The Impact of Modulated Color Light on the Autonomic Nervous System

MARY J. ROSS *Ph.D.*, PAUL GUTHRIE[1] *Ph.D.*, JUSTIN-CLAUDE DUMONT[2] *MA*

[1] Department of Psychology, Midwestern State University, Wichita Falls, Texas, USA
[2] Trinity Western University, Langley, BC, Canada

ABSTRACT

The purpose of this study is to evaluate the impact of modulated light projections perceived through the eyes on the autonomic nervous system (ANS). Three types of light projections, each containing both specific colors and specific modulations in the brainwaves frequency range, were tested, in addition to a placebo projection consisting of non-modulated white light. Evaluation was done using a combination of physiological measures *(HR, HRV, SC)* and psychological tests *(Amen, POMS).* Significant differences were found in the ANS effects of each of the colored light projections, and also between the colored and white projections.

INTRODUCTION

The therapeutic use of light and colors has a long historical tradition, originating in ancient cultures such as Egypt, Greece and India. After Newton's discoveries it became 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 nineteenth and early twentieth 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 development of new chemical drugs such as antibiotics, until by the 1940s it was more or less forgotten by modern medicine. Only recently is there a renewed interest in the subject throughout the world, with the impetus of research institutions such as NASA.

It is now becoming clearer that light acts on us through multiple pathways, notably the optic nerve linked to the brain's visual cortex providing a pathway for visual effects of light, and the more recently discovered retinohypothalamic tract providing a pathway for non-visual (also referred to as non-image forming - NIF) effects of light (Brainard, 2001). This second pathway leads to the suprachiasmatic area of the hypothalamus, mediating circadian rhythms and melatonin secretion, and furthermore involved in the regulation of our 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 (Terman, 2007).

It is now generally accepted that light and color have an impact on the ANS (Breiling, 1996; Liberman, 1991), and some studies have been made on this subject (e.g. Sakakibara S, 2000; Palienko, 2001; Wallace, 2003 & McManemin, 2005). However specific effects have not yet been widely evaluated clinically, especially in relation with *chromotherapy* (i.e. therapy based on colored light).

It is also known that light can have a profound impact on mood through photic brainwaves entrainment (Siever, 2003), a process in which brainwaves tend to naturally fall in sync with pulsing visual stimuli. This method has been refined with the "Light Modulation" technique developed by Sensortech Inc., in which arrays of inter-connected Low-Frequency Oscillators (or "LFOs") control, or "modulate", the two basic parameters of light: color, and intensity (Martel, 2001; Martel, 2007).

This light modulation system allows full control of the colors and brainwaves photic driving properties of a light projection. Moreover it allows the control of cyclic light movements: through coordinated phase control of the intensity and/or color parameters, it is possible to generate apparent movement patterns in the light projection.

Patterns such as a left-to-right linear movement or an outward movement expanding from the center of the visual field towards the edges are considered to have a subtle tendency to bring arousal and stimulation (Martel, 2001). Conversely 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 bring 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 (Martel, 2001). This type of light session is currently implemented in Sensortech's Sensora systems, and also in consumer products such as OSIM's uVenus and uGalaxy.

The purpose of the present study is to evaluate the effects of these light projections on the ANS, as well as their mood-enhancing effects. A secondary goal is to determine if certain clusters of symptoms are associated with the subject's response to the light projections.

METHOD

117 subjects were recruited to participate in the study, which took place in 2 locations: Midwestern State University, Texas, USA (40 subjects) and Centre de Santé Satori, Québec, Canada (77 subjects). Subjects were normal healthy individuals, 19 to 72 years old (average age: 43), with 89 women and 28 men.

The study protocol for each subject was as follows:

1. Completion of Information Sheet and Informed Consent form.
2. Intake questionnaire.
3. Van Obberghen Color Preference Test, according to the Color Institute method.
4. POMS standardized psychological test (Brief Form), pre-session.
5. Subject sits on reclining chair in the light session room for the remaining steps, in reclining (near-supine) position.
6. 10 minutes rest period.
7. 5 minutes pre-session (Baseline) HRV *(Heart Rate Variability)* / SC *(Skin Conductance)* recording.
8. 20 minutes light session, concurrent with 20 minutes HRV/SC recording.
9. Short subjective mood evaluation questionnaire, post-session.
10. POMS standardized psychological test (Brief Form), post-session.
11. 5 minutes post-session HRV/SC recording.

Steps 3-11 were performed on a computer screen, with input data captured directly to digital files.

Each subject received a light session randomly selected from one of four types:

Type 1: "Energizing"

Light projections with enhanced energizing and stimulating effects (potentially linked to the sympathetic ANS) considered to be obtained by using various combinations of colors in the warm-color range (Red, Orange, Yellow) with brainwaves modulations in the Beta range (13-20Hz), and right-ward or outward light movements (Martel, 2001).

Type 2: "Balancing"

Light projections with enhanced balancing and centering effects considered to be obtained by using patterns containing equal proportions of all colors in the spectrum, in combination with brainwaves modulations in the higher Alpha range (8-12Hz), and equal proportions of inward and outward light movements (Martel, 2001).

Type 3: "Relaxing"

Light projections with enhanced relaxing and pacifying effects (potentially linked to the parasympathetic ANS) considered to be obtained by using various combinations of colors in the cool-color range (Green, Blue, Indigo) with brainwaves modulations in the Theta/Alpha range (7-8Hz), and left-ward or inward light movements (Martel, 2001).

Type 4: Placebo (White Light)

Light projections consisting of static, uniform white light.

Subjects were not told which type of light session they would be receiving or anything about its potential effects, and the researchers did not know beforehand which session type was administered to each subject. The light sessions were administered with standard equipment made by Sensortech Inc: the colored light source is the LED-based LPA-3 light projector, projecting from behind the subject's head towards a 1.8m-diameter circular screen inclined at 45° and located 1.2m from the subject's head. This configuration is designed so that the colored light projection subtends a significant proportion (75°) of the subject's visual field, and is illustrated in Figure 1. The treatment room is light-proofed and darkened during the light session (Figure 2), so that no external stray light perturbs the light projection being tested.

All four light sessions last 20 minutes each, which is considered sufficient to realize their potential effects on the ANS and mood (Martel, 2001). In order to remove light intensity as a variable in the study, all four light sessions are normalized to the same average light level of 63 lux, as measured at the position of the subject's eyes.

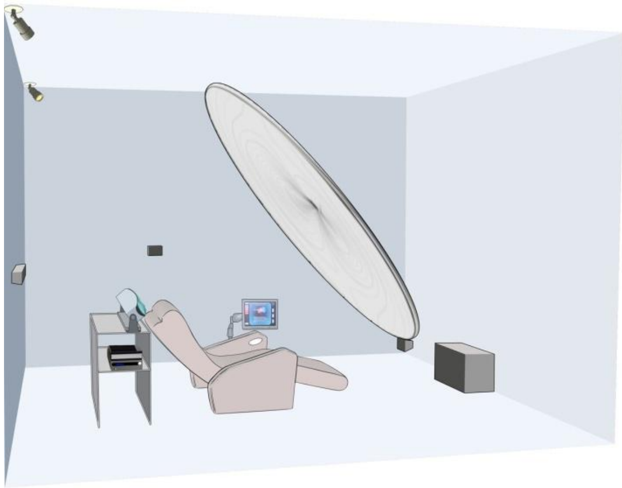

Figure 1 - Treatment room configuration

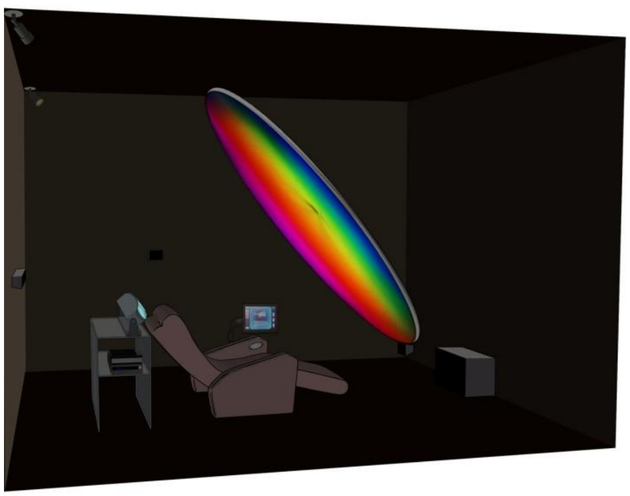

Figure 2 - Treatment room during light session

Physiological Measures:

ANS state is estimated from physiological measures of Heart Rate Variability (HRV) and Skin Conductance (SC).

HRV is a measure of the variations in the inter-heart beat intervals (R-R 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 semi quantitative method of assessing activities in the ANS (Højgaard et al., 1998), as it will be used in this study. 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 this study, we are considering the following measures yielded from HRV analysis:

Time-domain Measures:

- ***Heart Rate (HR):*** general indicator of relaxation, decrease linked to ANS parasympathetic activation.
- ***SDNN:*** standard deviation of normalized NN (beat-to-beat) intervals. Increase broadly linked to better adaptability and health (Lehrer, Woodfolk, & Sime, 2007).

Frequency-domain Measures:

- ***Very Low (VLF):*** 0.003 to 0.04Hz. Relates to the vascular tone loop of the baroreflex system, thermal regulation, and activity of the renin-angiotensin system; linked to the sympathetic action of ANS (Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996; Berntson et al., 1997).
- ***Low (LF):*** 0.04 to 0.15Hz. Relates to baroreflex function (blood pressure maintenance); linked to both sympathetic and parasympathetic ANS actions (refs. idem).
- ***High (HF):*** 0.15 to 0.4Hz. Relates to processes modulating gas exchange efficiency, respiratory sinus arrhythmia (RSA), and activity from the vagus nerve; linked to parasympathetic ANS action (Akselrod et al., 1981).
- ***LF/HF:*** often used as a metric of sympathetic/ parasympathetic ANS balance.

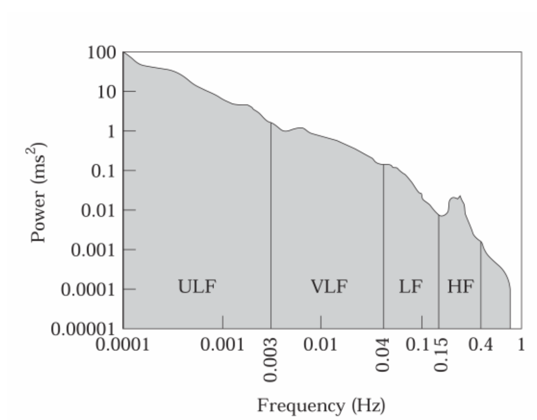

Figure 3 - HRV Spectral Bands

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.

Psychological Measures:

Profile of Mood States or **POMS** (McNair, Lorr, & Droppleman, 1971) is a factor-analytically derived inventory that measures six identifiable mood or affective states: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, Confusion-Bewilderment. POMS provides a fast, statistically proven method of assessing transient, fluctuating active mood states. In this study, it was administered twice: before the light session, and after the session. It therefore allowed evaluating the mood impact of the light session.

A simple post-session **Subjective Evaluation** questionnaire was constructed by the investigators to evaluate:

- if the light session induced changes in the way the subject feels emotionally, physically or in his/her thoughts;
- if it induced changes in the subject's level of calmness, alertness, tension, energy or wakefulness;
- if the subject fell asleep during the session.

INSTRUMENTS

Light Source: Sensortech Inc. LPA-3 Light Projection Array, with integrated Light Modulation processor.

Projection Screen: Sensortech Inc. PS-Mini, circular 1.8m diameter, silver surface.

HRV and Skin Conductance Sensors: Thought Technology Ltd T7400M Procomp 2 Dual Channel System, SA9306M EKG Sensor, SA9309M Skin Conductance Sensor, SA7700 TT-USB Receiver, with SA7900 Biograph Infinity Analysis Software.

Light Level Meter: Extech Model 401036.

RESULTS

Physiological Measures:

Of the 117 HRV records obtained, 33 were invalidated by technical difficulties (due to interference between the PC and the HRV sensors), leaving 84 HRV/SC data sets that were then normalized. HRV values were calculated according to the clinically recommended short-term 5-minutes recording segmentation (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996), resulting in 6 values per measured HRV/SC parameter: a pre-session baseline value, 4 intra-session values (Tr1-Tr4 at 5, 10, 15, and 20 minutes, with Tr4 being the end-of-session value), and a post-session value. Since we are 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 where any of the standardized values were found to have $z > |3.29|$. 19 HRV cases and 1 SC case were thus identified as univariate outliers, departing substantially from the other data points. These cases were eliminated from further analysis, leaving the number of valid HRV and SC records listed in Table 1.

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

Table 1 - Number of HRV and SC records per Session Type

Paired t-test two-tailed probability "p" values were calculated between the Baseline (before) and Tr4 (after) results for each measured parameter in order to evaluate their statistical significance, with $p>0.05$ considered non-significant.

Table 3 summarizes all **Mean Heart Rate (HR)** and **Heart Rate Variability (HRV)** results. Mean Heart Rate (HR) and Heart Rate Variability SDNN results are shown in Figure 4 and Figure 5. It can be seen that HR has been decreased by 2.5% to 3.8% at the end of session (Tr4) for the three light modulation sessions, with the Balancing type leading to the greatest and most rapid decrease; in contrast, the "placebo" White session shows no statistically significant change (with $p=0.137$). SDNN shows a marginally significant Baseline-Tr4 increase for the Balancing (22%, $p=0.04$) and Relaxing (18%, $p=0.05$) sessions; the Energizing and White sessions show statistically non-significant increases ($p>0.05$). Both frequency-domain HRV VLF and LF (Figure 6) show clear Baseline-Tr4 increases for all three light modulation sessions, while the White changes are again non-significant. All HRV HF Baseline-Tr4 changes are non-significant, except for the Relaxing session which shows a 25% increase ($p=0.03$). As for the HRV LF/HF ratios, only the Balancing session showed a significant Baseline-Tr4 change ($p=0.03$) with a marked increase (x3.7).

Skin conductance SC results are shown in Table 2**Error! Reference source not found.** and Figure 7. All session types cause significant Baseline-Tr4 SC decreases, with the Relaxing (30%) and Balancing (28%) sessions being most marked, and the Energizing (17%) session being the least. White (22%) is intermediate.

	Baseline	Tr4	P
Energizing	2.13 100%	1.60 82.7%	0.045
Balancing	3.25 100%	2.12 69.7%	0.000
Relaxing	2.67 100%	1.84 71.6%	0.001
White	2.93 100%	2.12 77.9%	0.007

Table 2 - Average skin conductance

	Mean Heart Rate			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	0.023	58.30	66.42	0.105	136.0	273.6	0.032	214.4	281.3	0.026	138.2	144.6	0.198	1.70	1.54	0.211
	100.0%	96.6%		100%	115.3%		100%	201.1%		100%	155.1%		100%	119.6%		100%	195.5%	
Balancing	66.33	63.65	0.010	60.72	74.69	0.041	132.0	292.8	0.004	190.8	239.3	0.013	156.8	166.7	0.159	2.03	3.14	0.034
	100.0%	96.2%		100%	121.9%		100%	209.1%		100%	181.3%		100%	119.3%		100%	370.6%	
Relaxing	68.09	66.42	0.044	58.41	68.87	0.054	136.5	333.2	0.019	229.39	262.02	0.059	143.28	162.20	0.032	1.87	2.43	0.109
	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	0.137	53.91	56.39	0.088	215.8	169.6	0.102	186.9	159.5	0.191	82.1	100.9	0.076	2.17	2.29	0.288
	100.0%	98.3%		100%	109.5%		100%	166.6%		100%	119.2%		100%	121.0%		100%	148.3%	

Table 3 - Average Mean Heart Rate (bpm and % relative) and Heart Rate Variability results

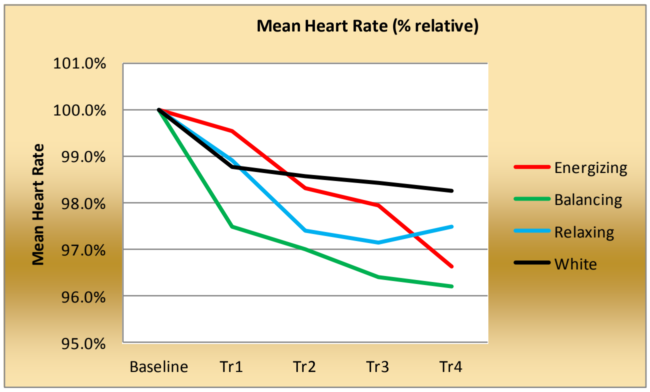

Figure 4 - Mean Heart Rate, relative trends

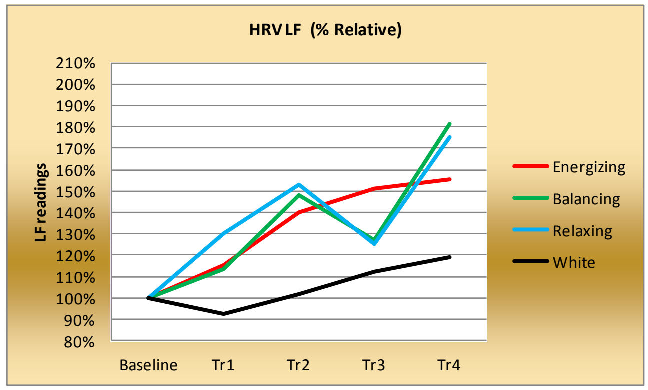

Figure 6 - HRV LF, relative trends

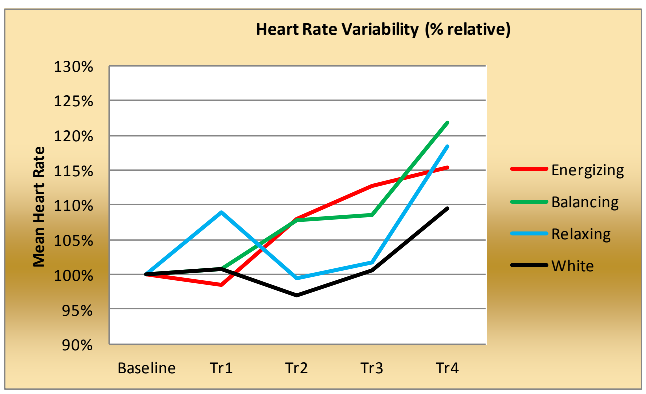

Figure 5 - SDNN Heart Rate Variability, relative trends

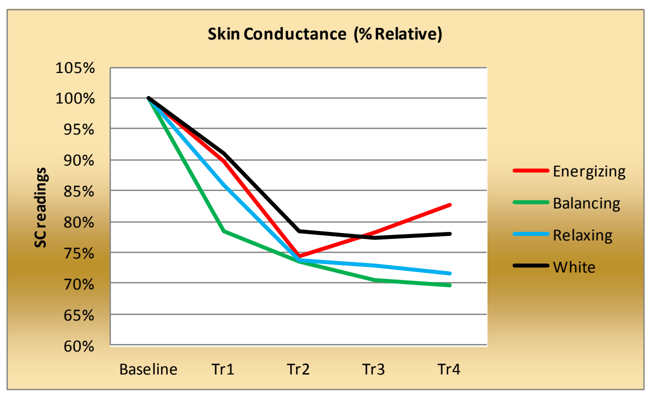

Figure 7 - Skin conductance, relative trends

Psychological Measures:

All subjects responded to the psychological questionnaires, with the following proportions:

Session Type:	Number of subjects
Energizing	31
Balancing	30
Relaxing	25
White Light	31
Total	*117*

Table 4 - Number of subjects responding to Psychological questionnaires

The **POMS** pre- and post-questionnaires allow 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 disturbance. Results for this index are shown below; all three light modulation sessions display significant TMD decrease, with Balancing being most marked, and the White session caused no significant TMD change (p=0.14).

	Baseline	Post	Post-Baseline Difference	p
Energizing	7.48	0.84	-6.65	0.004
Balancing	8.31	0.17	-8.14	0.003
Relaxing	6.80	0.92	-5.88	0.025
White	1.68	-0.74	-2.42	0.144

Table 5 - POMS Total Mood Disturbance Index

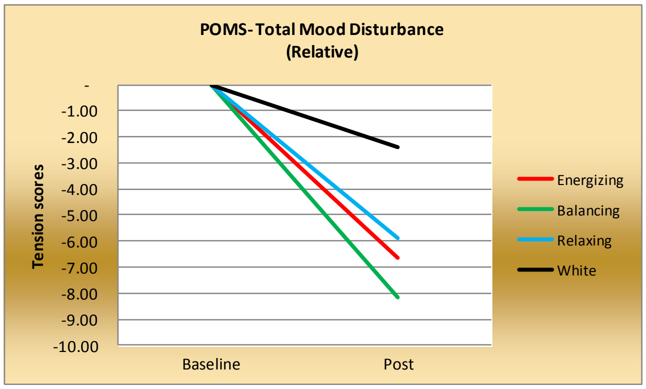

Figure 8 - POMS TMD, relative trends

Baseline and Post results for the six POMS moods are summarized in Table 7. To facilitate interpretation of differences induced by the light sessions, relative trends are obtained by standardizing the averaged Baseline values to 100%.

- Tension and Confusion indexes are significantly reduced (6%-13%) by all four session types.
- Anger, Fatigue, and Depression are significantly reduced by all three light modulation sessions, with Balancing having the most marked decrease (8%-13%). The White session has a smaller impact (2%-7%), with Anger change being non-significant.
- Vigor is decreased nearly twice as much by the White session (13%) than by the three light modulation sessions (7%-8%).

The post-session **Subjective Evaluation** questionnaire asked subjects if they felt any change at the emotional, physical, and thinking levels, with "No Change", "Neutral", "Mixed", "Pleasant", and "Unpleasant" available as options. Table 6 summarize the results, with the first 3 responses lumped in the same column.

The three light modulation sessions brought more "Pleasant" changes (42%-65%) than the White session (35%) at both Emotional and Thinking levels, with no "Unpleasant" changes reported for any of the session types.

The Relaxing brought the most "Pleasant" Physical changes (52%). All three light modulation sessions brought a few "Unpleasant" changes (3%-10%).

	Emotional			Physical			Thinking		
	None, Neutral or Mixed	Pleasant	Un pleasant	None, Neutral or Mixed	Pleasant	Un pleasant	None, Neutral or Mixed	Pleasant	Un pleasant
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 6 - Feeling Emotional, Physical or Thinking Changes

Subjects were also asked if they perceived feelings in any of 8 physical areas. Some notable results:

- Head, Legs, and Arms were the areas with the most feelings experienced (32%-37% average).
- The Energizing session brought the most feelings in the Head and Arms area (44%).
- White triggered most feelings in Legs and Arms (44% each).

As part of the Subjective Evaluation, subjects 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, having Energy, Tense, Sleepy. Finally, they were asked if they fell asleep during the session. The most significant results are:

- Most subjects (77%-89%) felt more Calm after the session, with Relaxing being the most marked at 89%. None reported feeling less Calm.
- Substantially more subjects reported feeling more Alert (28%-42% more alert, 7%-12% less alert) after the light modulation sessions than after the White session (10% more, 29% less). The Energizing session brought the most alertness (42%).
  Substantially more subjects reported having more Energy (16%-35% more energy, 4%-17% less energy) after the light modulation sessions than after the White session (10% more, 23% less). The Energizing session brought the most energy (35%).
- Most subjects reported feeling less tense after all session types (58%-76%), with the Relaxing session being the most marked (76%).
- Fewer subjects reported feeling more Sleepy (44%-57% more sleepy, 16%-26% less sleepy,) after the light modulation sessions than after the White (65% more, 10% less). The Energizing session brought the most "less Sleepy" responses (26%).
- Fewer subjects fell asleep during the light modulation sessions (25%-37%) than during the White (47%).

	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	31.94	0.000	35.29	32.68	0.000	38.45	36.19	0.007	51.26	47.19	0.007	41.29	36.77	0.014	39.35	36.13	0.000
	100%	88.1%		100%	92.6%		100%	94.1%		100%	92.5%		100%	89.1%		100%	91.8%	
Balancing	36.70	33.23	0.003	36.77	32.50	0.000	39.40	36.20	0.001	52.23	47.80	0.010	39.77	34.53	0.002	41.50	36.03	0.000
	100%	90.6%		100%	88.4%		100%	91.9%		100%	91.5%		100%	86.8%		100%	86.8%	
Relaxing	35.40	31.88	0.001	35.32	33.00	0.040	38.24	36.40	0.049	49.64	45.72	0.005	39.88	35.12	0.004	39.88	35.80	0.005
	100%	90.1%		100%	93.4%		100%	95.2%		100%	92.1%		100%	88.1%		100%	89.8%	
White	34.00	31.03	0.000	33.84	32.39	0.005	37.29	36.65	0.224	55.90	48.74	0.000	38.32	35.55	0.047	39.84	36.19	0.000
	100%	91.3%		100%	95.7%		100%	98.3%		100%	87.2%		100%	92.8%		100%	90.9%	

Table 7 - Indexes for the six POMS moods (Tension, Depression, Anger, Vigor, Fatigue, and Confusion)

DISCUSSION

In trying to analyze the meaning of our physiological measures, it is essential to understand better the relationship between the ANS and HRV, especially its frequency-domain components VLF, LF, and HF. Traditionally VLF is linked to sympathetic ANS action, HF to parasympathetic, LF is considered to involve both, and LF/HF is linked to sympathetic/parasympathetic balance (Akselrod, 1981).

However this view has been evolving and may be an oversimplification (Eckberg, 2000; Lehrer, Woodfolk, & Sime, 2007). In particular, research has shown that it does not apply so directly in situations with low sympathetic nervous tone, such as while resting in supine position. There is evidence that the sympathetic system contributes only minimally to supine LF HRV (Myers et al., 2001). 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 (Højgaard et al., 1998): this is in line with our own observation, with values of SDNN and all three HRV bands VLF, LF & HF showing an increase during the light sessions (Table 3), and also with the LF/HF results being mostly statistically unclear.

The quasi-supine resting position adopted in our protocol is considered important by the designers of the Sensora system using light modulation, in order to induce a more receptive state in subjects (Martel, 2001). It unfortunately renders more problematic the evaluation of the ANS balance purely from our HRV trends. That being said, it remains generally clear that for healthy individuals:

- A relative decrease in HR (Heart Rate) is indicative of increased relaxation, or parasympathetic ANS action. Figure 4 shows that all light modulations sessions lowered HR substantially more than the White session, with Balancing having the most marked HR reduction. HR reduction can naturally be expected from the simple act of reclining for 20 minutes; while we cannot evaluate how much of the observed HR influence is due to reclining or to the light projections, we see that the light modulation projections did not prevent a significant overall HR reduction whereas the White session did 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, i.e. a mode 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 (McCraty et al., 2006). All three light modulation sessions led to a significant LF increase (Figure 6), with the Relaxing having the most marked increase.

Skin conductance (SC) graphs show a clear SC decrease for all light sessions (Figure 7), which is to be expected since it reflects a relaxation due to the resting quasi-supine position. Interestingly, the Balancing and Relaxing sessions led to lower SC than our placebo reference White (indicating a deeper relaxation), while the Energizing session led to a slightly higher SC than White (indicating a relaxed state, but with higher arousal).

Turning to our psychological assessments, a most noticeable result is the decrease in POMS TMD (Total Mood Disturbance) shown by all three light modulation sessions (Figure 8), while the placebo White had no significant TMD influence. POMS Anger, Fatigue, Depression, and Vigor indexes were differentially influenced by light modulation and by our placebo White (Table 7). All showed a marked improvement with the modulated light sessions, with the Balancing session having the greatest effect.

The post-session 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 6). The Energizing had the highest Emotional impact, while the Relaxing had the highest impact on Thinking.

The reported impact of subjective states is quite consistent with the light modulation sessions' intent: the Energizing brought the highest increase in Alertness and Energy, and the greatest decrease in Sleepiness. The Relaxing brought the greatest increase in Calmness and the greatest reduction in Tense state.

The following table summarizes the differential results obtained for our four types of light sessions:

	Physiological Measures	Psychological Measures
Energizing	• Higher SC arousal	• Lowest POMS Tension • Highest feelings of Alertness and Energy • Most pleasant changes at Emotional level
Balancing	• Highest SC reduction • Highest LF • Highest LF/HF ratio	• Lowest POMS TMD, Depression, Anger, Confusion
Relaxing	• Higher SC reduction • Higher LF	• Highest feeling of Calmness • Most pleasant changes at Physical and Thinking levels
White Light	• Medium SC reduction • No significant HR effects • No significant HRV effects	• Lowest POMS Vigor • Least reductions in POMS Tension, Depression, Fatigue, Anger • Lowest feelings of Alertness and Energy • Highest occurrences of falling asleep

Table 8 - Differential measurement results for 4 light session types

While we did observe significant effects of light on the ANS and the mood state of subjects, we 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 (e.g. red activating sympathetic ANS, blue activating parasympathetic ANS). This may be a function of the quasi-supine resting position adopted in our protocol which will be changed in future studies. When we compare the responses to the light for the physiological measures and the psychological measures, the psychological responses were consistently more significant and the average p value for each of the four conditions is less than 0.05 (see Table 9). This suggests that the effects of colored light have a wider spectrum than single-cause physical action, and may be influencing multi-leveled psychophysiological interactions involving the body's homeostasis as well as psychological perceptions and associations.

Both the visual and the non-visual NIF optic pathways are probably implicated. While the link between the non-visual 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 to 480nm) and only transmit a light intensity signal, whereas 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 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 (McCraty et al., 2006).

There may also be an interaction between both of these ANS influence modalities: recent research has demonstrated light-induced non-visual modulation of cognitive brain responses (Vanderwalle, 2007; Vanderwalle, 2009). These light-induced responses propagate from the hypothalamus to various brain structures involved in cognition (including the prefrontal cortex) after approximately 20 minutes, which is consistent with the duration of the light sessions administered in this research.

Area	Measure	Energizing	Balancing	Relaxing	White
ANS	HR	0.02	0.01	0.04	0.14
	SDNN	0.10	0.04	0.05	0.09
	HRV-VLF	0.03	0.00	0.02	0.10
	HRV-LF	0.03	0.01	0.06	0.19
	HRV-HF	0.20	0.16	0.03	0.08
	HRV- LF/HF	0.21	0.03	0.11	0.29
	Ave. level of p	0.05	0.02	0.03	0.09
	% of measures with p<.05	50%	67%	50%	0%
Emotional Cognitive	Skin conduction	0.04	0.00	0.00	0.01
	Tension	0.00	0.00	0.00	0.00
	Depression	0.00	0.00	0.04	0.00
	Anger	0.00	0.00	0.05	0.22
	Vigor	0.00	0.01	0.00	0.00
	Fatigue	0.01	0.00	0.00	0.05
	Confusion	0.00	0.00	0.00	0.00
	Ave. level of p	0.01	0.00	0.01	0.04
	% of measures with p<.05	100%	100%	100%	86%

Table 9 - Probability "p" values for 4 light session types

A mechanism of action theorized for light modulation's effects is that it maintains the subject's attention (through the perceived beauty of the pure colors, and their softly pulsing movements on the screen), while allowing him/her to relax deeply both physically (resting quietly in quasi-supine position) and mentally (because there is no message or cognitive content to be analyzed in the non-representational light projections) (Martel, 2001). This combination of awareness and relaxation has similarities with the meditation state, in this case induced without any conscious effort from the subject; 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. Subjects experiencing the light modulation sessions reported falling asleep less often than during the White session, had higher Vigor indexes and lower Fatigue indexes (Table 7), had higher

HRV VLF levels (Table 3) linked to sympathetic ANS action: all these elements point to light modulation inducing increased arousal. At the same time, lowered Heart Rate (Figure 4) and lowered skin conductance (Figure 7) indicating a relaxed and resting condition, increased SDNN (Figure 5) and HRV LF (Figure 6) indicating greater heart coherence, and increased pleasant Emotional changes (Table 6), all point to a more deeply harmonious mood state.

CONCLUSION

Significant differences in the effects of light modulation projections compared with an equivalent intensity of white light were observed, including decreased heart rate, increased HRV SDNN, VLF, and LF levels, decreased POMS Total Mood Disturbance index. The combination of parameters (color range, brainwaves-range modulation, synchronized phase control leading to moving light patterns) used in the three types of light modulation sessions tested ("Energizing", "Relaxing", "Balancing") result in significant physiological and mood differences, consistent with their intended effects on a number of measurement indexes.

There is a growing interest into the therapeutic potential of light (e.g. Treman, 2007; Castro, 2011). The effects demonstrated here indicate that colored light could significantly enrich this potential, and warrant further research into the colored aspect of light therapy (or chromotherapy). Next steps in this direction could include separate testing of each light modulation parameter to better understand their relative effects; evaluating the relative impact of the visual and non-visual pathways in the chromotherapeutic process; and longer-term clinical testing of promising well-being and psychiatric applications. It has been known for quite a while that healing environments beneficially alter health (Ulrich, 1984); clearly our innate appreciation of colored light is a gateway to creating such environments for the future.

REFERENCES

Akselrod, S., Gordon, D., Ubel, F., Shannon, D., Berger, A., & Cohen, R. (1981). Power spectrum analysis of heart rate fluctuation: A quantitative probe of beat-to-beat cardiovascular control. *Science*, 213, 220-222.

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., & Malik, M. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34*, 623-648.

Brainard, G., Hanifin, J., Greeson, J., et al. (2001). Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. *J Neurosci*, 21, 6405–6412.

Breiling, B. (1996). *Light Years Ahead.* Celestial Arts.

Castro, R., Angus, D.C., Rosengart, M.R. (2011). The effect of light on critical illness. *Critical Care*, 15:218.

Eckberg, D. L. (2000). Physiological basis for human autonomic rhythms. *Annals of Medicine, 32,* 341-349.

Højgaard, M., Holstein-Rathlou, N.-H., Agner, E., & Kanters, J. K. (1998). Dynamics of spectral components of heart rate variability during changes in autonomic balance. *Am J Physiol Heart Circ Physiol 275*, 213-219.

Lehrer, P., Woodfolk, R., & Sime, W. (2007). *Pinciples and Practice of Stress Management, p.227-233.* Guilford Press.

Liberman, J. (1991). *Light: Medicine of the Future.* Bear & Company Inc.

Martel, A. (2001). Sensora Technical Article. *AVS Journal, Vol.1#3*.

Martel, A. (2007). Light Modulation, A New Way of Looking at Light. *Professional Lighting Design, No.57*.

McCraty, R., Atkinson, M., Tomasino, D., & Trevor Bradley, R. (2006). *The Coherent Heart : Heart–Brain Interactions, Psychophysiological Coherence, and the Emergence of System-Wide Order.* Institute of HeartMath

McManemin, F. A. (2005). Autonomic Nervous System and Light Frequencies. *Journal of Optometric Phototherapy* .

McNair, D. M., Lorr, M., & Droppleman, L. F. (1971). *Manual for the Profile of Mood States.* San Diego, CA: Educational and Industrial Testing Services.

Myers, C., Cohen, M., Eckberg, D., & Taylor, J. (2001). A model for the genesis of arterial pressure Mayer waves from heart rate and sympathetic activity. *Autonomic Neuroscience: Basic and Clinical, 91*, 62-75.

Palienko, I. (2001). Effect of different light and color stimulation of the cerebral hemispheres on cardiac rhythm self-regulation in healthy individuals. *Fiziol Zh (Ukraine), 47 (1),* 73-75.

Palienko, I. (2001). Spectral analysis of heart rate responses to light and color stimulation of the cerebral hemispheres. *Fiziol Zh (Ukraine), 47(2)*, 70-73.

Sakakibara S, H. H. (2000). Autonomic nervous function after evening bright light therapy: spectral analysis of heart rate variability. *Psychiatry Clin Neurosci (Australia), 54(3)* 363-4.

Siever, D. (2003). Audio-Visual Entrainment: History and Physiological Mechanisms. *AAPB Biofeedback Magazine, Vol.31#2* .

Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology. (1996). HRV: Standards of Measurement, Physiological Interpretation, and Clinical Use. *Circulation 1996;93*, 1043-1065.

Terman, M., (2007). Evolving applications of light therapy. *Sleep Med. Rev.*, 11, 497–507.

Ulrich, R. (1984). View through a window may influence recovery from surgery. *Science*, 224, 420–421.

Wallace, L. (2003). Heart Rate Variability and Syntonics. *Journal of Optometric Phototherapy*

Vandewalle, G., et al (2007). Brain responses to violet, blue, and green monochromatic light exposures in humans: prominent role of blue light and the brainstem. *PLos ONE* 2 (11): e1247. doi:10.14371/journal.pone.0001247.

Vandewalle, G., Maquet, P., Dijk, D.J. (2009). Light as a modulator of cognitive brain function. *Trends Cogn Sci*, 13:429–438.

APPENDIX

MSU Study Approval Memorandum

Human Subjects In Research Committee

Institutional Review Board in Compliance with 45 CFR 46

MSU Policy 2.37

MEMORANDUM

TO: Paul Guthrie

RE: The Impact of Modulated Color Light on the Autonomic Nervous System

DATE: May 13, 2010

Your proposal for research utilizing human subjects has been reviewed and approved by the above named committee.

The number assigned this project is 10051301

Please include this file number in any presentation or publication arising from this research. You may be required to place a copy of this letter within the thesis or other class, department, or college documentation. This approval is valid for one calendar year following granting of approval status. Your may request an extension by submitting a letter requesting such to the HSRC committee chair.

Respectfully,

Chair, Human Subjects in Research Committee (IRB)