing group's results being the most marked (76%); (5) fewer participants in the light-modulation groups reported feeling more sleepy (44%-57%) than did participants in the white group (65% more); the energizing group gave the most "less sleepy" responses (26%); and (6) fewer participants fell asleep during the light modulation sessions (25%-37%) than during the white sessions (47%).

DISCUSSION

Physiological Measures

In analyzing the meaning of the physiological measures, it was essential to understand the relationship between the ANS and HRV better, especially its frequency-domain components VLF, LF, and HF. Traditionally VLF is linked to sympathetic ANS action, HF to parasympathetic action, LF to both, and LF/HF to the sympathetic/parasympathetic balance.[18]

However, this view has been evolving and may be an oversimplification.[15,20] In particular, some research has shown that the relationships do not apply so directly in situations where individuals have low sympathetic nervous tone, such as while resting in a supine position. Evidence exists that the sympathetic system contributes only minimally to supine LF HRV.[21] The simple act of lying down has been reported to cause an increase in total HRV power (SDNN) and in the powers of all frequency domains VLF, LF, and HF.[14] This finding is in line with the current research team's own observations, with the values of the SDNN and all three HRV bands—VLF, LF, and HF—having shown an increase during the light sessions (Table 2) and also with the LF/HF results being mostly statistically unclear.

The designers of the Sensora system consider the quasi-supine resting position adopted in the current study's protocol to be important when using light modulation to induce a more receptive state in participants.[10] It unfortunately renders more problematic the evaluation of the ANS balance purely from the current study's HRV trends. Despite that difficulty, some results make it generally clear that the light-modulation sessions can have benefits for healthy individuals.

A relative decrease in HR is indicative of increased relaxation (ie, parasympathetic ANS action). Figure 4 shows that all light-modulation sessions lowered HR substantially more than the white sessions, with balancing having the most marked HR reduction. HR reduction can naturally be expected from the simple act of reclining for 20 minutes. While the research team cannot evaluate how much of the observed HR influence was due to reclining or to the light projections, the team observed that the light-modulation projections did not prevent a significant overall HR reduction, whereas the white session did do so.

A relative increase in SDNN is a sign of increased well-being. Both the balancing and relaxing sessions significantly increased SDNN (Table 3; Figure 5). Some of the best-known HRV biofeedback methods, such as those designed by the HeartMath Institute, aim at increasing the LF HRV band as a way of increasing psychophysiological coherence (ie, a mode

Table 9. Differential Measurement Results for Four Light-session Types

	Physiological Measures	Psychological Measures
Energizing	• Lowest SC reduction (Table 3)	• Lowest POMS tension (Table 6) • Highest feelings of alertness and energy (Table 8) • Most pleasant changes at emotional level (Table 7)
Balancing	• Highest SC reduction (Table 3) • Highest LF (Table 2) • Highest LF/HF ratio (Table 2)	• Lowest POMS TMD (Table 3) • Lowest POMS depression, anger, confusion (Table 6)
Relaxing	• Second-highest SC reduction (Table 2) • Second-highest LF (Table 2)	• Highest feeling of calmness (Table 8) • Most pleasant changes at physical and thinking levels (Table 7)
White	• Medium SC reduction (Table 3) • No significant HR effects (Table 2) • No significant HRV effects (Table 2)	• Lowest POMS vigor (Table 6) • Least reductions in POMS tension, depression, fatigue, anger (Table 6) • Lowest feelings of alertness and energy (Table 8) • Highest occurrences of falling asleep (Table 8)

Abbreviations: SC = skin conductance; POMS = Profile of Mood States; LF = low frequency; HF = high frequency; TMD = total mood disturbance; HR = heart rate; HRV = heart rate variability.

of functioning characterized by distinctive psychological and behavioral correlates as well as by specific patterns of physiological activity throughout the body, brought about by positive emotional states).[22] All three light-modulation sessions led to a significant LF increase, with the relaxing group having experienced the most marked increase (Figure 6).

SC graphs show a clear SC decrease for all light sessions, which is to be expected since it reflects a relaxation due to the resting quasi-supine position (Figure 7). Interestingly, the balancing and relaxing sessions led to lower SC than did the placebo white sessions, indicating a deeper relaxation, while the energizing session led to a slightly higher SC than did the white session, indicating a relaxed state, but with higher arousal.

Psychological Measures

Turning to the current study's psychological assessments, a most noticeable result was the decrease in POMS TMD shown by all three light-modulation sessions (Figure 8), while the placebo white session had no significant TMD influence. POMS anger, fatigue, depression, and vigor indexes were differentially influenced by light modulation and by the placebo white session (Table 6). All showed a marked improvement as a result of the modulated light sessions, with the balancing group experiencing the greatest effect.

The postsession subjective questionnaire also showed a differential influence from the light-modulation sessions; more pleasant changes at the emotional and thinking levels were reported for the colored light than for the white (Table 7). The energizing sessions had the highest emotional impact, while the relaxing had the highest thinking impact.

The reported impact of subjective states was quite consistent with the intent of the light-modulation sessions; the energizing group experienced the highest increase in alertness and energy, and the greatest decrease in sleepiness (Table 8). The relaxing brought the greatest increase in calmness and the greatest reduction in tension.

Table 9 summarizes the differential results obtained for the current study's four types of light sessions. While the research team did observe significant effects for light on the ANS and the mood state of participants, it did not find a clear-cut relationship between ANS balance and the color ranges used in the light-modulation sessions, as has previously been proposed (eg, red activating sympathetic ANS or blue activating parasympathetic ANS). This finding may be a function of the quasi-supine resting position adopted in the current study's protocol, which the research team will change in future studies.

When the team compared the responses to the light for the physiological and psychological measures, the psychological responses were consistently more significant, and the average *P* value for each of the four conditions was less than .05 (Table 10). This finding suggests that the effects of colored light have a wider spectrum than a single-cause physical action and may influence multileveled psychophysiological interactions involving the body's homeostasis as well as psychological perceptions and associations.

Both the visual and the nonvisual NIF optic pathways are probably implicated. While the link between the nonvisual retinohypothalamic pathway and the ANS is clear—through hypothalamic ANS regulation, the intrinsically photosensitive retinal ganglion cells (ipRGC) responsible for its activation respond mostly to a color range centered around blue (~460-480 nm) and only transmit a light-intensity signal. On the other hand, the visual pathway relies on the trichromatic sensitivity of the three types of retinal photoreceptor cone cells—maximally sensitive to red, green and blue—to generate hue as well as intensity signals. The visually pleasing, mood-enhancing properties of the colored-

Table 10. *P* Values for Four Light-session Types

Area	Measure	Energizing	Balancing	Relaxing	White
ANS	HR	.023	.010	.044	.137
	SDNN	.105	.041	.054	.088
	HRV-VLF	.032	.004	.019	.102
	HRV-LF	.026	.013	.059	.191
	HRV-HF	.198	.159	.032	.076
	HRV- LF/HF	.211	.034	.109	.288
	Average level of *P*	.099	.044	.053	.147
	% of measures with $P < .05$	50%	83%	50%	0%
Emotional Cognitive	SC	.045	.000	.001	.007
	Tension	.000	.003	.001	.000
	Depression	.000	.000	.040	.005
	Anger	.007	.001	.049	.224
	Vigor	.007	.010	.005	.000
	Fatigue	.014	.002	.004	.047
	Confusion	.000	.000	.005	.000
	Average level of *P*	.010	.002	.015	.040
	% of measures with $P < .05$	100%	100%	100%	86%

Abbreviations: HR = heart rate; SDNN = standard deviation of normalized NN (beat-to-beat) intervals; HRV = heart rate variability; VLF = very low frequency; LF = low frequency; HF = high frequency; SC = Skin Conductance.

light sessions could very well mediate ANS influence through the visual pathway, with cognition-driven neural mechanisms similar to those revealed by ANS susceptibility to positive emotions.[22]

An interaction may also exist between both of these ANS-influence modalities. Recent research has demonstrated a light-induced nonvisual modulation of cognitive brain responses.[23,24] These light-induced responses propagate from the hypothalamus to various brain structures involved in cognition, including the prefrontal cortex, after approximately 20 minutes. This amount of time is consistent with the duration of the light sessions administered in the current study.

A mechanism of action theorized for light modulation's effects is that it maintains the participant's attention—through the perceived beauty of the pure colors and their softly pulsing movements on the screen, while allowing him or her to relax deeply, both physically—through resting quietly in quasi-supine position—and mentally—because no message or cognitive content needs to be analyzed in the nonrepresentational light projections.[12] This combination of awareness and relaxation has similarities to the meditative state, in this case induced without any conscious effort by the participant; it could conceivably be linked to peak performance and therapeutic integration.

This theory of action is consistent with many of the measurements obtained in this study. Participants experiencing the light-modulation sessions reported falling asleep less often than did participants in the white sessions, had higher vigor indexes and lower fatigue indexes (Table 6), and had higher HRV VLF levels (Table 2) linked to sympathetic ANS action. All these elements point to the idea that light modulation induces increased arousal. At the same time, the light-modulating sessions (1) lowered HR (Figure 4) and SC (Figure 7), indicating a relaxed and resting condition; (2) increased SDNN (Figure 5) and HRV LF (Figure 6), indicating greater heart coherence; and (3) increased pleasant emotional changes (Table 7), all pointing to a more deeply harmonious mood state.

A major paradox in this study occurred because of the participants' quasi-supine position. On one hand, this position could be an important component in establishing a receptive state conducive to the colored light's influence on the ANS. On the other hand, the position interferes with the validity of HRV measurements as an assessment of ANS state. Future studies maintaining a quasi-supine position may benefit from use of methods to measure physiological ANS other than HRV.

CONCLUSION

The research team observed significant differences in the effects of light-modulation projections between baseline and postsession as compared with an equivalent intensity of white light, including decreased heart rate, increased HRV SDNN, VLF, and LF levels, and decreased POMS TMD. The combination of parameters—color range, brainwave-range modulation, and synchronized phase control leading to moving light patterns—used in the three tested types of light modulation sessions—energizing, relaxing, and balancing—resulted in significant physiological and mood differences, consistent with their intended effects on a number of measurement indexes.

The effects demonstrated in the current study indicated that colored light could significantly enrich the therapeutic potential of light and that the current study's results warrant further research into the colored aspect of light therapy (ie, chromotherapy). Next steps in this direction could include (1) separate testing of each light-modulation parameter to understand the relative effects better, (2) evaluation of the relative impact of the visual and nonvisual pathways in the chromotherapeutic process, and (3) longer-term clinical testing of promising well-being and psychiatric applications. Medical researchers have known for quite a while that healing environments beneficially alter health; clearly humans' innate appreciation of colored light is a gateway to creating such environments for the future.

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