THE EFFECT OF ACUTE BRIGHT LIGHT EXPOSURE ON SOCIAL AFFILIATION

By

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Abstract

In recent decades, bright light has emerged as a useful tool in numerous clinical and non-clinical applications, with the potential to influence circadian rhythms, sleep, mood, and several other functional domains. However, despite the existence of plausible neurological pathways through which light could also influence social behavior, little is known at this point about the direct effects of bright light exposure on social interaction. Accordingly, the present study – utilizing a sample of young adults endorsing at least mild seasonal fluctuations in clinically relevant domains – examined the acute effects of a single 45-minute session of bright white light (15,000 lux) versus dim red light (200 lux) exposure on affiliative behavior. A significant interaction was observed between light condition and prior retinal sunlight exposure in the prediction of affiliative desire. Specifically, among study participants unexposed to high levels of morning blue-wavelength sunlight prior to the experiment, those in the bright light condition preferred the company of a stranger (another study participant) at a significantly higher level than did those in the control condition. In fact, they were nearly 6 times more likely than those in the dim red condition to elect such affiliation while awaiting a stressful speech task. No such between-group differences were observed among the subset of participants who, through nonadherence to the study protocol, were previously exposed to morning sunlight. Overall, these findings support the hypothesis that bright light exposure carries the potential to enhance affiliative drive, perhaps via cerebral serotonergic mediation. The results also raise the possibility that this salubrious alteration of social behavior may account for some of the established therapeutic effects of light therapy.

Keywords: light treatment, social behavior, serotonin, social interaction, affiliation motivation, phototherapy

Table of Contents

List of Tables

List of Figures

The Effect of Acute Bright Light Exposure on Social Affiliation

The domains of neurocognitive functioning (e.g., Brown, Tapert, Granholm, & Delis, 2000; Cannon et al., 1994; Lenzenweger, Clarkin, Fertuck, & Kernberg, 2004) and interpersonal social behavior (for review, see Cohen & Wills, 1985) constitute, respectively, two important areas of longstanding interest in the study of mental illness. However, only in recent decades have investigators begun to pursue in earnest an integrated understanding of the complex interrelationships between the brain, social behavior, and mental health. The pursuit is perhaps best illustrated by the emergence of *clinical social neuroscience* (Cacioppo et al., 2007) as an interdisciplinary field focused on illuminating the interplay between neural processes, social behaviors, and mental health.

Notably, social behaviors and their corresponding neurological processes are both of central interest in the quest to clarify – and to more effectively address – the proximate and distal causes of unhealthy lifestyle choices, which are now responsible for most of the top ten causes of mortality and morbidity in the U.S. (United States Department of Health and Human Services, 2010). In fact, lifestyle-based interventions carry considerable promise in the prevention and amelioration not just of physical disease, but also numerous forms of mental illness (for review, see Walsh, 2011).

The cultivation of positive social relationships – a key lifestyle domain – appears to be important to both physical and psychological well-being (for review, see Cohen & Wills, 1985; Dalgard, Bjørk, & Tambs, 1995; House, Landis, & Umberson, 1988; Ozbay et al., 2007). For example, the experience of robust and supportive social connections is associated with increased happiness, quality of life, resilience, and cognitive capacity (Fowler & Christakis, 2008; Jetten, Haslam, Haslam, & Branscombe, 2009). Interventions designed to enhance social support also

appear to protect against the experience of major mood disorders (for review, see Hidaka, 2012; Ilardi, 2009; Weissman & Markowitz, 1998).

Of course, lifestyle-based interventions span myriad domains that extend beyond social behavior – for example, the habits of diet, sleep, physical activity, substance use, and light exposure. One relevant interventional strategy, the use of artificial bright light (or targeted sunlight exposure) to influence circadian rhythms and neural signaling, has come into increasingly widespread use in recent decades (for review, see Terman & Terman, 2005). Accordingly, the current examination seeks to elucidate the interaction between bright light exposure and social affiliation among individuals with a history of clinically relevant seasonal variation in symptoms of depression, prime candidates for light-based intervention (for review, see Terman & Terman, 2005).

Light Therapy

Plants and animals entrain circadian rhythms through *zeitgebers*, the environmental cues that assist in regulation of each organism's biological clock. In animals, circadian rhythms assist in the cyclical regulation of biochemical, physiological, and behavioral processes. Light, the strongest zeitgeber for mammals, is processed through the eyes' retinal ganglion cells that contain specialized photoreceptors, which in turn signal the suprachiasmatic nucleus (SCN) in the brain's anterior hypothalamus (Moore & Eichler, 1972; Stephan & Zucker, 1972) through photopigments such as melanopsin (for a review, see Rollag, Berson, & Provencio, 2003). This pathway, designated the retinohypothalamic tract, wherein the SCN generates circadian rhythms, aids the body in directing the circadian clock and, in turn, assists the body in hormonal release, particularly melatonin regulation (Berson, Dunn, & Takao, 2002; Gooley, Lu, Chou, &

Scammell, 2001; Hannibal, Hindersson, Knudsen, Georg, & Fahrenkrug, 2002; Hattar, Liao, Takao, Berson, & Yau, 2002).

Melatonin, synthesized from tryptophan and secreted by the pineal gland, assists in the transmission of daily and seasonal circadian messages emanating from the SCN, while simultaneously contributing to numerous other physiological processes (for a review, see Goldman, 1999; Reiter, 1993; Simonneaux & Ribelayga, 2003). Highlighting its reciprocal relationship with the SCN, melatonin production surges at night in response to diminished light. Similarly, as the SCN drives arousal and waking with the presence of light, its effects are counteracted by the influence of SCN-based melatonin receptors, which trigger the induction of sleep as light decreases (Challet, 2007). Melatonin production and the retinohypothalamic tract illustrate the brain's sensitivity to light, which derives from a hypothesized evolutionary mechanism designed to anticipate predictable cycling of physiology and behavior in response to environmental changes. Consequently, the chief cues for entrainment of the human circadian system, as a byproduct of evolutionary phylogenetic selection pressures, are sunrise and sunset.

Prescribed to treat a host of conditions, light therapy, or *phototherapy*, consists of exposure to daylight or artificial bright light for a determined period of time at a specific time of day. Application of light therapy has been examined in circadian phase sleep disorders, such as jet lag (Boulos et al., 2002) and shift work problems (Eastman et al., 1995), and disorders of sleeping and waking (Terman et al., 1995). Simultaneously, research on light therapy has yielded particularly encouraging results in the treatment of seasonal affective disorder (for review, see Terman & Terman, 2005), and the intervention appears to be useful in many other mood disorders, including non-seasonal depression (for review, see Prasko, 2008), bipolar disorder (Sit, Wisner, Hanusa, Stull, & Terman, 2007), antepartum and postpartum depression (Oren, Wisner,

& Spinelli, 2002), and premenstrual dysphoric disorder (Krasnik, Montori, Guyatt, Heels-Ansdell, & Busse, 2005). Other promising clinical applications include the treatment of behavioral disturbance and insomnia in dementia (Ancoli-Israel, Martin, Kripke, Marler, & Klauber, 2002), primary and secondary features of Parkinson's disease (Willis & Turner, 2007), attention deficit hyperactivity disorder (Rybak, McNeely, Mackenzie, Jain & Levitan, 2006), seasonal variations in eating disturbances associated with bulimia nervosa (Lam, Goldener, Solyom, & Remick, 1994), and general symptom elevations found in chronic anorectic women (Daansen & Haffmans, 2010).

Although the medical use of sunlight can be traced to antiquity (Kellogg, 1910, 2003; Wehr, & Rosenthal, 1989), it gained popularity in the late 19th century when Dr. J.H. Kellogg promoted light therapy for an array of illnesses, including so-called melancholia (Kellogg, 1910, 2003). Light therapy also garnered a 1903 Nobel Prize for N.R. Finsen for his research on the treatment of lupus vulgaris. Other skin-related problems treated by light therapy include acne vulgaris (Papageorgiou, Katsambas, & Chu, 2000), psoriasis (Walters et al., 1999), and eczema (Polderman, Wintzen, le Cessie, & Pavel, 2005). However, light as a therapeutic modality for treatment of mental illness fell out of favor after the early part of the 20th century, due in part to a paucity of supporting empirical evidence.

However, subsequent research on the relationship between light and melatonin production (Wetteberg, 1978; Lewy, Wehr, Goodwin, Newsome, & Markey, 1980) ignited a resurgence of interest between mental health and light. Early trials targeted treatment of seasonal affective disorder, with the first published study by Rosenthal and colleagues (1984) showing a reduction in depressive symptoms compared to placebo after exposure to bright light. Numerous trials have since refined and extended the aforementioned treatment protocol. Most

such studies (e.g., Avery, Khan, Dager, Cox, & Dunner, 1990; Lewy, Sack, Miller, & Hoban, 1987; Prasko et al., 2002; Sack et al., 1990; Terman et al, 1990) show morning light exposure to be superior to evening light, which reflects the natural diurnal variation in retinal photoreceptor sensitivity (Remé, Wirz-Justice, & Terman, 1991). On the basis of this finding, it has been hypothesized that the therapeutic effect of light arises from its ability to induce a phase-shifting of the brain's circadian clock (Lewy et al., 1987). Specifically, the biological mechanism through which light is hypothesized to treat depressive symptoms is through the suppression of melatonin production in the brain, which may induce a therapeutic alteration of dysregulated circadian rhythms (Lewy et al., 1980).

Following the influential study of Rosenthal and colleagues (1984), the optimal therapeutic dosage and length of light presentation emerged as a topic of intensive investigation. Rosenthal and colleagues used a regimen of 2,500 lux – a unit of illumination equal to a luminous flux of 1 lumen per square meter – presented for 6 hours, 3 hours in the morning and 3 hours in the evening. More recent research has suggested an optimal length and luminance of light exposure as 10,000 lux for a period of only 30 minutes (Terman et al. 1990; Terman, Terman, & Ross, 1998), which has now become the standard treatment dosage. However, lower light intensities can be effective if applied for longer durations (Eastman, Young, Fogg, Liu, & Meaden, 1998; Lewy et al., 1998), as researchers have observed an inverse relationship between length of light presentation and strength of the light when reviewing treatment efficacy. Therefore, as illuminance decreases, length of presentation should increase proportionally in order to maintain a therapeutic effect (Even, Schröder, Friedman, & Rouillon, 2007).

Within five years of Rosenthal and colleagues' (1984) landmark work on treating depressive symptoms with bright light, 25 published studies attested to the potential efficacy of

light therapy for seasonal affective disorder (Terman et al., 1989), and a subsequent meta-analysis assembled by the Committee on Research on Psychiatric Treatments of the American Psychiatric Association (Golden et al., 2005) concluded that light therapy is superior to placebo in reducing symptoms of seasonal affective disorder, with a large effect size of 0.84. Additionally, remission rates were found to be nearly three times higher (Odds Ratio of 2.9) among light therapy patients in comparison with those receiving placebo. Golden and colleagues also found that light therapy was an effective stand-alone treatment for non-seasonal depression, with an effect size of 0.53. They also noted that this observed effect size is similar to that commonly reported in antidepressant medication trials, while individuals treated with light therapy incur lower levels of health care costs compared to pharmacological treatment (Cheung et al., 2012). In summary, there is considerable published evidence that retinal exposure to light of sufficient intensity and duration, at an appropriate time of day, can have marked effects on the affective and physiological symptoms of seasonal-onset depressive illness, with a likely therapeutic benefit for non-seasonal depression as well. However, there is still no consensus on the direct mechanism of action for the therapeutic effect of light therapy, inasmuch as it induces many potential neurotransmitter changes (e.g., Lambert, Reid, Kaye, Jennings, & Esler, 2002) of clinical significance.

Light therapy has likewise proven to be beneficial in the treatment of sleep disorders characterized by a misalignment of sleeping and waking compared to the individual's circadian clock. Selective application of bright light in the morning or in the evening has been effective in instituting normal sleep-wake cycles (for a review, see Gooley, 2008), and appropriately-timed exposure to bright light can shift the sleep-wake cycle to earlier or later times in order to align a disruption between the circadian system and desired sleep-wake schedule. This methodology

has been applied to circadian disorders such as *non-24-hour sleep-wake disorder*, in which the sleep-wake cycle is free-running, as well *shift work sleep disorder*, in which insomnia occurs during the day, and fatigue during nighttime, among individuals who must remain awake at night (for a review, see Gooley, 2008). Similarly, jet lag, a circadian rhythm sleep disorder characterized by insomnia or excessive daytime sleepiness in response to transmeridian jet travel that alters typical rhythm, has been treated successfully with light therapy (Boulos et al., 2002).

Light therapy has also been examined as an adjunctive treatment in numerous other health contexts. For example, women treated for cancer report better quality of life when provided light therapy compared to placebo (Jeste et al., 2013). Light therapy has also been applied to patients with Parkinson's disease, demonstrating a positive effect on sleep, mood, and motor function (for review, see Rutten et al., 2012). Excessive daytime sleepiness is also improved (Videnovic et al., 2014), and such symptom changes can decrease strain on those providing care to demented individuals (Sloane et al., 2014). There is also a potential effect of phototherapy in improving delirium in older hospitalized patients (Chong, Tan, Tay, Wong, & Ancoli-Israel, 2013). The array of such health-related applications highlights the potential significance and utility of light therapy in numerous clinical domains.

Bright Light and Serotonin

Prior to its conversion to melatonin, tryptophan – a key amino acid derived from diet – is converted to serotonin, a chemical neurotransmitter (Fernstrom, 1983; Schaechter & Wurtman, 1990; Wurtman & Anton-Tay, 1969). In humans, serotonergic cells are found throughout the body, but are most concentrated in the intestines and only a small percentage found in the human brain. Almost all forms of life produce serotonin. Its ubiquity, from bacteria to human physiology, indicates an evolutionary change in function from simple intercellular messaging to

complex neuromodulation. In human physiology, serotonin's concentration in the gut makes it a key element in appetite and the emetic process (Berger, Gray, & Roth, 2009). However, the neurotransmitter's smaller concentration in the brain has led to intense debate and interest (for review, see Young, 2007).

The putative role of serotonin in the brain has long interested clinical science (e.g, Young, 2007). The monoamine theory in the 1950s first popularized the belief that neurological abnormalities are related to depressive illness (for review, see Lieberman III, 2003; Nutt, 2008). However, interest in serotonin exploded with subsequent advances in psychotropic medication research. In fact, the development of selective serotonin reuptake inhibitors (SSRIs) represented the first *purposeful* application – as opposed to accidental discovery – of a directed mechanism of action for a psychotropic medication, a process called *rational drug design*. The rationale was to design a new medication that could target a specific neuronal site of serotonin-based action, in this case uptake pumps, while avoiding unwanted collateral effects on receptors or other sites. In other words, the goal was to produce serotonergic agents that were more selective. The marketing of SSRIs began in the 1980's as a treatment for depression (Lieberman, 2003), and SSRI use has now become so popular that the category recently constituted four of the five most commonly prescribed antidepressant medications in the U.S. (Drug Topics Staff, 2010a, 2010b). SSRIs increase the level of serotonin within the synaptic cleft by inhibiting its reuptake into the presynaptic cell, thus increasing the level of serotonin available to be absorbed postsynaptically. This mechanism has been hypothesized to treat depression, although it has also been hotly contested within the scientific community (for review, see Lacasse & Leo, 2005), especially with accumulating evidence that antidepressants are only moderately more effective than placebos in treating major depression (e.g., Kirsch et al., 2008; Kirsch, Moore, Scoboria, & Nicholls, 2002).

The shared antidepressant features of SSRIs and light therapy have led to an examination of potential serotonergic effects of bright light exposure. Such effects have long been inferred from known seasonal and diurnal variations in serotonergic signaling, for example, the finding of lower serotonin concentrations at night versus daytime, and during the winter versus summer months in post mortem brains (Carlsson, Svennerholm, & Winblad, 1980). However, early examination of artificial bright light's effects on serotonin-based central nervous system activity in depressed individuals yielded mixed results (Rao et al., 1992), probably due to the difficulty of accurately assessing serotonin-based activity in real time. Studies with experimental animals, however, have demonstrated an unequivocal relationship between short-term light exposure and enhanced serotonin-based activity in the SCN (Glass, Selim, Srkalovic, & Rea, 1995; Moyer & Kennaway, 2000; Penev, Turek, Wallen, & Zee, 1997).

Considerable evidence suggests that bright light triggers serotonergic activity in the human brain as well. For example, higher cerebral serotonin transporter density, which is associated with lower synaptic serotonin levels, is significantly higher in humans in the fall and winter compared to spring and summer (Praschak-Rieder, Willeit, Wilson, Houle, & Meyer, 2008). Likewise, sunlight directly influences serotonin turnover in the brain, with the lowest rate of turnover in the winter, and more rapid turnover with increased daily luminosity (Lambert et al., 2002). Bright light exposure is also mood-protective against the serotonin decrease triggered by experimental tryptophan depletion (aan het Rot, Benkelfat, Boivin, & Young, 2008). Additionally, as previously reviewed, human circadian rhythms and downstream biological effects are strongly affected by a short duration of bright light exposure (e.g., Lewy et al., 1980; Wetteberg, 1978). Likewise, it is now known that bipolar individuals homozygotic for the long genetic variant of the serotonin transporter-linked polymorphic region (5-HTTLPR) show

longer-lasting mood elevation after a combination of light therapy and sleep deprivation, in comparison with heterozygotes and homozygotes for the short variant (Benedetti et al., 2003). These findings, cumulatively, suggest that the altering of serotonergic circuitry – as opposed to the mere phase-shifting of circadian rhythms – may account for some of the therapeutic effects of bright light exposure.

Serotonin and Social Behavior

The extant research literature on the role of serotonin in social behavior is too extensive for a complete review herein, but several key findings are worthy of note, many of which are drawn from the animal literature. For example, within mere hours of enhanced serotonin exposure, solitary grasshoppers are transformed into gregarious locusts capable of large-scale vegetation destruction (Anstey, Rogers, Swidbert, Burrows, & Simpson, 2009). On the other hand, lobsters injected with serotonin will display an increase in dominant, alpha-like behaviors (Kravitz, 1988). A similar effect is seen with crayfish, wherein serotonin mediates both the flight reaction and social dominance (Yeh, Fricke, & Edwards, 1996). Conversely, many animal species (e.g., nonhuman primates, rodents) exhibit increased aggressive behavior when serotonin levels are *lower* (Higley et al., 1997). Likewise, when placed on a tryptophan-free diet, which leads to reduced serotonergic signaling, some species exhibit greater aggressive tendencies, especially during competitive social interactions like feeding (Chamberlain, Ervin, Pihl, & Young, 1987).

Nonhuman primate research is particularly relevant in underscoring the role of serotonin in social behavior. For example, Rhesus macaques, which are characterized by relaxed dominance hierarchies and high rates of post-conflict conciliation, usually carry only the "long," highly expressed allelic version of the 5-HTTLPR, while macaque species that are more

hierarchical and intolerant tend to be polymorphic, with at least one "short" (less fully expressed) allele (Canli & Lesch, 2007; Thierry, 2000). Similarly, among macaques, 5-HTTLPR short-allele carriers spend less time gazing at faces than at non-face images, and less overall time than long-allele carriers looking in the eye region of faces (Watson, Ghodasra, & Platt, 2009). Particularly interesting is the fact that increased cerebral serotonin-based activity in nonhuman primates generally increases affiliative behaviors (Mehlman et al., 1995; Raleigh, 1987). The effect does not appear to derive merely from a decrease in aggression, but also via an increase in the grooming of other animals (Mehlman et al., 1995), raising the possibility that some serotonergic signaling motivates behavior in a prosocial direction.

In humans, low levels of the serotonin metabolite 5-hydroxyindoleacetic acid (5-HIAA) – indicative of overall low serotonin turnover in the brain – have been found in the cerebrospinal fluid of violent criminals compared to healthy volunteers (Virkkunen & Linnoila, 1996). Similar findings are reproduced with individuals who engaged in particularly violent and lethal suicide attempts (Asberg, Schalling, Traskman-Bendz, & Wagner, 1987; Lidberg, Tuck, Åsberg, Scalia-Tomba, & Bertilsson, 1985). Furthermore, suicide attempters with low 5-HIAA have been found more likely to commit violent acts after childhood exposure to violence, in comparison with suicide attempters with high 5-HIAA (Moberg et al., 2011). Also interesting is the finding that lower 5-HIAA concentration predicts greater impulsivity among violent criminal offenders (Virkkunen & Linnoila, 1996). The potential association between low serotonergic activity and aggressive behavior is also supported by the use of drugs that increase serotonin functioning in treating pathological aggression (e.g., Vartiainen et al., 1995). Finally, SSRI use may increase extraversion in depressed individuals (Tang et al., 2009).

To date, however, only a few studies have examined the effect of directly increasing cerebral serotonin-based activity on aggressive or affiliative behavior in otherwise healthy individuals. Knutson and colleagues (1998) administered paroxetine (an SSRI) to healthy individuals and studied their behavior in a standardized laboratory dyadic puzzle task. The researchers found evidence that SSRI ingestion – and an inferred increase in serotonin-based signaling (Preskorn, Feighner, Stanga, & Ruth, 2004) – restricts antisocial behaviors, both by reducing the experience of negative affect and by increasing social affiliation in cooperative tasks. Cooperative communication and cooperative play may also be enhanced in response to SSRI administration in healthy individuals (Tse & Bond, 2002). Finally, SSRIs, in comparison to placebo, may render people more likely to judge harmful actions in moral judgment dilemmas (e.g. killing an innocent person to save five others) as forbidden, particularly in individuals high in trait empathy (Crockett, Clark, Hauser, & Robbins, 2010).

Manipulating levels of tryptophan, the amino-acid serotonin precursor, has proven to be a similarly fruitful approach to the investigation of serotonergic effects. For example, increasing circulating tryptophan increases self-ratings of agreeableness and decreases the frequency of quarrelsome behaviors (aan het Rot, Moskowitz, Pinard & Young, 2006; Moskowitz, Pinard, Zuroff, Annable, & Young, 2001). Vice versa, tryptophan depletion increases the proclivity to retaliate in the *Ultimatum Game* test, which reflects a willingness to incur personal costs to punish the perceived unfairness of others (Crockett, Clark, Tabibnia, Lieberman, & Robbins, 2008). Cooperative communication and cooperative play are both decreased with acute tryptophan depletion (Wood, Rilling, Sanfey, Bhagwagar, & Rogers, 2006). A recent randomized, double blind study showed that tryptophan depletion attenuated the attractiveness of positive faces in women (Beacher et al., 2011). Tryptophan depleted women also rated the

intimacy and romance of photographed couples lower compared with nondepleted women (Bilderbeck et al., 2011). Such converging lines of evidence suggest that serotonin plays a role in mediating social judgment and decision-making, with increased serotonergic activity generally leading to increased sociality (Blair, 2007)

Bright Light and Social Behavior

The importance of adequate and timely light exposure for healthy biosocial functioning is evident in myriad species. Many rodents, like humans, depend on the light-dark cycle to cue appropriate circadian phases, such as sleeping (Trachsel, Tobler, & Borbély, 1987), eating (Poirel, 1974), and even seeking out mates (Stefanick, 1983). Likewise, disruption of the natural light-dark cycle causes mice to exhibit physiological and behavioral changes indicative of stress (Van der Meer, Van Loo, & Baumans, 2004). In fact, relative sunlight deprivation can induce behavioral indicators of both anxiety and anhedonia in mice (Prendergast & Kay, 2008), and total deprivation of light leads to neuronal damage and the expression of depressive behaviors (Gonzalez & Aston-Jones, 2008). Among female meadow voles, day length variations have been found to affect same-sex social behaviors (Beerya, Loo, & Zucker, 2008). Likewise, the reciprocal interrelationship of social behavior and biological regulation is underscored by the finding that female rats have a reduced ability to maintain light-cued circadian cycles when separated from other rats (Cambras, Castejón, & Díez-Noguera, 2011).

Despite the existence of plausible neurological pathways through which light could influence social behavior, the direct effects of light on social interaction have not been well studied in humans. In fact, I am aware of only three relevant findings in the extant literature. Some preliminary evidence suggests that individuals prefer more personal space when in dim light as opposed to typical room lighting (Adams & Zuckerman, 1991). However, the only

published evidence of the direct effect of bright light on social interaction in humans stems from the work of aan het Rot and colleagues (2008b). They found that individuals with mild symptoms of seasonal depression – indicated by noticeable social, dietary, and mood changes – perceived social interactions as less quarrelsome and more agreeable when they were exposed to higher levels of natural bright light, independent of the season, day, time, or location of the assessment. In conjunction with work showing the ameliorating effect of bright light on mood in tryptophan depletion (aan het Rot et al., 2008a), aan het Rot concluded that bright light modulates the activity of serotonergic pathways that have an effect on both social behaviors and mood. On the other hand, a recently attempted replication of the aan het Rot (2008b) study, utilizing three weeks of artificial bright light exposure, did not find similar effects (Hsu, Moskowitz & Young, 2014). Clearly, further evidence is necessary to firmly establish and explicate the hypothesized connection between light exposure and social behavior – especially affiliative behavior, which has not yet been directly examined in the light therapy literature.

Other Contextual Moderators of Affiliative Drive

In addition to ambient light level, other features of the environment appear capable of moderating affiliative behavior. Notably, exposure to acute stress typically exerts a pronounced effect. In the classic stress-affiliation paradigm (Schachter, 1959), participants are assigned to anticipate a stressful event (originally painful electric shocks) and then asked to choose an affiliate with whom to await the event. Schachter found that participants typically prefer to wait with others who are either experiencing the same situation or a similar perceived emotional state. Building upon the theoretical work of Festinger (1954) regarding social comparison, Schachter proposed an *emotional comparison* theory. It posits an affiliative drive to seek out the company of similar others when faced with a novel, stressful situation, inasmuch as they would

presumably afford the opportunity for the social comparisons needed to inform one's own emotional self-assessment.

Schachter's emotional comparison hypothesis has received at least some empirical support (for review, see Cottrell, Epley, Suls, & Miller, 1977). However, the desire for cognitive clarity has been proposed as an alternative motive underlying the observed preference for similarity among those whose company is sought out when facing acute stressors (Kulik, Mahler, & Moore, 1996). It posits that a stress motivates individuals to seek social interactions with others that are experienced and thus may provide coping strategies for the impending threat. Interestingly, both theories imply that people seek interaction with others to gain insight into their own stressful predicaments. More recent theories have posited alternate views of affiliation and stress. For example, the *tend-and-befriend* theory states that the affiliative drive during stress is an adaptive process, naturally selected over the millennia by virtue of its serving to help protect the individual from potential threats and other stress-related adverse consequences (Taylor et al., 2000). But regardless of the precise motivation that underlies the affiliative drive, an abundance of research now documents the fact that people generally seek the company of others when facing novel stressors. And the affiliation-under-stress paradigm provides a useful experimental methodology that lends itself well to testing the potential serotonergic effects of bright light.

Study Rationale

Bright light exposure appears to enhance cerebral serotonin-based signaling (e.g., Lambert et al., 2002), and this process may in turn mediate an increase in prosocial and affiliative behavior (Crockett et al., 2010; Knutson et al., 1998; Tse & Bond, 2002). However,

the direct effects of bright light exposure on affiliative behavior have not yet been examined in humans. Such an examination constitutes the primary aim of the present study.

Epidemiological studies (Grimaldi et al., 2009; Kasper et al., 1989) have found that 85-90% of people experience measurable changes in mood and behavior during months of reduced daylight. One-third of such individuals also report at least mild dysfunction and vegetative symptoms similar to – though less severe than – those observed among individuals with seasonal onset depression. Consequentially, *seasonality* has been posited as a salient continuum of responses to cyclic variations in ambient light exposure, with clinical diagnoses at one end and no seasonal variations at the other (e.g., aan het Rot et al., 2008b; Hsu et al., 2014). In brief: individuals with clinically relevant seasonal fluctuations are hypothesized to be particularly sensitive to the effects of variation in light exposure.

Light therapy effects two facets of social cognition – specifically, the perception of others' quarrelsomeness and agreeableness during a brief interaction – have recently been demonstrated (aan het Rot et al., 2008b) among participants with seasonal variation in depressive symptoms. Accordingly, the current investigation examines the role of bright light on the desire to affiliate, along with actual affiliative behavior, among individuals who endorse at least mild seasonal variation in mood, appetite, energy, sleep, and related phenomena. Further, because whole brain serotonin turnover is positively associated with morning sunlight exposure (Lambert et al., 2002), the present study incorporates the use of light blocking lenses to minimize the potential confounding effect of participant sunlight exposure on the morning of the experimental procedure.

Additionally, as previously reviewed, the affiliation-under-stress paradigm (Schachter, 1959) is an established and reliable method of measuring affiliative behavior – the desire to

connect in a positive, affective manner with another person. It provides a quantifiable and controlled measure of affiliative drive, and thereby serves as a particularly useful tool for examining the potential effects of bright light exposure on social affiliation in the present study.

The principal study hypothesis is that acute bright light exposure should increase participants' expressed preference to affiliate in response to stress. Specifically, I hypothesized that participants exposed to bright light would – when waiting to undergo a stressful experimental task – express a greater preference to be with others, as opposed to waiting alone, than would those in a dim light comparison group. Following Schachter (1959), I also expected participants to report a stronger preference to be with others who are waiting to undergo the *same* stressful situation, as opposed to those simply waiting for an unrelated experiment. I also expected such effects to be moderated by any prior exposure to high level, blue-wavelength sunlight on the day of the experiment (i.e., by participant adherence to wearing the assigned light blocking lenses prior to undergoing the study procedure).

In addition to participant self-report of affiliative preferences, the present study employs several objective measures of affiliative behavior via the coding of participant interactions with a study confederate, who was alleged to be another study participant about to undergo a similar stressful experiment. I hypothesized that participants would more frequently smile at and gaze toward the confederate following bright light, as opposed to dim light, exposure. Likewise, I expected the bright light-exposed participants to sit in closer proximity to the confederate, and to exhibit a greater frequency of conversational engagement.

Method

Participants

All study participants were undergraduate students recruited from an introductory psychology course at a large Midwestern university; they were required to serve in a research participant pool as a course requirement. Individuals in the participant pool who completed a voluntary online preliminary screening and satisfied the study inclusion/exclusion criteria were eligible to participate in the current study. To meet inclusion criteria, individuals were required to endorse a score of six or greater, indicating at least a mild level of severity, on a measure of seasonality. Exclusion criteria included: (a) a self-reported history of bipolar disorder; or (b) retinal light sensitivity. All participants provided written consent, and the study was approved by the university's Institutional Review Board.

Materials

Sunlight Jr. light boxes (The Sunbox Company, Gaithersburg, MD) provided artificial bright light in the experimental procedure. The Sunlight Jr. is a triangular box (14.5" Tall x 7" Wide (Face) x 6″ Sides) that emits a full spectrum of light, employing a spectrally transparent prismatic diffuser to block ultraviolet rays. The box is designed to emit light at an illuminance of 10,000 lux at a distance of 14 inches. For the control (dim light) condition, a red filter was positioned over the prismatic diffuser to filter all but red light, thereby reducing the illuminance to approximately 200 lux at a distance of 14 inches. The aforementioned artificial light apparatus – including the dim light control – has been used in previous examinations of bright light (Botanov & Ilardi, 2013).

Participants were provided with amber tinted glasses (Yiding Company, China) designed to block all visible light at wavelengths below 550 nm (blue-green and lower frequencies). Light

at such blue-green frequencies is believed to mediate the primary neurological effects of retinal light exposure (Wright, Lack, & Kennaway, 2004), and is thus particularly important to control in the context of the present investigation. The glasses are designed with side shields/protection to provide all-around light absorption. The temple length is adjustable (9 - 11.4 cm), and each lens is approximately 15 cm x 5.5 cm x 5.5 cm in size. The glasses are designed to be worn over corrective lenses, if necessary. Similar lenses have been established as the *de facto* method of preventing retinal blue light exposure in the extant literature (e.g., Burkhart & Phelps, 2009; Fargason, Preston, Hammond, May, & Gamble, 2013).

Measures

The Seasonal Pattern Assessment Questionnaire (SPAQ) is a self-report measure assessing symptoms of seasonal onset depression (Rosenthal et al., 1984). The SPAQ includes a Global Seasonality Scale (GSS), which assesses the extent of seasonal change via the following six areas; sleep, mood, social activity, energy, weight and appetite. Each item is scaled 0-4, indicating the level of seasonal change, with 0 indicating *no change* and 4 indicating *extremely marked change* (see Appendix A). Studies examining the psychometric properties of the SPAQ have demonstrated strong specificity, but findings on sensitivity have been mixed (Magnusson, 1996; Mersch et al, 2004). The scale has been shown to have good test-retest reliability (Christensen, Larsen, & Gjerris, 2003). Due to mixed findings concerning sensitivity and poor positive predictive value (Magnusson, 1996), the SPAQ is intended principally for use as a screening instrument (as in the present study), and not as a diagnostic measure. As previously stated, the current study adopted a score of 6 to indicate at least a mild level of seasonality. This cutoff score is based on previous examination of the effect of light on social interactions (e.g., aan het Rot et al., 2008b; Hsu et al., 2014).

The Beck Depression Inventory – Second Edition (BDI-II [Beck, Steer, & Brown, 1996]) is one of the most widely used self-report instruments for measuring the severity of depressive symptoms. The BDI-II is a 21-item questionnaire designed to measure the presence and severity of depressive symptoms over the past two weeks. Each item is scored on a scale value of 0 to 3, with 3 being the most severe. The BDI-II has a high internal consistency with a reported alpha of 0.91 (Beck, Steer, Ball, & Ranieri, 1996), a high test-retest reliability, $r = 0.93$ (Beck et al., 1996) and construct validity (Beck et al., 1996; Beck, Steer, & Garbin, 1988; Whisman, Perez, & Ramel, 2000).

The desire for affiliation or isolation was assessed via four items. A forced-choice item assessed whether participants desired to wait for 10 minutes, while experimenters prepared the speech task, either: (a) "alone"; (b) with "a student participating in another study"; or (c) "with a student participating the same study." Similar categorical measures of affiliation have been used in prior research (e.g., Leroy, Christophe, Delelis, Corbeil, & Nandrino, 2010). Using a Visual Analog Scale (for review, see Wewers & Lowe, 1990) ranging from 0 (*not at all*) to 100 (*completely*) with the midpoint (50) as neutral, the other three items assessed preference to be: (a) alone; (b) with an individual undergoing a different study; or (c) with an individual undergoing the same stressful task. Similar assessments of affiliation preference have been commonly collected via Likert scales (e.g., Rofé, Y. 2006).

Procedure

Participants completed the consent process and demographic questionnaires on the day prior to the experimental session. On the same day, they were provided blue light blocking lenses and instructed to wear the glasses while outdoors as they traveled to the experimental session the following morning. Participants were informed that the glasses should only be

removed for driving or other similar safety precautions. The stated goal of the study was to examine the role of different colored light on stress during a speech task. Participants were randomly assigned, via a computer generated random ordered list, either to the bright white light condition (15,000 lux) or the low-level red light condition (200 lux).

For the bright light condition, individuals were seated alone at a table in a room with two light boxes. The primary box was positioned 14 inches from the eyes, above the head, and facing the participant at a 45-degree angle. To increase illuminance to 15,000 lux, a secondary light box was positioned on the table, 12 inches from the eyes, below the head at a 30-degree angle. For the control condition, a singular dim red light box was positioned precisely as the primary bright light box. To maintain a naturalistic balance between the experimental light sources and the ambient room light, the experiment room's fluorescent overhead lighting was dimmed to 50 lux.

Prior to light exposure, participants completed a brief assessment battery (Appendix B). During the 45-minute light exposure participants faced forward (in the direction of the light source) and were instructed to watch a nature video on a computer screen. An experimenter unobtrusively monitored adherence to the procedural instructions throughout the session, but did not interact with the participants in any other capacity. After the 45-minute exposure, participants were again informed about the upcoming speech task and completed a final assessment battery (Appendix B). To help mask the true study hypotheses, the majority of assessment items assessed potential side effects (modified version of the Toronto Side Effect Scale [see Appendix C, Botanov & Ilardi, 2013]) and mood (Positive and Negative Affect Schedule - Expanded Form [Watson & Clark, 1994] and a 5-point Visual Analog Scale of mood

[see Appendix B]). The four items assessing desire for affiliation were embedded within the final assessment battery.

After the assessment battery, participants were brought into a separate room and informed that they were to wait with an individual participating in the same experiment (in reality a confederate). The chair they were instructed to sit in was placed in a pre-marked position, at a fixed distance from the confederate. However, participants were free to move their chair as close to or far away from the confederates as they desired. Confederates were seated at a 90-degree angle, at a table, beside the participant.

The participants were informed that the camera was already recording in preparation for the upcoming speech task. Based on the research design of Gump & Kulik (1997), the participant-confederate dyadic interaction lasted two minutes, and was videotaped. After the dyadic interaction period, a researcher entered the room and escorted the confederate out under the guise that they were being taken to a different room to complete their speech portion of the experiment. Afterward, the experimenter entered the room and informed the participant that a measure of the chair's distance from the table must be taken in order to appropriately record the speech task. In reality, the experimenter measured the distance of the closest chair leg to the confederate's pre-marked position using a measuring tape (centimeters).

All confederates were female, and trained to interact with participants in a calm and neutral manner. Confederates were trained to wait for the participant to initiate conversation, to reply and make eye contact appropriately, but not to continue the conversation past an appropriate response. Appropriate responses were defined as answering or responding to the participant and verbally reflecting a similar statement or question. Precautions were taken to

ensure that each participant had no previous acquaintance with the confederate. Confederates were blinded to participant's light condition.

Based on the design of Gump & Kulik (1997, variables of interest include the frequency of smiling and gazing toward the confederate, the distance participants sat from confederates, and whether participants reengaged the confederate in conversation after the initial introduction. A smile was defined as "eyes open and the corners of the mouth turned up." Gazes were defined as eye movement in the direction of the confederate. Any verbal interaction from the participant was considered a form of conversation. Coders of dyadic interactions were blind to each participant's assigned study condition.

Following the videotaped interaction, a modified Trier Social Stress Test (TSST) was introduced. The TSST is a standardized protocol for inducing moderate psychosocial stress in a controlled laboratory setting. It is a speech performance task consisting of a brief preparation period followed by a test period in which the subject has to deliver a speech in front of an audience (Kirschbaum, Pirke, & Hellhammer, 1993). The TSST is often modified to suit study goals (e.g., Ruiz et al., 2010; Weimers, Schoofs, & Wolf, 2013). Since the current investigation is primarily interested in inducing stress concerning the speech task and not the consequences of the actual task, participants were exposed to shorter periods of stress; two minutes of preparation and three minutes of speech. All sessions occurred between 8:00 a.m. and 11:00 a.m. in rooms with no natural light sources. Data collection began in September 2013 and ended in May 2014.

Data Analysis Plan

Unless otherwise noted, all data analyses were conducted using PASW Statistics 18, Release Version 18.0.0 (SPSS, Inc., 2009, Chicago, IL, www.spss.com). Before testing the primary study hypotheses, analyses examined potentially confounding baseline characteristics.

Chi-square goodness-of-fit analyses were used to examine potentially unequal proportions of gender and group size. Potentially confounding effects of age, depressive symptomatology, length of time spent outdoors on the day of the study, and hours of sleep prior to the experimental session were each evaluated by means of one-way analysis of variance (ANOVA).

A logistic regression model, or the *logit* model, as it is often referred to, is a special case of a generalized linear model and analyzes models where the outcome is a nominal variable. Logistic regression is a nonparametric test used to analyze the relationship between a categorical dependent variable and a set of independent variables. Due to small cell sizes, participants endorsing a preference to be with another person, either someone enrolled in the same study or a different study, were combined into one group. Thus, a binary affiliative outcome variable (alone vs. others) was created. A binary logistic regression analysis was conducted in order to test the primary nonparametric study hypotheses of the dichotomous outcome variable. The complete model contained the predictor variables of condition (bright vs. dim light), retinal sunlight exposure (adherence[1] to wearing amber colored lenses or not), and the interaction term condition-by-sunlight exposure. The complete model was compared to a constant only model that contained no predictor variables. An alpha level of .05 was utilized for the primary nonparametric analyses.

In order to test the primary parametric study hypotheses, a between-subjects, 2 (bright vs. dim light) x 2 (glasses-adherent vs. not) factorial design was utilized. The continuous measures of desire for isolation and affiliation to individuals undergoing the same task were designated as

[1] The term adherence is being used to describe the study instruction for participants to wear blue-wavelength light blocking lenses for any time spent outdoors on the morning prior to the experimental procedure. Some participants failed to follow this guideline while driving, which was not technically a protocol violation, inasmuch as they were permitted to remove the glasses in situations where failure to do so might compromise their safety. However, direct sunlight exposure while driving is still regarded as a form of nonadherence to the protocol's ideal.

dependent variables and each analyzed via two-way ANOVA. To limit the potential inflation of experimentwise Type I error due to multiple significance tests, a Bonferroni adjusted alpha levels of .025 per test (.05/2) was utilized for the primary parametric analyses.

For significant omnibus logistic regression and ANOVA tests, post hoc comparisons were calculated to identify where significant differences actually lie. For logistic regression, separate chi-square goodness-of-fit tests were utilized for each light condition using the procedure developed by Goodman (1963). For significant ANOVA results, post hoc testing examined simple main effects within the sunlight-exposed and non-exposed groups and each light condition.

In order to test the behavioral study hypotheses, a between-subjects, 2 (bright vs. dim light) x 2 (glasses-adherent vs. not) factorial design was utilized. Two-way ANOVA was used to examine the distance that participant sat from confederate, quantity of smiles, and frequency of glances toward the confederate. A binary logistic regression analysis was conducted in order to test the behavioral nonparametric study hypothesis of the dichotomous outcome variable (isolation vs. affiliation). The complete model contained the predictor variables of condition (bright vs. dim light), retinal sunlight exposure (adherence to wearing amber colored lenses or not), and the interaction term condition-by-sunlight exposure. The complete model was compared to a constant only model that contained with no predictor variables. To limit the potential inflation of experimentwise Type I error due to multiple significance tests, an alpha level of .01 was utilized in all behavioral hypotheses analyses.

Cohen's d (*d*) is calculated as the standardized difference between two means and was utilized as the effect size for simple main effects. All standard mean differences were analyzed via an online calculator (Soper, 2014). Eta-square is a measure of effect size and measures the

strength of interaction effects on a continuous variable. Eta-square can be interpreted as the proportion of variance within the dependent variable explained by one independent variable while controlling for another independent variable. Eta-squared was calculated using the following formula:

$$\eta^2 = \frac{SS_{Between}}{SS_{Total}}$$

Cramér's V (Cramér, 1999) ranges from 0 (indicating no association between the variables) to 1 (perfect association) and was calculated as the effect sizes of the categorical dependent variables using the following formula:

$$V = \sqrt{\frac{\chi^2}{N(k-1)}}$$

The final stage of analysis was an exploratory examination between continuous measures of affiliation/isolation within each group for sunlight-non-exposed participants. A set of Pearson correlation coefficients was computed to assess the association between participant's preferences to be alone, with others undergoing a different study, and others undergoing the same study. To limit the potential inflation of experimentwise Type I error due to multiple significance tests, an alpha level of .01 was utilized in all exploratory analyses. A within-subjects, repeated measures, 2x2 factorial design using time (pre, post) by condition (bright light, dim light) was used to analyze potential mood effects in the same subset. Specifically, main effects of time (pre, post) and light condition (bright white, dim red), as well as a time-by-condition interaction effect, were analyzed using a repeated measures ANOVA for mood ratings via the Visual Analog Scale.

Post hoc testing examined potential effects of gender on the study results. Logistic regression was used to examine the association between the continuous study variables and

gender. A series of chi-square goodness-of-fit tests were utilized to examine the association between gender and the categorical study variables. Similar analyses were conducted for BDI-II scores and seasonality scores as measured by the GSS on the SPAQ.

Power Analysis

I am unaware of any published studies that have examined the effect of bright light on affiliative behavior during stress. Accordingly, it is challenging to arrive at a robust estimate of the anticipated effect size of the study's experimental manipulation. Perhaps the most relevant work to date is that of aan het Rot and colleagues (2008a), who examined the effect of bright light on others' perceived agreeableness. They observed a large effect, with Cohen's *d* equal to approximately 1.9. If one were to conservatively assume that bright light exposure can produce an effect on affiliative behavior during stress even one-fifth as large as that observed by aan het Rot, it would imply an effect size of approximately $d = .38$. The planned use of 60 study participants would yield sufficient statistical power to detect such an effect at a likelihood of over .80 when employing the traditional statistical significance of alpha = .05 (Faul, Erdfelder, Buchner, & Lang, 2009).

Results

Sixty-six undergraduate students (56% female), with an age range of 18 to 32 (M = 19.5, SD = 2.0), met prescreen criteria and were consented to participate in the present investigation. The sample included individuals identifying as White (59%), African American (4%), Asian (4%), Hispanic (9%), and mixed or other race/ethnicity (5%). Ten participants (15%) did not endorse any race/ethnicity, and one participant did not complete the demographic portion of the study.

Thirty-five of the 66 participants (53%) were randomly assigned to the bright light condition and 31 to the dim red light condition. One participant was excluded from the study prior to light exposure due to retinal safety concerns (despite their having satisfied prescreen criteria regarding light sensitivity). Ten participants (evenly divided between the two conditions) did not return after the first portion of the study, and thus failed to complete the light exposure portion of the protocol. Finally, due to experimenter (research assistant) error, two participants did not complete the final assessment battery immediately following their light exposure.

The proportion of participants in the sample did not differ significantly by gender ($\chi 2$ [1, N = 65] = 1.74, p = .19) or light condition ($\chi 2$ [1, N = 66] = .24, p = .62). Likewise, a univariate ANOVA revealed no significant preexisting differences between participants in the two experimental conditions with respect to their baseline characteristics (Table 1): age (t[63] = .63, p = .53), depressive symptomatology (t[63] = -.91, p = .37), hours of sleep prior to testing (t[54] = .48, p = .63), or duration spent outdoors prior to the experiment (t[54] = 1.05, p = .30). Figure 1 presents the frequency distribution of the BDI-II data. Table 2 presents the continuous outcome variables while the sunlight-non-exposed subset is presented in Table 3 and Table 4 presents data for the sunlight-exposed subset. Table 5 presents the categorical affiliative endorsements between conditions. Due to small sample sizes, the three discrete affiliative choices were converted to a binary choice (alone vs others). Table 6 presents the new binary outcome variable and the dichotomous variable for conversation reengagement for each condition.

A logistic regression analysis was conducted to predict the binary affiliative choice (“alone” or “others”) using the predictors of condition (bright white or dim red), retinal sunlight exposure (full adherence to wearing blue light blocking lenses or not), and the interaction term

for condition-by-retinal sunlight exposure. A test of the full model against a constant only model was statistically significant, indicating that the predictors, as a set, reliably distinguished between the binary affiliative decisions, $\chi 2$ (3, N = 53) = 8.77, p = .03.

The Nagelkerke's R^2 value of .211 suggests that about 21% of the variance in binary affiliative choice was accounted for by the predictor variables. Predictive accuracy overall was 72% (74% for alone and 67% for others). The Wald criterion demonstrated that only *light condition* made a significant contribution to prediction (p = .02). Participants were almost 6 times more likely to choose "others" in the bright light condition compared to dim light in a binary affiliative decision (Exp(B) = 5.78). Table 7 presents the logistic regression results. Chi-square goodness-of-fit analysis for the subset of participants not exposed to high levels of retinal sunlight indicated that the proportion of participants endorsing affiliation was significantly higher in the bright light group than those in the dim red group, $\chi 2$ (1, N = 15) = 5.40, p = .02, V = .60 (Figure 2).

A two-way ANOVA revealed no main effect of light condition, F(1, 52) = .14, p = .71, or retinal sunlight exposure, F(1, 52) = .98, p = .33, on participants' actual level of preference to affiliate with others undergoing the same experiment. However, the light condition-by-sunlight exposure interaction effect was significant, F(1, 52) = 6.28, p < .02, η^2 = .03. A follow-up analysis of simple main effects revealed that the sunlight-non-exposed subset in the bright light condition (M = 58.95, SD = 31.80) endorsed a significantly higher (F[1, 52] = 6.37, p = .015, d = .96) level of preference to affiliate with others undergoing the same experiment compared to sunlight-exposed participants (M = 30.13, SD = 28.31). No such effect was indicated in the red light group, F(1, 52) = 1.10, p = .30. Participants in the sunlight-non-exposed subset in the bright light condition also endorsed a significantly higher (F[1, 52] = 6.75, p = .01, d = .86) level

of preference to affiliate with others undergoing the same experiment compared to those in the dim light condition (M = 35.25, SD = 22.41). No such effect was indicated in the sunlight-exposed subset, $F(1, 52) = 1.64$, $p = .21$. These effects are presented in Figure 3.

A two-way ANOVA revealed no significant main or interaction effects between light condition and retinal sunlight exposure with respect to the level of preference for isolation or for affiliation with others undergoing a different experiment. Similarly, two-way ANOVA revealed no significant main or interaction effects between light condition and retinal sunlight exposure on the behavioral measures (distance participant sat from confederate, quantity of smiles, and number of glances toward the confederate). Table 8 presents the aforementioned ANOVA results.

A logistic regression analysis was conducted to predict whether participants reengage in conversation with a confederate (yes or no) using the predictors of condition (bright white or dim red), retinal sunlight exposure (full adherence to wearing blue light blocking lenses or not), and the interaction term for condition-by-retinal sunlight exposure. A test of the full model against a constant only model was statistically significant, indicating that the predictors, as a set, reliably distinguished between the binary affiliative decisions, $\chi 2$ (3, N = 53) = 8.69, $p = .03$.

Nagelkerke's R^2 of .403 demonstrates that about 40% of the variance is accounted for by the predictor variables on conversation reengagement. Prediction success overall was 76% (94% for no and 44% for yes). The Wald criterion demonstrated that only retinal sunlight exposure made a significant contribution to prediction ($p < .02$) while controlling for the other variables. Participants were 40 (Exp(B) = 40.00) times more likely to not reengage in conversation if they were sunlight-exposed (i.e., did not adhere to wearing blue light blocking lenses).

Exploratory analyses examined the associations between preference levels of the three continuous measures of affiliation/isolation in the retinal sunlight-non-exposed (adherent), and exposed (non-adherent) subsets, respectively. Pearson correlations between participant's levels of preference to be alone, with others undergoing the same experiment, and others undergoing a different experiment are provided in Table 9. As shown, among adherent participants, there was no significant association between either affiliative preference and the preference to be alone in the bright light group.

Finally, an exploratory, within-subjects, repeated measures ANOVA was used to examine potential mood effects of the experimental manipulation among adherent participants – with time (pre, post) and condition (bright light, dim light) as the independent variables. It revealed no significant main effect for time, $F(1, 26) = .40$, $p = .53$, light condition, $F(1, 26) = 2.03$, $p = .17$, or the interaction effect, $F(1, 26) = 1.10$, $p = .30$, on mood.

Post hoc analyses revealed that the proportion of females in the bright light group was significantly greater than males ($\chi 2$ [1, N = 29] = 5.83, $p < .02$). No such difference was found in the dim red group ($\chi 2$ [1, N = 26] = .62, $p = .43$). However, post hoc testing revealed no significant associations between gender and the categorical variables of binary affiliative choice ($\chi 2$ [1, N = 52] = .12, $p = .73$), reengagement in conversation ($\chi 2$ [1, N = 25] = 1.42, $p = .23$), and adherence to wearing amber tinted glasses ($\chi 2$ [1, N = 55] = .02, $p = .86$). Similarly, logistic regressions revealed no significant associations between gender and the continuous dependent variables of preference to be alone ($\beta = .03$, $p = .53$), preference to affiliate with someone participating in the same study ($\beta = -.14$, $p = .87$), distance participant sat from confederate ($\beta = .71$, $p = .20$), quantity of smiles ($\beta = .67$, $p = .57$), and number of glances toward the confederate ($\beta = .18$, $p = .71$).

Similarly, post hoc analyses revealed no significant associations between BDI-II scores and the binary affiliative choice (β = -.06, p = .26), reengagement in conversation (β = -.15, p = .19), adherence to wearing amber tinted glasses (β = - .01, p = .88), preference to be alone (r = .17, p = .23), preference to affiliate with someone participating in the same study (r = -.15, p = .30), distance participant sat from confederate (r = .24, p = .22), quantity of smiles (r = .10, p = .64), or number of glances toward the confederate (r = -.15, p = .50). Post hoc analyses revealed a significant association between seasonality and number of glances toward the confederate (r = -.48, p < .02) and reengagement in conversation (β = -.22, p < .05). However, no significant association was revealed between seasonality and the binary affiliative choice (β = -.11, p = .14), adherence to wearing amber tinted glasses (β = .03, p = .58), preference to be alone (r = .19, p = .21), preference to affiliate with someone participating in the same study (r = -.11, p = .46), distance participant sat from confederate (r = .02, p = .90), or quantity of smiles (r = -.33, p = .11).

Discussion

The present investigation represents the first reported examination of the effects of bright light exposure on human affiliative social behavior in a controlled experiment. To increase the likelihood of detecting bright light effects, the study recruited only participants with likely increased neurological sensitivity, as indicated by seasonal variation in the experience of sub-syndromal depressive symptomatology (Grimaldi et al., 2009; Kasper et al., 1989). Likewise, the experimental light exposure occurred in the morning, when photosensitivity is typically at its peak (Remé et al., 1991). Participants were also asked to wear, during the daylight hours immediately prior to the experiment, sunglasses fitted with specialized lenses to block the blue-green spectrum of sunlight that strongly stimulates retinal photoreceptors (Wright et al., 2004),

thereby attenuating the potentially confounding influence of natural light exposure on the day of the experiment.

Consistent with *a priori* study hypotheses, sunlight-non-exposed study participants who received a single 45-minute session of bright (15,000 lux) white light were significantly more likely than those in the control (200 lux) condition to prefer the company of a stranger (another study participant) while they were awaiting a stressful speech task. When faced with a simple categorical choice, those in the bright light condition were nearly 6 times more likely than those in the control (dim red light) condition to elect the company of another person.

Such a result is broadly congruent with the two other published investigations of bright light exposure effects on human social behavior (aan het Rot et al., 2008b; Hsu et al., 2014), inasmuch as both reports also observed significant social effects. It is also consistent with the earlier finding of a stronger preference for "personal space" among those with prolonged dim light, as opposed to brighter light, exposure (Adams & Zuckerman, 1991).

How might such social effects of light exposure be mediated? Perhaps the most parsimonious candidate mechanism is the well-documented enhancement of cerebral serotonin-based signaling in response to acute retinal light stimulation (Lambert et al., 2002). Similar alterations in serotonergic signaling – e.g., via pharmaceutical agents (Preskorn et al., 2004) – can influence an array of social behaviors, including cooperation (Knutson et al., 1998; Tse & Bond, 2002), the disapproval of actions that harm others (Crockett et al., 2010), and the inhibition of violence/aggression (Higley et al., 1996; Virkkunen & Linnoila, 1996). Exposure to bright light may thus enhance affiliative drive via its own acute serotonergic effects.

On the other hand, while the current study and that of aan het Rot and colleagues (2008b) both observed an immediate prosocial effect of bright light exposure, such results appear to run

somewhat counter to those of Hsu and colleagues (2014), who found that bright light exposure actually increased quarrelsome behavior (and also decreased submissiveness). The apparent inconsistency can perhaps be explained, however, by between-study differences in the length of light exposure, inasmuch as the latter study incorporated three weeks of daily exposure, while the former observed the effects of acute exposure. Further, in the current investigation affiliative behaviors were examined in response to stress, whereas Hsu et al. examined typical daily interactions – a key methodological difference that could also plausibly account for the discrepant findings. Another obvious consideration derives from the possibility that affiliative desire (preference for the company of another) and quarrelsome behavior are not always antithetical. It is conceivable that someone could both want to affiliate with others and yet still be inclined to engage in quarrelsome behavior, and it is not inconceivable that light exposure could increase the likelihood of both social outcomes.

Notably, Hsu and colleagues (2014) attributed their contrary finding to a potential light-induced increase in irritability and agitation, possibly stemming from light box side effects (although the side effects of light box use may also be overstated in the literature [Botanov & Ilardi, 2013]). A related possibility lies in the fact that repeated bright light exposure may enhance some forms of cerebral dopamine-based signaling (e.g., Cawley et al., 2013), which carries the potential to induce agitation. Certainly, the aforementioned contrasting findings suggest the possibility that bright light effects on social behavior – and perhaps on various cerebral neurotransmitter systems – may vary as a function of the number of exposures (and total exposure duration). It is, at the very least, a possibility worthy of further examination.

It is also important to note that the present study's attempt to block inadvertent morning sunlight exposure - via amber tinted, blue wavelength-light blocking lenses – proved to be an

important methodological feature, inasmuch as I observed a significant interaction between experimental condition (bright light versus dim red) and morning sunlight exposure in the prediction of participants' social affiliative preferences. Specifically, *a greater desire to affiliate was only observed among the bright-light-exposed participants who actually avoided morning sunlight exposure* through the use of their assigned glasses.

Similar measures to control for (or even simply to measure) such inadvertent sunlight exposure have only been adopted by a handful of other labs to date, primarily those examining the interplay between light exposure and sleep (Burkhart & Phelps, 2009; Fargason et al., 2013; Sasseville, Benhaberou-Brun, Fontaine, Charon, & Hebert, 2009). The great majority of published light exposure studies, however, have not taken such steps. Such a methodological limitation could potentially help explain the rather mixed reported effects of bright light exposure among otherwise healthy individuals, with some studies showing a mood benefit (Avery et al., 2001; Kasper et al., 1989; Partonen & Lönnqvist, 2000) and others showing none (Bauer, Kurtz, Rubin, & Marcus, 1994; Genhart, Kelly, Coursey, Datiles, & Rosenthal, 1993; Rosenthal Rotter, Jacobsen, & Skwerer, 1987). Such a methodological caveat might also help account for the apparent difference in findings between the present study and that of Hsu et al. (2014), who observed a light-associated increase in quarrelsome (as opposed to affiliative) behavior, but did not control for the potential confounding effects of sunlight exposure.

Although the observed affiliative social effect of bright light exposure in the present study may be serotonergically mediated, other interpretive possibilities exist, as well. For example, light therapy has well-established salubrious mood effects (for review, see Terman & Terman, 2005), and positive mood changes may plausibly underlie a greater desire to affiliate. On the other hand, previous research in our lab (Botanov, 2011; Botanov, Pressman, & Ilardi, nd)

utilizing a highly similar single-session light exposure protocol, found no significant mood changes among relatively healthy, young samples. And, in fact, mood data on the present study participants, collected for a related investigation, revealed no significant effects of light exposure on mood.

An alternative hypothesis is that enhanced cerebral dopamine-based activity may play a prominent meditational role, since several lines of evidence support the potential of light exposure to trigger dopaminergic effects. For example, Parkinsonian patients treated with light therapy have been found to require less dopamine replacement therapy (Willis & Turner, 2007), while bright light appears to be protective against reductions in mood and agreeableness among women undergoing acute dopamine depletion (Cawley et al., 2013). Thus, it remains possible that light-induced effects on other neurological networks, particular dopamine, are responsible for the present study results regarding social affiliative drive.

Interestingly, on the study's *dimensional* ratings of *affiliative* preference, a large, statistically significant between-group difference was only observed regarding desire for the company of a potential companion enrolled in the *same* study. There was also a smaller, moderate-sized between-group effect observed regarding the desired companionship of someone enrolled in a completely different study, but it was not statistically significant – perhaps owing to the relatively total small sample size of non-sunlight-exposed study participants (n = 37), and the correspondingly low statistical power afforded to detect between-group effects. Alternatively, Schachter's (1959) social comparison theory would seem to predict that stressed individuals should preferentially seek affiliation with others experiencing *similar* stress – i.e., those enrolled in the same study (as opposed to an unrelated study) – in accordance with the present findings.

Of course, social comparison theory is not without its critics (e.g., Rofe, 1984). Rofe's competing *utility theory* has, in fact, has demonstrated an ability to account for some of the conflicting results from studies that examining affiliation across different stressful situations (e.g., Kulik & Mahler, 1987; Kulik, Mahler, & Earnest, 1994; Rofe´ & Lewin, 1986, 1988; Rofe´, Lewin, & Hoffman, 1987). Within Rofe's framework – which suggests, in effect, that people tend to affiliate whenever they perceive the benefits outweigh the costs – myriad decision-making elements beyond mere social comparison can influence affiliative desire. For example, participants in the present study could have anticipated social awkwardness in having to wait in the company of a stranger who was not participating in the same speech task, thereby reducing their affiliative drive in that context.

Notably, no significant effects of bright light exposure were observed on any of the study's behavioral measures of affiliation – smiling or glancing at the confederate, engaging the confederate in conversation, or sheer physical proximity. While there are numerous potential reasons for such a non-finding, low statistical power is perhaps the most obvious. Accurate behavioral data were obtained for only about one-half of the study sample. Some of the data were lost due to experimenter error (e.g., video recorder not turned on, video recorder pointed in the wrong direction, confederate failing to attend experimental session). However, some participants also broke study protocol by using their personal phones during the waiting period (thus potentially contaminating their behavioral ratings). Because the waiting period was purposely disguised to appear as a brief time completely unrelated to the experiment, it was difficult to prevent such participant contra-protocol cellphone use without hinting at the true nature of the study.

It is also quite possible that no significant between-group differences on study behavioral measures would have been observed even if the investigation had been adequately powered. It may be, for example, that bright light is quite capable of inducing the observed changes in self-reported *perceptions* of social affiliative preference, but that such cognitive changes fail to influence any actual affiliative *behavior*. This possibility is supported, in fact, by the low observed correlations between participants' reported affiliation preferences and their observed affiliative behavior, at least as indicated by the study's behavioral measures. Alternatively, it may be that the study's measured behaviors were simply too nuanced – or perhaps too heavily influenced by other factors (e.g., dispositional extraversion) – to be significantly altered by acute bright light exposure. Personality characteristics, state anxiety, and cultural expectations are merely three of the many factors that could potentially limit the reliability or validity of behavioral measures in the current study paradigm. Nevertheless, the degree to which acute light exposure influences actual social behavior is an empirical question, and one worthy of further exploration, even if such a pursuit ultimately requires substantial methodological innovation on the part of future investigators.

Surprisingly, participants were found to be significantly *less* likely to reengage in conversation with a confederate if they were inadvertently exposed to morning sunlight prior to the experiment, regardless of their light-exposure condition. This is the opposite of what was expected, since such sunlight exposure should presumably *increase* affiliative drive. However, the contradictory results are potentially a consequence of a study confound – specifically, the fact such exposure stemmed from study non-adherence. Thus, the above finding can be restated: participants who did not adhere to study protocol (via wearing of the amber tinted glasses) were much *less* likely to engage in conversation with a confederate. Accordingly, a potential third

variable, such as antisocial personality traits – lowered need for social contact and difficulty adhering to rules/regulations – may well explain this unexpected finding.

Exploratory study analyses among adherent participants revealed, as expected, a strong positive correlation between the desire to affiliate with someone in the same study and the desire to affiliate with someone in a different study. Likewise, among those in the control (dim light) condition, strong inverse correlations were observed between reported preference for isolation and preference for affiliation (either with someone in the same experiment or a different one), as anticipated. However, in the bright light group a different pattern was observed (Table 9). Specifically, there was no significant association between the preference for isolation and the preference for affiliation.

These findings suggest the intriguing possibility that bright light exposure – at least during stress – may partially decouple the seemingly related drives to isolate or to affiliate. Put a bit differently: bright light may enhance the preference to affiliate – as observed – without substantially altering the preference for isolation. Of course, when light-exposed participants were forced to choose, they preferred affiliation much more often than did those in the control condition.

Post hoc analyses indicate no associations between gender and depressive symptomatology on the variables of interest in the current investigation. Thus, the significant difference in gender proportions between groups is unlikely to affect the dependent variables. The majority of dependent variables were also not associated with the present study's measure of seasonality. However, findings demonstrate a significant association between two behavioral measures of affiliation (glances toward confederate and reengagement of conversation). These results indicate a potential confound of the seasonality measure or potentially these results are an

artifact of multiple significance testing. The current sample included individuals with mildly seasonal variations in clinically relevant domains and also those that fall into the severe range. Future investigations should tease apart the effect of seasonality level on the affiliative drive after bright light exposure.

The present study is characterized by a few important limitations in addition to those already described. Notably, the generalizability of the present findings may be limited by the fact that all participants were at least mildly seasonal – i.e., those prone to seasonal fluctuations in depressive symptomatology. The current study assumes a continuum of seasonality, with clinical diagnoses at one end and no symptomatic variations at the other (e.g., aan het Rot et al., 2008a; 2008b; Hsu et al., 2014), but those who experience no seasonally-related symptoms may be *categorically* disparate from the range of seasonal fluctuations. Even though an estimated 44% of the population may endorse the current study's requisite threshold level of seasonality (Kasper et al., 1989), study results may not necessarily generalize to the entire population at large.

The current investigation also utilized a single-session light exposure. While such acute exposure allows for a high degree of experimental control, it does not reflect the common implementation of light therapy, typically applied on numerous consecutive days for a span of several weeks at a time. Similarly, the effects of sunlight over numerous days may not be well replicated with a single session of artificial bright light. Another potential limitation lies in the use of a relatively young participant sample with a mean age under 20. It would be desirable, therefore, to include, in any attempted replication, participants with a broader range of ages and numerous days of light exposure.

An additional limitation of the present study is the fact that only about 70% of the sample adhered to wearing amber tinted glasses. While the nonadherence allowed for testing of

interesting effects related to sunlight exposure, the results are only correlational (inasmuch as such sunlight exposure was not directly manipulated as part of the experiment). Thus, the observed differences between the two groups may be due to other, unknown variables. Another limitation, as with most studies comparing different levels of light, is the fact that participants were not blinded to their assigned light condition, thereby raising the possibility that participants in different light groups had different expectations.

Another limitation stems from potential unanticipated consequences of the dim light control condition. The effect of red uniform coloring has been demonstrated to enhance performance in sporting contests (Hill & Barton, 2005). The authors argued that the color red conveys aggression or dominance in nature and thus affects human interactions providing otherwise evenly matched athletes an advantage. Furthermore, athletes wearing red are judged as more aggressive by referees (Bjoern, 2014). Therefore, the dim red light condition may prime participants to perceive aggression from others and thus reduce their desire to affiliate. However, the effect of the color red on perception of aggression has been inconsistent across studies (e.g., Ioan et al., 2007; Elliot, Maier, Moller, Friedman, & Meinhart, 2007; Sutter & Kocher, 2008). Additionally, dark rooms with no light – in comparison to well-lit rooms – induces ingroup favoritism and threat-relevant prejudice of outgroups (Schaller, Park, & Faulkner, 2003; Schaller, Park, & Mueller, 2003). Even thought the control condition was not totally dark, a similar prejudicial process may have taken place in the present study and affected participant decision to affiliate.

Importantly, the current results indicate increased affiliative drive in response to bright light during stress, but the results may not apply to the much larger class of affiliative behaviors that are completely unrelated to stress. Humans vary constantly, throughout the day, in the

degree to which they desire social contact (O'Connor & Rosenblood, 1996). Therefore, the observed effects of bright light exposure may not fully generalize to the broader context of daily variations in affiliative drive. Similarly, the results may differ in relation to the extent of stress participants' experience. While a large body of evidence indicates that the stimuli utilized in the current study induces physiological stress, participants in this study did not self-report high levels of distress. A follow up study can assess the need for a stress inducing manipulation to examine the role of light in affiliative behavior.

It is also of relevance, however, that I observed not just statistically significant results, but also a large effect size regarding participants' preference for affiliation. It was almost a full standard deviation higher among those in the bright light group. Additionally, the binary, forced choice to affiliate (or not) indicated a large, striking association (V = .60) with light condition. Such stark differences may indicate the pervasive existence of significant social effects of acute bright light exposure in everyday, real world settings.

An additional strength of the current study lies in its novel application of artificial bright light at a higher intensity than is typically used by either clinicians or consumers. Artificial light exposure is generally employed with the intent to replicate the neurological effects of natural sunlight. However, the standard recommended dosage is 10,000 lux for 30 minutes (Wirz-Justice, Benedetti, & Terman, 2009), despite the fact that sunlight can reach illuminance levels over 10 times larger. One of the primary reasons for the relatively low standard dosage compared to sunlight is a concern about side effects at higher lux levels (for review, see Terman & Terman, 2005). However, recent research has brought into question the degree to which adverse effects from light therapy are truly widespread, particularly in healthy individuals (Botanov & Ilardi, 2013). With this caveat in mind, the current experimental design increased

the dosage and illuminance of light therapy by 50% for 45 minutes, with the intended purpose of better simulating sunlight conditions than the standard recommended dosage.

Future Directions

Seasonal individuals represent a subset of the population that is particularly sensitive to light changes. The present finding provides further support not only for the clinical use of bright light, but also for its use in non-clinical populations. The latter is an important consideration, inasmuch as up to 10% of young adults report consistently low mood in the winter, but only a small subset meet the full diagnostic criteria for seasonal onset depression or other mood disorders (Wicki, Angst, & Merikangas, 1992). The psychosocial effect of bright light may have a beneficial effect in everyday life and, thus, potential implications for preventing depressive illness (Bar, 2009). Accordingly, the present findings, if replicated, might point to a distinct new application of light therapy – alteration of social behavior among otherwise healthy individuals. Of course, future investigations should examine if similar effects are also observed among individuals with no reported seasonal variations in depressive symptomatology.

While the current findings suggest an affiliative effect of artificial bright light, the effect of sunlight on affiliation-under-stress may vary. Future investigations should seek to increase ecological validity through examining the effect of natural light exposure compared to dim lighting.

Finally, despite the present study's indirect support for the hypothesis of serotonergic mediation of bright light on social behavior, such serotonergic effects are merely inferred. Inclusion of relevant cerebral serotonergic measurements – e.g., via fMRI, or even cerebrospinal fluid measurements of serotonin metabolites – would strengthen the conclusions of future

investigations. Similarly, measurement of other candidate neurotransmitters (e.g., dopamine) would further elucidate our understanding of bright light and social behavior.

Conclusion

The principal strength of the present study lies in careful experimental control – via the use of a control group and manipulation of sunlight exposure on the day of the study – to elucidate the effects of bright light on affiliative social behavior. The present findings make a potentially significant contribution to our understanding of the importance of bright light. Specifically, the results indicate that a single acute exposure bright light may increase the desire for affiliation, perhaps via the mediation of cerebral serotonergic pathways. However, further research is necessary to more clearly elucidate the interrelationships among light exposure, cerebral serotonergic activity, and social behavior.

The present findings also suggest the desire for isolation and affiliation may be somewhat distinct decision-making processes. Furthermore, they indicate that the careful control of natural sunlight exposure must be undertaken by investigators who seek to clearly understand the effects of artificial bright light exposure. The current study is also the first to examine a higher dosage and illuminance of bright light. In summary, bright light has previously demonstrated biological and psychological effects, but the current findings support the existence of psychosocial effects as well.

Table 1

Baseline Participant Characteristics By Experimental Condition

	Bright White (n = 34)		Dim Red (n = 31)		Total (n = 65)	
Characteristic	M	SD	M	SD	M	SD
Age	19.29	(1.19)	19.61	(2.65)	19.45	(2.01)
BDI-II	7.62	(6.08)	6.32	(5.34)	7.00	(5.74)
Hours of Sleep	6.77	(1.36)	6.94	(1.32)	6.85	(1.33)
Minutes Outdoors	12.40	(6.69)	14.81	(10.30)	13.52	(8.56)
Seasonality	14.76	(4.70)	17.75	(4.55)	16.22	(4.82)

Table 2

Continuous Outcome Measures By Experimental Condition

	Bright White			Dim Red			Total		
	M	SD	n	M	SD	n	M	SD	N
Isolation preference	55.03	29.92	29	65.63	24.38	24	59.83	27.81	53
Affiliative preference (different study)	44.03	24.80	29	31.38	21.81	24	38.30	24.12	53
Affiliative preference (same study)	51.00	33.10	29	39.42	22.87	24	45.75	29.23	53
Sitting distance (cm)	31.33	8.12	12	32.53	5.58	17	32.03	6.64	29
Glances	4.22	2.33	9	2.60	2.23	15	3.21	2.34	24
Smiles	1.00	1.33	10	.27	.80	15	.56	1.08	25

Table 3

Continuous Outcome Measures By Experimental Condition for Individuals Not Exposed to High Levels of Sunlight

	Bright White			Dim Red			Total		
	M	SD	n	M	SD	n	M	SD	N
Isolation preference	52.19	29.56	21	64.00	26.63	16	57.30	28.57	37
Affiliative preference (different study)	46.62	26.56	21	32.94	21.62	16	40.70	25.18	37
Affiliative preference (same study)	58.95	31.80	21	35.25	22.41	16	48.70	30.21	37
Sitting distance (cm)	29.25	8.96	8	32.18	5.83	11	30.95	7.23	19
Glances	4.00	1.87	5	1.91	2.02	11	2.56	2.16	16
Smiles	1.50	1.52	6	.27	.91	11	.71	1.26	17

Table 4

Continuous Outcome Measures By Experimental Conditions for Individuals Exposed to High Levels of Sunlight

	Bright White			Dim Red			Total		
	M	SD	n	M	SD	n	M	SD	N
Isolation preference	62.50	31.56	8	68.88	20.39	8	65.69	25.88	16
Affiliative preference (different study)	37.25	19.27	8	28.25	23.33	8	32.75	21.19	16
Affiliative preference (same study)	30.12	28.31	8	47.75	22.88	8	38.94	26.48	16
Sitting distance (cm)	35.30	4.44	4	33.17	5.57	6	34.10	5.02	10
Glances	4.50	3.11	4	4.50	1.73	4	4.50	2.33	8
Smiles	.25	.50	4	.25	.50	4	.25	.46	8

Table 5

Categorical Affiliative Endorsement By Experimental Conditions

Sunlight	Condition	Alone	Affiliate (different study)	Affiliate (same study)
Non-Exposed	Bright White	9	3	9
	Dim Red	13	1	2
Exposed	Bright White	7	0	1
	Dim Red	6	1	1

Table 6

Binary Outcome Measures By Experimental Conditions

	Bright White		Dim Red		Total	
Outcome	Yes	No	Yes	No	Yes	No
Affiliate	13	16	5	19	18	35
Reengage Conversation	4	5	5	11	9	16

Table 7

Results of Binary Logistic Regression Analysis Testing Effect of Light Condition and Retinal Sunlight Exposure on Binary Affiliation Decision

	Source	Wald	*df*	*p*	Exp(B)
Step 1					
	Light Condition	5.09	1	.02	5.78
	Sunlight Exposure	.13	1	.72	1.44
	Light*Sunlight	2.80	1	.09	.07

Table 8

ANOVA Results for Light Condition and Retinal Sunlight Exposure on Affiliation

	Source	*df*	*F*	*p*
Isolation preference				
	Light Condition	1	1.18	.28
	Sunlight Exposure	1	.83	.37
	Light*Sunlight	1	.11	.75
Affiliative preference (different study)				
	Light Condition	1	2.54	.12
	Sunlight Exposure	1	.98	.33
	Light*Sunlight	1	.11	.74
Glances				
	Light Condition	1	1.19	.29
	Sunlight Exposure	1	2.60	.12
	Light*Sunlight	1	1.19	.29
Smiles				
	Light Condition	1	1.97	.18
	Sunlight Exposure	1	2.12	.16
	Light*Sunlight	1	1.97	.18
Sitting Distance				
	Light Condition	1	.01	.91
	Sunlight Exposure	1	1.86	.19
	Light*Sunlight	1	.98	.33

Table 9

Pearson's Correlation Coefficients for Light Conditions and Preference to Affiliate/Isolate among Non-sunlight-exposed Individuals

		Affiliate (different study)	Affiliate (same study)
Dim Red	Alone	-0.68*	-0.75**
	Affiliate (different study)		0.72*
Bright White	Alone	0.14	0.22
	Affiliate (different study)		0.84***

Note: * $p < .01$, ** $p = .001$, *** $p < .001$

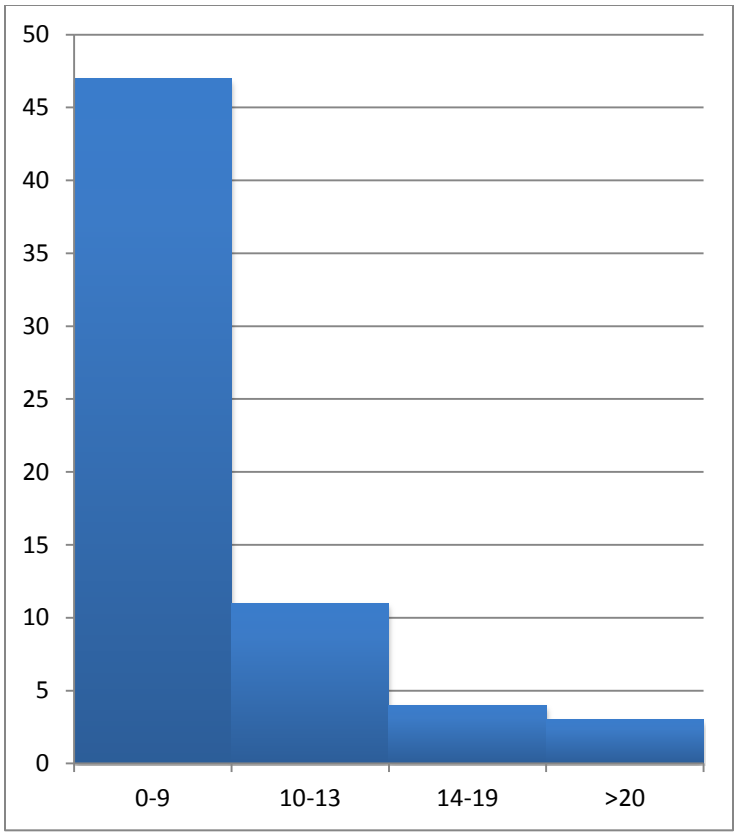

Figure 1. Histogram of BDI-II scores.

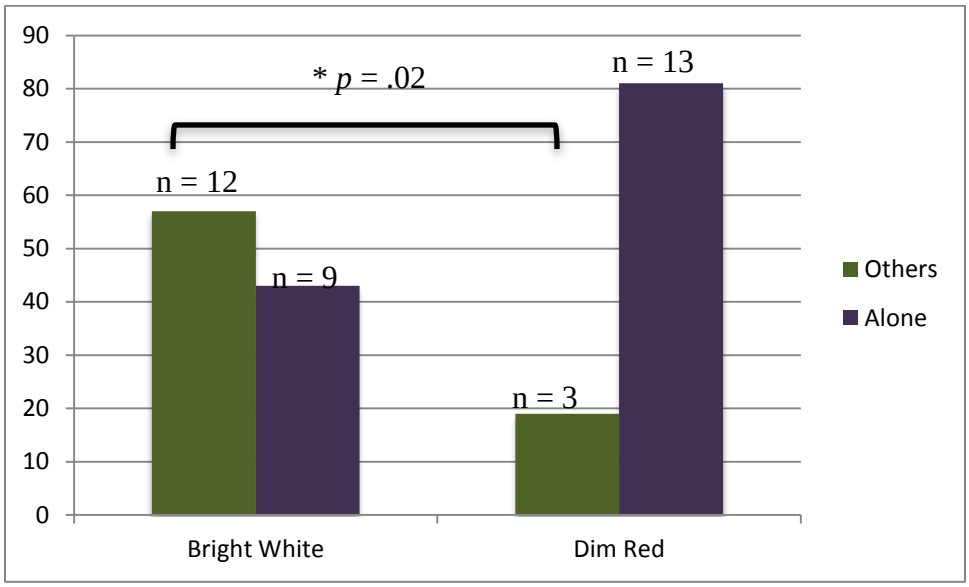

Figure 2. Proportion of non-sunlight-exposed participants endorsing isolation/affiliation by experimental condition.

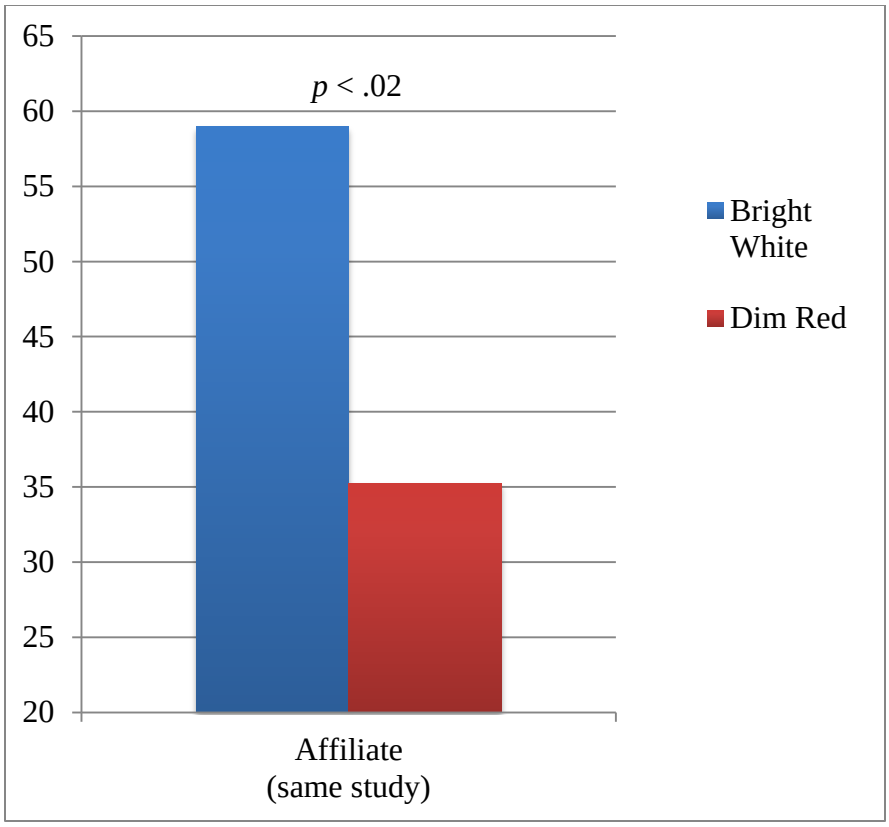

Figure 3. Level of preference for affiliation/isolation between conditions of non-sunlight-exposed participants.

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Appendix A: Global Severity Scale

To what degree do the following change with the seasons?

	No Change - 0	Slight Change - 1	Moderate Change - 2	Marked Change - 3	Extremely Marked Change - 4
Sleep length (1)	❍	❍	❍	❍	❍
Social activity (2)	❍	❍	❍	❍	❍
Mood (overall feeling of well being) (3)	❍	❍	❍	❍	❍
Weight (4)	❍	❍	❍	❍	❍
Appetite (5)	❍	❍	❍	❍	❍
Energy level (6)	❍	❍	❍	❍	❍

Appendix B: Assessment Battery

First Assessment Period

What is your gender?

- ❍ Female (0)
- ❍ Male (1)

What is your age (please use a two digit number)?

What is your race / ethnic group? (multiple responses allowed)

- ❑ White/Caucasian (1)
- ❑ Black or African American (2)
- ❑ American Indian or Alaska Native (3)
- ❑ Asian (4)
- ❑ Hispanic, any race (5)
- ❑ Other (6)

Are you currently diagnosed with a depressive disorder?

- ❍ Yes (1)
- ❍ No (0)

Have you ever been diagnosed with a depressive disorder?

- ❍ Yes (1)
- ❍ No (0)

Are you currently taking any medications for depression?

- ❍ Yes (1)
- ❍ No (0)

Second Assessment Period

What time did you go to sleep last night?

What time did you wake up TODAY?

How many hours of sleep did you get?

How many alcoholic beverages (of any type) have you consumed over the past 24 hours?

- ❍ 0 (0)
- ❍ 1-2 (1)
- ❍ 3-5 (3)
- ❍ 5 or more (5)

Did you take any allergy medication in the past 24 hours?

- ❍ Yes (1)
- ❍ No (0)

Do you currently have or believe you have a fever, a cold, or the flu?

- ❍ Yes (1)
- ❍ No (0)

Approximately, how many MINUTES have you spent outdoors today?

Did you drive to this experimental session?

- ❍ No (0)
- ❍ Yes (1)

Move the bar to best describe your mood at the current moment.

- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)

Final Assessment Period

Move the bar to best describe your mood at the current moment.

- ❍ 1 (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)

2. You will need to wait in a different room for a few minutes until we set up the speech task. Would you prefer to spend that time:

- ❍ Alone (1)
- ❍ With a student participating in another study (2)
- ❍ With a student participating in the same study (3)

Using the bars below, while we set up the speech task what level of preference do you have for each situation (0= not at all; 50 = neutral;100= completely)?

_____ Alone
_____ With a student participating in another study
_____ With a student participating in the same study

Appendix C: Modified version of the Toronto Side Effect Scale

For each symptom listed on the left, rate the severity or degree of trouble caused by the symptom (ranging from "Absent" to "Severe") at the CURRENT MOMENT.

	0 - Absent	1 - Mild	2	3 - Moderate	4	5 - Severe
1. Nervousness	❍	❍	❍	❍	❍	❍
2. Agitation	❍	❍	❍	❍	❍	❍
3. Tremor or shakiness	❍	❍	❍	❍	❍	❍
4. Muscle twitching	❍	❍	❍	❍	❍	❍
5. Abdominal pain	❍	❍	❍	❍	❍	❍
6. Upset stomach	❍	❍	❍	❍	❍	❍
7. Nausea	❍	❍	❍	❍	❍	❍
8. Weakness or fatigue	❍	❍	❍	❍	❍	❍
9. General dizziness	❍	❍	❍	❍	❍	❍
10. Daytime drowsiness	❍	❍	❍	❍	❍	❍
11. Sweating	❍	❍	❍	❍	❍	❍
12. Flushing	❍	❍	❍	❍	❍	❍
13. Headache	❍	❍	❍	❍	❍	❍
14. Blurred vision	❍	❍	❍	❍	❍	❍
15. Eye strain	❍	❍	❍	❍	❍	❍
16. Dry mouth	❍	❍	❍	❍	❍	❍
17. irritability	❍	❍	❍	❍	❍	❍
18. Restless energy	❍	❍	❍	❍	❍	❍