Lightwear: An Exploration in Wearable Light Therapy

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ABSTRACT
We present "Lightwear", a series of garment-based, lightweight, light-emitting wearables designed to administer light therapy for on-the-go treatment of Seasonal Affective Disorder (SAD). Bright Light Therapy (BLT) has been used to treat SAD for more than 25 years. While light boxes continue to serve as the predominant method of treatment, it often requires a user to sit at a dedicated location for a sustained period of time (30-60 minutes), rendering therapy inconvenient and resulting in unsatisfactory compliance rates. To date, there have been few successful products developed for wearability and portability to ease the uncomfortable nature of light box treatment. However, new low-profile, light-emitting sources yield opportunities for less cumbersome textile integration and wearability. We explore the integration of light into textile substrates that focus on fashion-forward wearables which can, in turn, address BLT efficacy, usability, and convenience.

Author Keywords
Bright Light Therapy; Seasonal Affective Disorder; Wearable Technology; Fashion

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Seasonal Affective Disorder (SAD), also referred to as winter depression [10], is a disorder that causes the onset of depressive-type symptoms, typically during the fall and winter months [8]. This mood disorder is often linked to limited sunlight exposure [4], resulting in biochemical changes in the brain [12]. It often presents in regions further from the equator that have shorter daylight hours and affects approximately 5% [8] of adults in the United States alone, with women at a higher risk (4:1) for onset [8, 23]. Bright Light Therapy (BLT), the most common form of SAD treatment, uses light boxes that emit artificial light

Figure 1. Fiber optic light-emitting scarf.

(simulating natural light) to offset depression-related symptoms associated with SAD. Such symptoms include hypersomnia, increased appetite and weight gain, fatigue, irritability, and social disengagement [23, 24]. Light boxes are commercially available and come in a number of configurations to meet the specific needs of the individual. While light boxes have been clinically proven to help in the treatment of SAD, research has indicated that users often find them to be burdensome: 69% considered light boxes to be inconvenient due to extended sitting and up to 19% admittedly abandoned treatment [1]. Our motivation for researching mobile treatment options comes from low adherence rates around using light boxes. New light-emitting materials and smaller hardware profiles permit for the exploration of novel, wearable form factors that can serve as alternative light therapy treatment options.

RELATED WORK
A number of studies have ascertained that exposure to bright light could chemically 'trick' the brain into counteracting the depression-like symptoms associated with winter depression (SAD) [4, 10, 16, 23, 24, 26]. Since then, a number of studies have been conducted evaluating the efficacy of different light spectra [14, 15, 21], lux ratings [7, 9], treatment durations [20], time-of-day treatments [4, 11], placebos [4], as well as alternative treatment options such as dawn simulation [1] or negative ion exposure [24], pharmacotherapy [8], or combinations of these treatments [8, 24]. Light visors, hats or visors with lights embedded on the underside of the brim that shine towards one's face, have also been researched as a portable alternative to light

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box treatment [7, 13, 16, 19, 21]. As referred to in [13], various studies have found light visors to be effective in treating SAD, however, some studies failed to find a significant difference in the efficacy of BLT administered via light box versus a light visor. Light visors are of interest as they have been attributed as being more convenient than light boxes as they mediate the need to stay situated in a fixed position [19]. While light visors solve the problem of portability, they are still not as prolific as light box usage (findings from our initial survey revealed that none of the participants used a light visor to treat their SAD-related symptoms), suggesting other factors at play, such as efficacy, acceptability [2], and comfort. In addition, users are unlikely to think of wearing a visor when it is dark and cloudy outside. To date, we have found little research exploring other form factors or more wearable options that serve as alternatives to light visors. Given the advent of new materials such as fiber optic fabric, conductive textiles, and flexible 3D printed media, we explore how new form factors can be designed to address the noncompliance issues surrounding current BLT options.

Bright Light Therapy for SAD

Bright Light Therapy (BLT) has been used to successfully treat a number of conditions, including SAD, non-seasonal depression, jet lag, sleep disorders, dementia, skin disorders (psoriasis), and night shift work schedules[1]. BLT for SAD has historically entailed the use of full spectrum, white light (UV filtered out) administered using a light box. Light boxes can range in size from portable handheld devices to torso-length units and commonly range in price from $180 to $500 USD [8]. Standard bright light therapy entails a user being situated in front of a white, fluorescent lamp or light source producing 10,000 lux [8]. Users should be located within a certain range of the light box (typically 12 to 18 inches) [8] for approximately 30-60 minutes in the early morning [5]. The administration of light in the early morning is essential for proper treatment, as light administered later in the evening can severely impact sleep. The main criterion for treatment to have a beneficial effect is that one's eyes must be exposed to the light so that the light strikes the retina, however, a user is not required to look directly at the light. This often becomes a limiting factor as it prevents users from attending to other tasks.

Light visors have been developed to address this issue, however, visor usage is often met with significant tradeoffs. While a light visor solves the issue of portability, a user's eyesight often remains obstructed either due to the brightness of the light or the physical protrusions of the visor. Thus, users are cautioned to perform minimal, non-hazardous activities. Furthermore, prior research suggests that treatment efficacy is a function of total irradiated

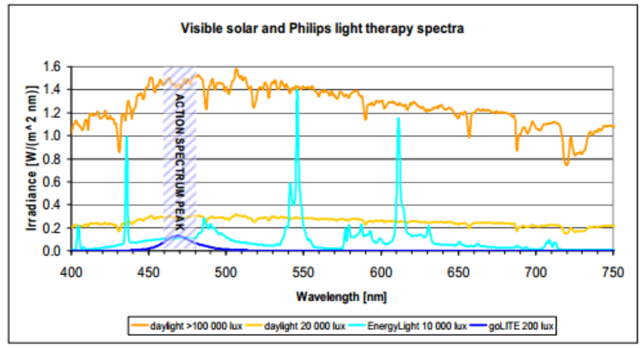

Figure 2. Action spectrum-blue light vs. other light sources [18].

energy. Similar effects can be obtained at exposure to higher intensities for shorter periods of time, and lower intensities for proportionally longer durations. For example, a standard treatment session of white light at 10,000 lux for 30 minutes is comparably effective to treatment at 2,500 lux (appropriate for the visor's distance from the face) administered for 2 hours [20], increasing treatment time substantially. Continuous exposure to a light source can be known to result in a number of side effects including irritability, headaches, eye strain, and nausea [8, 12]. Studies have also referred to the link between BLT used for melatonin suppression, with the result of treating winter depression [5, 17]. The association between the effects of light on circadian rhythm, melatonin levels, and SAD-symptom relief merit continued research. New research suggests that short wavelength light (blue) is significantly effective for melatonin suppression [27] and for alleviating SAD-symptoms [5]. This has prompted the development of new BLT products, such as the Philips goLite BLU energy light[2], that specifically harness blue light to treat SAD-related symptoms.

Light Spectrum

Various studies have tried to distill the appropriate spectrum of light for BLT [14, 15, 21]. While some studies yield conflicting results, full spectrum white light (with filtered UV) has consistently been used for BLT. New research on blue light has demonstrated beneficial effects on SAD-related symptoms [5, 18]. Additionally, applying blue light-emitting diodes for melatonin suppression has been found to yield more efficient levels of melatonin suppression in the 446-477 nm spectrum [27]. This research is promising yet is also proving to be somewhat controversial as high intensity blue light with wavelengths between 435-445 nm wavelengths may pose hazards to the retina [5]. Since the action peak for BLT appears to occur at around 470 nm (see Figure 2), light sources should have an energy concentration around this wavelength.

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[1]http://www.mayoclinic.org/tests-procedures/light-therapy/basics/why-its-done/prc-20009617

[2]http://www.usa.philips.com/c-p/HF3332_60/golite-blu-energy-light

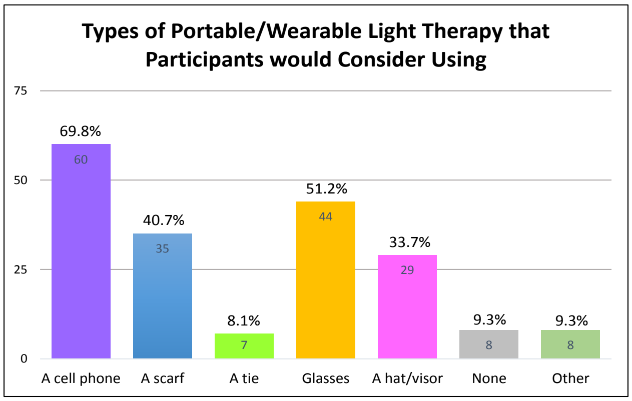

Figure 3. Reported wearable form factors that participants would consider wearing for light therapy.

USER-CENTERED DESIGN APPROACH

We decided to employ user-centered design methods to explore the design space of wearable BLT. Here we describe our online survey used to inform our design explorations.

Method

Multiple forms of user data collection were employed in order to gather pertinent information regarding the design of the wearable prototypes. A preliminary online survey was administered to those with SAD or SAD-related symptoms to assess current treatment methods and attitudes toward wearable forms of therapy. This data was used to inform the design of the wearables that were prototyped and evaluated with a pilot study to garner participant attitudes and contribute to overall prototype refinement. A larger, follow-up user study was conducted (currently under review) yielding insights for overall prototype wearability, convenience, user experience, and usability. Overall results complement the initial, qualitative findings we obtained and report here.

Recruitment

Online Survey

To capture feedback pertaining to Bright Light Therapy for Seasonal Affective Disorder, a global survey was administered to collect attitudes and experiences from individuals in regions (northern latitudes) with a higher incidence of SAD. Specific target audiences included individuals located in Washington, USA, New York, USA, the United Kingdom, Ireland, Finland, and Scandinavia.

Online Survey Results

We collected data on 101 individuals (42.6% female) between the ages of 18 and 70. Approximately eighty-five percent (86 individuals) of these participants were either clinically diagnosed with SAD or expressed SAD-related symptoms associated with autumn and winter seasons. Of interest to us were individuals who use or have used a light box to treat their SAD-related symptoms. Twenty-one individuals reported current (17) or prior (4) light box usage

Online Survey

1) For how many years have you had Seasonal Affective Disorder or exhibited SAD-related symptoms?
2) Do you currently participate in any form of bright light therapy?
☐ Yes ☐ No
3) Have you found bright light therapy to be beneficial?
☐ Yes ☐ No ☐ Somewhat
4) Do you find the use of a light box to be convenient or inconvenient?
☐ Yes ☐ No ☐ Neutral ☐ Other:__________
5) Have you ever stopped using a light box due to inconvenience?
☐ Yes ☐ No
6) Roughly how often do you use your light box during the fall/winter?
☐ Daily ☐ Weekly ☐ Monthly ☐ Less Than Monthly
7) Light therapy has been shown to have beneficial effects on mood for individuals with SAD-related symptoms. Would you be open to the possibility of using a portable or wearable form of light therapy treatment?
☐ Yes ☐ No ☐ Perhaps
8) What types of portable or wearable light therapy might you consider using? *(Check all that apply)*
☐A Cell Phone ☐A Scarf ☐A Tie ☐Glasses ☐A Hat/Visor ☐None ☐Other:_
9) What types of concerns might you have about using a more portable or wearable form of light therapy treatment? *(Check all that apply)*
☐ Battery Life ☐ Comfort/Discomfort ☐ Obstructions Caused by the Device
☐ Brightness of Light ☐ Heat ☐ Any Resulting Symptoms
☐ General Nuisance of the Device ☐ Social Awkwardness
☐ I Have No Concerns ☐ Other:___________

Figure 4. Select questions from the online survey.

to treat their symptoms. Of the 21 light box users, 9 (42.9%) individuals indicated that they found a light box to be inconvenient. Additionally, of those individuals who currently used a light box, 76.5% percent indicated that they have stopped using a light box due to inconvenience. This aligns with prior research reporting that 69% of those with SAD found light boxes to be inconvenient [1]. These figures also reinforce our motivation to explore new wearable, light-emitting treatment options. Reasons surrounding the inconvenience of light boxes were cited as having to remember to use it, lack of portability, bulkiness, having to remain in front of it for an extended period of time while essentially doing nothing, knowing how to set it up and angle it appropriately, and having to switch work locations where the light box is not located. We also used the survey to garner attitudes regarding the possible use of wearable/portable alternative treatment options for their SAD. From the 86 participants who identified as having SAD or SAD-related symptoms, 93% responded ‘Yes’ or ‘Perhaps’ to the possibility of using a portable or wearable form of light therapy. We surveyed the types of form factors that individuals might be interested in wearing to treat their SAD. The popular items were a cell phone (69.8%), glasses (51.2%), a scarf (40.7%), and a hat/visor (33.7%) (see Figure 3).

We used this data to inform the design of our wearables and to create form factors that we hoped were both convenient to wear and appropriate for emitting light toward the face/retina. A cell phone was excluded from our design as we were solely focused on wearable/textile options and it was considered highly unlikely that an individual would dedicate their phone to 30-60 minutes of daily BLT. In addition to collecting user feedback on receptivity toward particular wearable form factors, we polled participants on their existing concerns for wearable devices of this nature (as shown in Figure 4). Social awkwardness was the primary reported concern (79.1%), followed by comfort/discomfort (68.6%), general nuisance of the device (61.6%), obstructions caused by the device (52.3%) and battery life (41.9%). Of interest were the top 4 rated concerns as they also closely correspond to existing barriers related to BLT adoption. Thus, this feedback was dually noted for the prototyping phase and can be used to inform future wearable technologies in this design space.

DESIGN

Given the data collected, we were encouraged to create a wearable light therapy experience that users would want to use, or even enjoy using. There are a number of design considerations in the development of a wearable form of bright light therapy. We used these considerations to drive the development of our wearables, however, relaxing guideline #3, as we were strictly focused on prototyping wearable form factors and not conducting clinical trials:

1) Light must strike the retina, preferably from the peripheral view as opposed to a direct viewing angle.
2) Beneficial full-spectrum white light ranges from 2,500-10,000 lux [20], however, blue light has been shown to be effective at 200 lux [18].
3) Light intensity, radiance, and duration should be specific to Bright Light Therapy.
4) Proximity of the light and the wearable form should not interfere with daily routine and should be at a safe distance.
5) Light should be administered in the early morning.
6) User preference should be optimized for the location-based administration of light.
7) Heat dissipation and power tradeoffs must be managed.
8) Social/contextual appropriateness of a wearable device must be considered.
9) Form factors must be designed for comfort and wearability.

Given the need for light to strike the eyes, the wearable prototypes were designed for the upper chest and head regions. Data collected from the online survey was used to guide which form factors (hats, glasses, and scarves) to develop for our study. The light-emitting and other unconventional materials also drove the concept development as they permitted for malleability, form exploration, and alternative integration techniques. A total of 6 prototypes (2 scarves, 2 hats, a hooded neck piece, and glasses) were developed for evaluation. These wearables were designed to align with the current cultural fashion trends of the time (or to be deemed classical) and often were gender specific. Despite one's gender, all participants were asked to explore each wearable and to stack rank the prototypes based on preference.

Light-Emitting Materials

A number of light-emitting materials were used to explore the manner in which light could be embedded into wearable prototypes. These light sources include Philips LUXEON Rebel Color (blue) Lumileds[3], a light strip made up of WS2812 LEDs[4], Sparkfun Fiber Optic Fabric[5], and Corning Fibrance Light Diffusing Fiber[6]. The Corning Fiber was also accompanied by a ThorLabs Blue (470nm) Fiber-Coupled High-Power LED[7] and ThorLabs T-Cube LED Driver[8]. These light sources were specified at the peak wavelength (470 nm) shown to support melatonin suppression and offset SAD-related symptoms [5, 27]. We exercised caution around spectrum, intensity, distance, and lamp and lighting standards (IEC 62471:2006, section 4.3.3) [6], to ensure that our prototypes were safe for user testing. Beyond that, all light sources were purposefully diffused for added protection. These light sources were embedded in fashionably-oriented attire to strive for social appropriateness. Users could then hopefully employ light treatment at their discretion for contextually appropriate therapy scenarios.

Wearable Prototypes

Our design goal was to achieve desired form factors while incorporating light in a manner that was appealing. Thus, our wearables were designed for the purposes of fashion and utility, as certain prototypes enabled light to emanate from below the neckline, above the brow, or at one's periphery. For the overall design, it was important to have a relatively equal number of gender-oriented garments for testing purposes. This is one reason as to why there are duplicate items (two hats and two scarves). Early renditions of the prototypes were developed in an open work space for preliminary feedback. While the fascinator hat, hood, and teal cowl (scarf) were designed with a female user in mind (and the brown golfer's hat and fiber optic scarf with a male user in mind), initial feedback from passersby and external members of the research team revealed that many individuals gravitated toward prototypes geared to the opposite gender. We ascertained that while some prototypes were clearly not gender neutral, we could benefit from having pilot study participants evaluate all of the prototypes as there might be aspects from one form factor that could be applied to another, more preferred form factor.

Many of these wearable items featured season-appropriate designs, thus, the form factors leveraged the fact that most of these wearables would typically be worn in the fall and

[3]http://www.philipslumileds.com/products/luxeon-rebel/luxeon-rebel-color
[4]http://www.adafruit.com/datasheets/WS2812.pdf
[5]https://www.sparkfun.com/products/12712
[6]http://www.corning.com/specialtymaterials/advanced_optics/specialty_fiber/products/light_diffusing_fiber/index.aspx
[7]www.thorlabs.us/thorproduct.cfm?partnumber=LEDD1B
[8]www.thorlabs.us/thorproduct.cfm?partnumber=LEDD1B

winter months – the key time for SAD onset. One participant commented that a light visor fails conceptually in that the functional design of a visor is intended to be worn during a sunny day to keep light out of one's face (and yet it's being leveraged to mount light sources and administer light to an individual). While our prototypes maintained season appropriateness, we realize that a number of these items, such as the hood or a scarf, are traditionally worn outside. We developed wearables that aligned with both indoor and outdoor usage to garner user preference and also to permit for items that could be worn as one readies themselves for the day (e.g., worn eating breakfast or on one's public commute to work) as BLT is most effective when administered in the morning hours. Additionally, all of the prototypes were developed with generic operation (on/off) methods so that the users could report their insights into how they envisioned the prototypes working (using a timer, interaction methods, etc.).

1. Glasses

The glasses were chosen due to their gender-neutral aesthetic and because their larger frames support hardware integration. This prototype was 3D printed on an Edin 260V Objet printer and used Philips Lumileds embedded in the temples for peripheral illumination. Two layers of striated 3D printed clear PLA were placed in front of the LEDs so that it would diffuse the light over a larger surface area (to maximize exposure) and also not overwhelm the eye. Due to the close proximity of the light source to the eye in this particular prototype, lights were placed in one's peripheral vision as opposed to the rim above the eye so as not to trigger an upper lid drop (thus reducing the efficacy of light reaching the eye) [3].

2. Fiber Optic Scarf

The fiber optic scarf incorporated fiber optic fabric on one side of an existing cashmere gray scarf. Thus, one side has the appearance of a standard scarf while the opposing side has the mounted fiber optic material. Two blue Philips Lumileds were embedded on either side of the scarf with a standard on/off switch for operation. When not illuminated, the fiber optic fabric blends into the wearable relatively well as it has the appearance of stiffened gray fabric with small fiber optic cables running through it. When one side of the scarf is wrapped up and around one's neck, it creates a cowl that then casts the light up towards the user's face. The malleable rigidity of the fiber optic fabric lends to a scarf that can retain a semi-self-supporting structure, permitting the scarf to maintain its shape for continuous, directed light. This type of open-ended scarf permits for flexibility in how the item is worn. Some individuals wrap scarves up and around one's neck, while others prefer to wrap the scarf up and over the head, producing a hood-like effect that shields one from the elements. Designing a wearable with this flexibility in mind shed insight on the functional benefits of such as form factor as well as to how a user might choose to wear such a light emitting device.

Figure 5. Wearable light-emitting prototypes – Glasses (1), Fiber Optic Scarf (2), Teal Cowl (3), Fascinator Hat (4), Hood (5), and Classic Golfer's Hat (6).

3. Teal Cowl/Scarf

The cowl entailed a neck piece prototyped out of foam and fabric and reinforced with light weight metal ribbing so that the scarf could be reformed to permit for a change in light angle, height, and envelopment. The metal ribbing also contributed to a self-supporting structure that could easily remain in place on a user post-adjustment. This differed from the fiber optic scarf, which could be repositioned in a number of configurations. This discerning feature was employed to understand if participants preferred a set-it-and–forget-it form factor (the teal cowl stays in place), or a wearable that permitted a higher degree of reconfiguration.

Blue light LED strips[4] embedded in the cowl were used to simulate light emitted from below the neckline, allowing us to assess if users preferred light cast from below.

4. Fascinator Hat

A fascinator hat and veil were used as a way to administer light in front of the face. This form factor was chosen due to the advantageous property of the veil extending up and over one's face. In this manner, fashion guided function. However, recently published research has found that blue light administered to animals for melatonin suppression was as effective when administered in one eye versus two eyes [25]. Such a parameter invites new usage scenarios for SAD management, and can be leveraged in both the fascinator hat and the glasses. The convenience of treatment dedicated to one eye might minimize any potential nuisance or distraction caused by the light, but needs further validation in humans. The veil was constructed out of Mistyfuse, a thermoplastic polymer resin fusible used for soft, strong fabric bonding, as initial prototyping phases showed that it was well suited at diffusing light throughout the body of the veil – covering a larger surface area in front of the face. A Philips blue Lumiled was embedded in the outer ornamentation between the headpiece and the veil. An on/off switch and 2032 coin cell battery used to power the device were embedded in the anterior diskette of the hat.

5. Hood

The hood was an extension of the cowl, permitting for light to be cast from two directions: the collar region below the face and the enveloping hood that extends up and over the forehead. We chose to solely embed lights in the hood region so as to disambiguate feedback from that which might be associated with light emanating from a neckpiece. Corning Fibrance Light Diffusing Fiber was integrated into the underside of the hood. This light source is light weight, channels uniform, continuous bright light, and can curve and contour with fabric, making it advantageous for this application. The hood was created to be both soft and malleable, with inner conduits permitting for a guided integration of the Corning Diffusing Fiber. These conduits also help the Corning Fiber stay in place to ensure continuous exposure to the lights.

6. Brown Golfer's Hat

A classic golfer's hat was repurposed with Philips blue Lumileds embedded in the brim to project light toward the eyes/face from above. From a fashion standpoint, this hat differed from the other prototypes due to its familiarity, and was also used to ascertain the differences in which individuals experienced light cast on the face (e.g., the golfer's hat projecting from above and the fascinator hat projecting from the front-side). Mistyfuse was layered over the Lumiled to diffuse the intensity of the light and spread it out over a larger surface area. A switch and a 2032 coin cell battery (used to power the device) were housed inside the hat above the brim.

PRELIMINARY FINDINGS

Pilot Study

We conducted a small pilot study consisting of four participants (1 male, age range 26-45) to gather preliminary feedback on the six wearable form factors. Participants were recruited from the greater Seattle area and had exhibited SAD-related symptoms for at least 3 years. Participants either currently participated in Bright Light Therapy (used a light box) or had participated in BLT in the past. No participants had reported using a light visor. For the pilot study, participants were introduced to the wearable items individually in a randomized order. The prototypes were first presented to the participants on a mannequin so as to gain an overall impression of the wearable. Next, participants were encouraged to explore and interact with each prototype (a mirror was provided to use for feedback and appearance) and to talk aloud throughout the process. Participants were then instructed to fill out a questionnaire pertaining to each item.

User Feedback

Initial feedback revealed that all of the participants were rather receptive to the idea of wearable light therapy, noting the inconvenience of light boxes (in particular, themes emerged around dedicated sitting and remembering to use the box). In general, participants liked the convenience of the brown hat and the glasses. User commentary reflected both function and fashion as advantageous attributes of the prototypes:

P1: "[Glasses] Super convenient. Don't need to adjust it myself and try to figure out what the best angle is for light to enter my eyes."

P2:"[Golfer's Hat] I like that it is stylish…comfortable, easy, and something that I would wear"

P2: "[Fiber Optic Scarf] I like the scarf a lot. It's different without being out there. It's something that I can accept. It's eye-catching."

P3: "I have a knit poncho that would be perfect for incorporating light therapy into.

P3: "[Hood] I wouldn't wear this hood but if this were built into my favorite hoodie I would wear it all the time."

Of particular interest was a wearable that was fashionable (yet not too extreme) that could simultaneously administer light therapy. Two participants liked the idea of embedding lights in a hood or a scarf; however, due to personal stylistic preferences they seemed to prefer retrofitting their existing favorite hoodie or scarf with the lights as opposed to using the options presented to them.

Much to our surprise, participants did not feel that the social awkwardness of an illuminated device was an issue. One participant did mention light as being more flattering from below versus above and cited this as a concern. Participants were also asked to envision different scenarios of operating the prototypes. Three of the four participants highlighted existing, natural interactions with attire as a recipe for prototype operation. Examples include tapping a hat brim to turn the light on and off *(P4),* outfitting the hoodie with drawstrings that can be pulled to activate the light *(P2),* or wrapping the scarf to initiate illumination *(P1).*

DISCUSSION

In this work, non-traditional light emitting materials were used to explore wearable light treatment options as an alternative to traditional light box therapy for SAD. It is important to note that this initial phase of research was specifically an exploration of the design space surrounding attitudes toward wearable light therapy form factors. A formal user study investigating the user experience, usability concerns, and wearability factors related to these prototypes was conducted, with the findings currently under review, but complementary to what we initially report here. The wearable light sources that were used seemed optimal for seamless integration of light therapy into garments in order to simulate and study the preferences associated with light on and around the face. While light sources were used to recreate the light box experience, this study did not scientifically test the efficacy of these wearables on melatonin suppression or SAD-symptom reduction. Although, to our knowledge, there is no concrete link between melatonin production and SAD-onset, existing studies have demonstrated consistent findings when using blue narrow-band light-emitting diodes to offset melatonin production [27] and SAD-symptoms [5]. We see these scientific validation efforts as the next line of research, in addition to conducting long-term usability studies of the wearables themselves. Of particular interest is the exploration of the specific interaction techniques, use cases, and social appropriateness of these factors longitudinally, as they are expected to change with time.

For overall light garment development, there were a number of design tradeoffs that one had to take into account. A balance of gender-specific and gender-neutral designs was a priority, as well as form factors that could easily administer light toward the eyes and face. Some of the wearables were liked due to their multi-purpose function in the winter months – e.g., a hood provides protection from the elements and can adequately administer light to the front of the face. However, participants did indicate that garments strictly worn outdoors could lose their utility once indoors (2 participants were not inclined to wear a hood once inside a building). This reinforces the importance of modularity in design (e.g., a hood/neckpiece where the hood can be doffed while the neckpiece remains on the user and continues to administer treatment). This was complemented by one participant who indicated that she liked the fact that her need for light therapy gave her an excuse to wear a fashion-forward item that she typically wouldn't wear otherwise. This insight places emphasis on the advantages of designing garments with aesthetic qualities in mind to appeal to different user preferences.

With the design of such wearables there are still marked limitations with respect to power and heat dissipation. While the Philips Lumileds could operate off of 2032 coin cell batteries, the power draw requirements meant that continuous operation was capped at 5-6 hours. This could support anywhere from 4 – 24 treatments depending on therapy intervals. In such an instance, making the device rechargeable would eliminate excessive battery waste. The other light sources had different power requirements (i.e., constant current drivers instead of voltage drivers). For the purposes of testing, we were fine using tethered, off the shelf componentry. In order to make these prototypes truly usable and wearable, we would have to create custom designed power boards to reduce the weight and size of the power sources. These light sources would also have to be properly designed to account for heat dissipation through creative use of heat sinks. While heated clothing during the fall/winter may be seen as a benefit, care should be taken so as not to cause discomfort to a user during warmer months.

CONCLUSION

This work presents "Lightwear," an exploration of light-emitting wearables designed for the purposes of Seasonal Affective Disorder treatment. Developments in unconventional light-emitting materials have made it possible to study questions related to what it means to put light on the body for therapeutic purposes and continuous wear. These materials have also facilitated integration into wearable form factors, redefining our notion of Bright Light Therapy to account for portable, convenient, and fashionable items that can more easily accommodate the users' needs and address treatment noncompliance.

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