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Effects of telepresence light height and ambient light on glare and appearance

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EFFECTS OF TELEPRESENCE LIGHT HEIGHT AND AMBIENT LIGHT
ON GLARE AND APPEARANCE

A Thesis

Presented to

The Faculty of the Department of Industrial and Systems Engineering

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in Human Factors and Ergonomics

by

James P. Beno

August 2009

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EFFECTS OF TELEPRESENCE LIGHT HEIGHT AND AMBIENT LIGHT
ON GLARE AND APPEARANCE

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ABSTRACT

EFFECTS OF TELEPRESENCE LIGHT HEIGHT AND AMBIENT LIGHT ON GLARE AND APPEARANCE

by James P. Beno

Telepresence technology may soon appear in the home where changing light conditions could make it difficult to portray a person well on video. This research investigated whether the amount of telepresence fill light required for a well-lit appearance was enough to cause discomfort glare. Thirty participants adjusted the output of two fill lights: one in front of them (focusing on discomfort) and one in front of the remote telepresence user (focusing on appearance). Ambient light levels (48-71 lux, 118-130 lux, 269-281 lux) and fill-light positions (top of display, 30.5 cm higher) were varied. For all conditions, the amount of light required to produce a pleasing portrayal was greater than that at the point of discomfort. The mean discomfort threshold was the same for all ambient light conditions (663.46 cd/m², 8.44 lux at 2.44 m), possibly because background luminance did not change enough. The amount of light that produced a well-lit appearance was about the same for dim and moderate ambient light (3,348.65 cd/m², 51.61 lux at 2.44 m) but lower for bright ambient light (1,204.47 cd/m², 17.81 lux at 2.44 m). Raising the light source did not affect discomfort but did require more light for a good portrayal. Technology providers should consider collocating the fill light with the display, limiting its luminance to 663.46 cd/m² for low-light environments similar to this research, and raising or lowering that limit as the background luminance changes.

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Chapter 1

INTRODUCTION

Telepresence technology delivers realistic face-to-face communication experiences in an immersive environment. It accomplishes this through high-definition video processing, surround-sound audio, high-bandwidth networks, and carefully controlled physical environments (Kelly & Davis, 2008). Many Fortune 1000 companies are using telepresence systems to reduce travel costs and improve collaboration, while universities and medical schools are using them for distance learning. As new models are introduced at lower price points, telepresence will likely extend its reach to public meeting places, as well as the home office or family room (Lichtman, 2006). But home living spaces are not dedicated telepresence environments and may experience changing lighting conditions throughout the day. This could make it challenging to portray a person well on video without some form of supplemental lighting. This research investigated the usefulness of a fill light to enhance the portrayal of home telepresence users, paying attention to factors that may disrupt their sense of presence (see Figure 1).

Presence, when not representing physical nearness, has been defined as the “the perceptual illusion of nonmediation” (Lombard & Ditton, 1997, p. 1), or “a psychological state in which the virtuality of experience is unnoticed” (Lee, 2004, p. 32). This means a person is not aware of the technology mediating or conveying their experience with the world. It is a high degree of presence that makes telepresence different from traditional video conferencing. With telepresence, the environment and technology are designed to

simulate a life-size, in-person experience. In a meeting context, attendees actually appear to be sitting at the same table (and in the same room) with people at the remote site. They can make eye contact, clearly see facial expressions, and hear voices coming from the direction people are sitting (Lichtman, 2006). Ultimately, they forget about the technology and focus on the human interaction. In corporations and institutions, this sense of presence is largely due to the achievement of carefully controlled environments. The room layout, interior design, acoustics, and lighting are built to detailed specifications, and the technology is hidden as much as possible (Kelly & Davis, 2008). As Lombard and Ditton (1997) noted, for the illusion of presence, “the user should not

Figure 1. A photo of a participant in a simulated home family room. The participant is communicating with the moderator of the research in another room through telepresence. An adjustable fill light above the telepresence display may help produce a well-lit portrayal. But glare from such a light could disrupt the user’s feeling of presence.

see edges of displays, speakers, microphones, measurement devices, keyboards, controls, or lights” (p. 1). Focusing attention on these elements will likely dispel the illusion.

Portrayal, or how a person is presented to another, is also important in video-mediated communication. When viewing a mediated face, our natural in-person “judgements of identity, emotion, social behavior, attention and intention” (Chatting & Thorne, 2006, p. 3) can change based on how the video image portrays size, color, luminance differences, orientation, and other characteristics (Chatting & Thorne, 2006; Russell, 2002). As a result, video conference participants have received less favorable ratings or impressions compared to in-person attendees (Fullwood, 2007; Storck & Sproull, 1995). Good participant lighting is crucial to video-based communication, as it enables people to clearly see the features of the face. “Facial expression and body language are important conveyors of information, so good facial modeling helps people communicate more effectively. Flattering facial lighting also allows participants to feel more confident and enhances their visual presence to the remote audience” (IESNA, 2005, p. 11). Unflattering views and poor lighting have led to dissatisfaction with self-portrayal in casual home video conferencing (Chatting, Galpin, & Donath, 2006). Telepresence users are presented in high-definition video, which may increase their concern over self-appearance.

Lighting is one way to solve the problem of portrayal. Theaters, film and television studios create elaborate lighting arrangements that not only present a person well but convey a sense of composition and mood (Brown, 2008; London & Upton,

1998). Although actors on television may appear perfectly lit, what one at a distance does not see are the numerous light sources pointing at subjects in the studio. According to Brown (2008), a complex scene may have a *key light* (providing primary shape and form), a *fill light* (softening the shadows), a *back light* (to highlight the hair), a *kicker* (to define the side shape), an *eye light* (to lighten the eye sockets), and a *set light* (for the background or stage). The *ambient light* (either natural or artificial from a bounce) is also a part of the equation (Brown, 2008; IESNA, 2000). For video conferencing, it is typical to see a simpler three-point lighting system that consists of a key light, fill light and *background light*, which is similar to a set light (IESNA, 2005). Figure 2 represents a diagram of this lighting arrangement.

Lighting is used in video conferencing to deliver not just a quality portrayal but also a quality video image. If there is not enough light in the scene, the video image is filled with *noise* and appears grainy. Without a proper fill light, direct lighting from the ceiling can create harsh shadows in the eye sockets or below the chin. And if there are too many levels of contrast in the scene, the video image can appear saturated with areas of solid color and no detail (IESNA, 2005; IESNA, 2000). Unfortunately, “lighting that is designed for maximum visual comfort and minimal glare does not always lend itself well to the lighting requirements for high-quality camera images” (IESNA, 2000, p. 11-14).

In the home environment, it may be challenging to deliver an experience of presence and a quality portrayal at the same time. In a corporate environment, the

Figure 2. A typical lighting setup for video conferencing. Three types of lights are used: a key light, fill light, and background light (IESNA, 2005). The lights are placed above and to either side of the participant at 45° angles.

lighting arrangement can often be carefully designed to portray people well in a non-disruptive manner. But in the home office or family room, it is less likely that money will be spent to re-shape the environment to foster this sense of presence. Unlike the business setting, “the home cannot typically provide dedicated spaces, lighting, furniture and equipment for video conferencing. These systems must coexist with the many

demands made of the space, especially in the family living room” (Chatting, Galpin, & Donath, 2006, p. 395).

To ensure a person is well-lit in the home, a telepresence solution will need to work with existing windows and *luminaires* (self-contained lighting units), which can vary by configuration (floor lamps, table lamps, recessed downlights, track lighting, wall sconces), by lamp type (fluorescent, compact fluorescent, and incandescent filaments including tungsten and halogen), and by color temperature (IESNA, 2000). In addition, light in the room changes throughout the day and night. As the earth moves about the sun, the angle and amount of sunlight coming in through windows changes, potentially causing back-lit or side-lit situations (IESNA, 2000; London & Upton, 1998). If there is low natural light, the interior luminaires may be turned on or off in a variety of combinations, often based on personal preference. This results in highly variable ambient light levels and characteristics, with potentially low light situations in the evening. It is at this time that residents will be home from work or school and most likely to communicate with family and friends.

To account for changing lighting conditions in the home environment, one approach is for a telepresence solution to provide a supplemental fill light to reduce harsh shadows on the face, from either side-lit, back-lit, or top-lit situations (London & Upton, 1998). In the case of very low ambient light levels, this supplemental light may even become the primary light source. With this approach, the key light and background light are assumed to come from other light sources in the room, such as lamps or windows.

Because the source of directional lighting can vary by location and time of day, a centered placement of the fill light provides the most flexibility. This centered placement is a common position for corporate telepresence systems. Figure 3 represents a diagram of the single fill-light arrangement, where a window provides directional lighting (similar to a key light) and causes the participant to be side-lit. Other lamps in the room and reflected light function as the background light.

Figure 3. A lighting setup with a single fill light. This arrangement would help fill the shadows in side-lit, back-lit, or top-lit situations. A centered placement allows the light to work with directional light from different sources. In this example, directional light is coming from the left window, and ambient light serves as the background light.

An alternative approach may be to provide both a key light and fill light, emulating the three-point lighting system found in many studios and well-designed video conference rooms. With this approach, the background light is assumed to come from other sources in the room. The key and fill lights would do more than just compensate for low or directional lighting. Their positioning would result in a higher quality portrayal by providing more depth to the facial features. Figure 4 represents a diagram of this lighting arrangement.

With either approach, there is great variability in how the lights could be designed and placed. However, a common element would likely be the presence of a fill light coming generally from the direction of the telepresence display, as that is where people will be facing. Packaging the fill light and camera as a single unit may be more cost effective to manufacture and simpler for users to setup. As a consequence, the fill light would be closer to the participant's line of sight than the 45° recommended for video conferencing (IESNA, 2005). While this supplemental lighting may be a step toward better portrayal, it has the potential to disrupt any feelings of presence by creating glare.

Glare is generally defined as “hindrance to vision by too much light” (Vos, 2003b). One type of glare is caused by having too much light in the field of view, such as outside on a sunny day, which triggers a “photophobic response, in which the observer squints, blinks, or looks away” (IESNA, 2000, p. 3-29). Another type of glare is caused when a light source in the field of view exceeds a certain threshold of relative luminance,

Figure 4. A lighting setup with a key light and fill light. This arrangement would help fill the shadows, but also provide better shape and depth to facial features. In this example, ambient light serves as the background light.

which may reduce visual performance (disability glare), or produce a feeling of discomfort (discomfort glare) (CIE, 1983).

Disability glare is caused by light scattered in the cornea, lens and optical fundus of the eye and is more pronounced by age, eye pigmentation, and the angle of entry (Vos, 2003a). It results in a “luminous veil over the retinal image of adjacent parts of the scene, thereby reducing the luminance contrasts of the image of those parts on the

retina” (Boyce, 2003, p. 170). As a result, vision is disabled to some degree, and objects in the field of view may not be seen. Common examples are high-beam headlights from a car at night, driving toward the sun when it is low on the horizon, or approaching a dark tunnel entrance on a sunny day (the bright sky is the glare source, obscuring visibility within the tunnel).

Discomfort glare may be caused by fluctuations in pupil size or distraction from lights (Boyce, 2003). It is a “sensation of annoyance or pain caused by high luminances in the field of view” (IESNA, 2000, chap. 3, p. 30) and is affected by background luminance, source luminance, solid angle, angle from line of sight, and time (Vos, 2003b; CIE, 1983). Common examples are working at a desk in a relatively dim environment with a directly visible light source in the peripheral vision, or working at a computer with a bright window behind the display.

Researchers have defined a number of formulae to predict or assess the discomfort glare sensation within an environment (CIE, 1983). The *Unified Glare Rating (UGR)* formula was designed by the Commission Internationale de l’Eclairage (CIE) in 1995 to have “the best parts of the major formulae in terms of practicability and of familiarity with the results of glare prediction” (CIE, 1995, p. v). The glare rating produced by the formula is a “psychological parameter intended to measure any adverse subjective discomfort response to a visual environment containing light sources” (CIE, 1995, p. 6). The higher the UGR value, the greater the discomfort. The practical range of UGR values is from 10 to 30, with values below 10 considered to not produce

discomfort (CIE, 1995). A difference of one UGR value is the least-detectable difference in glare sensation. Figure 5 shows the components of the UGR formula that affect the sensation of discomfort glare. Boyce (2003) summarized their effects as follows:

Increasing the luminance of the glare source, increasing the solid angle of the glare source, decreasing the luminance of the background, and decreasing the deviation of the glare source from the line of sight will all increase the glare sensation. Changes of each component in the opposite direction will decrease the glare sensation. In practice, the components interact. (p. 172)

Figure 5. An example scene showing the components of the UGR formula. Discomfort glare is affected by the luminance of the light (L), the luminance of the background (L_b), the solid angle of the light (ω), and the position index of the light (P), which represents the angles from the vertical (α) and the line of sight (β).

Some have critiqued the usefulness and accuracy of the UGR for large-area glare sources and windows (Kim, Ahn, & Kim, 2008; Osterhaus, 2005; Kim & Koga, 2004; Osterhaus & Bailey, 1992), and for adding up the glare from multiple sources (Akashi, Muramatsu, & Kanaya, 1996). However, the UGR formula is well suited for predicting glare in interior environments with electrical lighting, such as in this experiment. And it has been found to correlate well with subjective ratings of discomfort glare (Akashi et al., 1996).

There are numerous studies of discomfort glare in the context of interior working environments (Helland et al., 2008; Boyce, 2005; Hedge, McCrobie, & Corbett, 1996; CIE, 1995; CIE 1983), in regards to large-area light sources such as windows (Kim, Ahn, & Kim, 2008; Osterhaus, 2005; Kim & Koga, 2004; Osterhaus & Bailey, 1992), and while driving in a vehicle (Lockhart, Atsumi, & Ghosh, 2004; Murray, Plainis, & Carden, 2002; Sivak, Flannagan, Traube, & Kojima, 1999). However, research on the effects of glare in a telepresence or video conferencing context, where the fill light is relatively close to the user's focal point for an extended period of time, has not been previously investigated.

Problem Statement

The purpose of this experiment was to determine the point at which a telepresence fill light produced discomfort glare, as well as the point at which it sufficiently filled the shadows of another person's face, as judged by participants. These thresholds were investigated for different amounts of ambient light in the room and for different vertical placements of a fill light. The main question was whether the amount of fill light

required to produce a pleasing portrayal was enough to cause discomfort glare for the participants.

Hypotheses

The following null hypotheses were tested for this experiment:

1. Light height will not affect discomfort threshold.
2. Light height will not affect required fill level.
3. Ambient light will not affect discomfort threshold.
4. Ambient light will not affect required fill level.
5. Light height and ambient light will not affect discomfort threshold.
6. Light height and ambient light will not affect required fill level.

The hypotheses related to discomfort threshold were based on an understanding of the relation between the variables in the UGR formula.

Definition of Terms

Light height. The independent variable light height (low, high) was the height of a fill light source placed either directly on top of a display or slightly above it.

Ambient light. The independent variable ambient light (dim, moderate, bright) was the average illuminance in the room produced by one of three combinations of floor and ceiling lamps.

Discomfort threshold. The dependent variable discomfort threshold was the participant-controlled voltage that produced a fill-light luminance judged to be on the border of comfort and discomfort.

Required fill level. The dependent variable required fill level was the participant-controlled voltage that produced an illuminance judged to sufficiently fill the shadows of a remote telepresence user's face.

Importance of the Study

Understanding the effect of a telepresence fill light on discomfort glare and appearance may help inform the design of telepresence solutions by technology providers. If light height has an effect on discomfort threshold, then it may suggest that a fill light source be placed further away from the display to maximize user comfort. On the other hand, if there is no significant difference, then it would allow a fill light to be collocated with the display. This may be more affordable from a manufacturing perspective and may be simpler for a user to setup in their home. However, if light height has an effect on required fill level, then it may require that the light source be close to the display to function as a fill light and avoid casting shadows.

If ambient light has an effect on discomfort threshold, then it may suggest a limit to fill light output for specific levels of room illuminance or background luminance. Even if there is no significant difference, the mean discomfort threshold could be used as a general limit for lighting situations similar to those in this experiment. Enforcing this limit in a product would maximize user comfort and ensure a quality user experience. If ambient light has an effect on required fill level, then the fill light output required to produce a well-lit appearance would be known for specific levels of room illuminance. Even if there is no significant difference, the mean required fill level could be used as a

reference point for lighting situations similar to those in this experiment. Understanding these illuminance requirements would help design an effective fill light that portrays users well and scores high in user satisfaction.

Even more insight can be gained by looking at the relation between discomfort threshold and required fill level in different ambient light conditions (see Figure 6). For situations where discomfort threshold is lower than required fill level, it would be wise to stop the fill light output at the discomfort threshold. This would avoid an uncomfortable experience and preserve the user's sense of presence. For situations where discomfort

Figure 6. A hypothetical relationship between dependent variables. If the required fill level is greater than the discomfort threshold in dim ambient light, then that region should be avoided.

threshold is higher than required fill level, there would be no conflict and fill light output could go up to the required level for a good appearance. By identifying the lowest point that is reached first for each ambient light condition, a target illumination range can be identified for the fill light. This knowledge would help select and design an economical fill light: one that operates within the required range but does not go outside of it and introduce discomfort glare.

Chapter 2

REVIEW OF LITERATURE

While searching the published literature, no past studies were found on glare in the context of telepresence or video conferencing. Therefore, literature was reviewed for the individual topics of presence, portrayal, and glare. Articles were selected if the subject matter was relevant to the context of use in this research.

Presence

Lombard and Ditton (1997) surveyed the literature and identified six conceptualizations of presence: social richness, realism, transportation, immersion, social actor within medium, and medium as social actor. Social richness refers to the level of intimacy and immediacy of the communication experience. Realism refers to the accuracy of the mediated representation in relation to the known world. Transportation refers to how well an experience provides a sense of being in another place, or how well it makes objects from another place appear to be local. Immersion refers to how well the senses perceive the virtual world to be reality and how well the mediating technology is hidden. Social actor within medium refers to how well a virtual entity is believed to be a real human or life form. And medium as social actor relates to how well the medium itself is viewed as a real entity. Based on their analysis, Lombard and Ditton (1997) proposed an all-encompassing definition of presence as “the perceptual illusion of nonmediation” (p. 5).

Lee (2004) also surveyed the literature and proposed a similar definition of presence. Although initially defined as “a psychological state in which the virtuality of experience is unnoticed” (p. 32), this was later revised as a result of the explication process to “a psychological state in which virtual objects are experienced as actual objects in either sensory or nonsensory ways” (p. 1). Lee identified three types of presence: physical, social, and self. Physical presence relates to experiences with virtual objects, such as in teleoperation, where robotics enable interaction with a remote environment. Social presence relates to experiences with virtual representations of people, such as during video conferencing. And self presence relates to the experience of one’s self in a simulated environment, such as when exploring an interactive virtual world.

Telepresence falls under Lombard and Ditton’s (1997) conceptualization of presence as transportation and Lee’s (2004) categorization of presence as social. Telepresence has been defined by Muhlbach, Bocker, and Prussog (1995) as “the degree to which participants of a telemeeting get the impression of sharing space with interlocutors who are at a remote physical site” (p. 301). Similarly, Kelly and Davis (2008) defined telepresence as a “two-way immersive communications experience that simulates an in-person, interactive encounter” (p. 2). Telepresence is differentiated from traditional video conferencing by high-quality spatial audio, high-definition video, life-size images, a simple user experience, high reliability, and carefully controlled environments designed to merge two rooms together (Kelly & Davis, 2008). Regarding

the origin of the term, Draper, Kaber, and Usher (1998) suggest that the “compound construction of ‘tele’ and ‘presence’ also seems to capture the idea of projection into a distant environment” (p. 354).

A number of researchers have investigated the factors that differentiate telepresence from video conferencing. Muhlbach et al. (1995) found that stereoscopic video enhanced participants’ sense of spatial presence, and that large eye contact angles reduced recognition of nonverbal cues during communication. However, Suwita, Bocker, Muhlbach, and Runde (1997) found that wearing special glasses for stereoscopic video was disturbing to participants. Wearing any type of mediating technology might result in a low sense of presence, based on Lombard and Ditton’s (2007) definition of presence as the “illusion of nonmediation” (p. 1).

Suwita et al. (1997) found that a life-size representation facilitated the formation of interpersonal impressions, and that high-definition video displays helped with the recognition of facial expressions and mood. Both of these characteristics are key selling points for telepresence today (Lichtman, 2006; Kelly & Davis, 2008). Yamaashi, Cooperstock, Narine, and Buxton (1996) investigated the use of two displays for telepresence communication. A large wide-angle display was provided to support peripheral vision, and this was linked with a smaller detailed display to support foveal vision. Direct selection of a region in the larger view automatically updated the smaller view. In a letter recognition task, conditions where the displays were linked had less

camera operations and faster completion times compared to conditions requiring pan, tilt, and zoom camera actions.

Portrayal

A few studies have explored the human factors of portrayal in the context of video-mediated communication. Chatting, Galpin, and Donath (2006) investigated the conflict between presence and portrayal in casual home video conferencing. Home users are often not satisfied with their appearance due to loss of eye contact, unflattering views and poor lighting. Chatting et al. (2006) explored ways of enhancing home video conferencing images to increase user satisfaction. They found that a blurred background was more preferred over the raw video image or one with a cartoon-like background. However, both the raw video and blurred background tended to score higher than the cartoon on presence ratings.

Shi, Yu, Li, and Li (2004) created software to compensate for poor lighting in desktop video conferencing by manipulating raw video camera images. Their system detected human faces by looking for common skin tone patterns and then applied exposure and contrast adjustments. Liu, Zhang, and Zhang (2007) created a similar system that was based on a target profile of 400 celebrity images, referencing various different skin tones. Their system adjusted not only the brightness of the images but also the color tone. Participants rated the converted video images as higher quality than the raw video images.

Chatting and Thorne (2006) stated that when viewing a mediated face, our natural in-person “judgements of identity, emotion, social behavior, attention and intention” (p. 3) can change based on how the video image conveys size, color, luminance differences, orientation, and other characteristics. Russell (2002) found that changing the luminance differences between different parts of the face affected attractiveness. Participants rated females more attractive when they had greater luminance differences between the eyes, mouth, and the rest of the face. Males were rated more attractive when they had less luminance differences. Nass, Kim, and Lee (1998) investigated how people responded to verbal feedback from their own video image, or from another person’s video image. They found that participants who saw their own face cared more about how they appeared to others, felt more responsible for the evaluations, and perceived the feedback as more valid. Chatting, Galpin, and Donath (2006) also found that participants rated the idea of being able to control their own appearance very appealing and important.

There is evidence that video conference participants received less favorable ratings or impressions compared to in-person meeting participants. Fullwood (2007) had participants engage in an imaginary mind-reading exercise to encourage interpersonal interaction. The video-mediated participants were rated as less likable and intelligent, possibly due to distortion of nonverbal signals and lack of direct eye contact. Similarly, Storck and Sproull (1995) conducted a longitudinal study of graduate students working together on a course project. They found that although performance did not change between remote and in-person participants, the impressions of remote participants were

less positive. While “desirable to work with” ratings increased over the study for in-person participants, they decreased for the remote participants appearing only on video.

Discomfort Glare

Discomfort glare in the context of interior working environments has been studied by a number of researchers. In a longitudinal study, Helland et al. (2008) found that computer workers reported worse lighting and glare, and greater visual discomfort, after moving from single offices to a shared environment with large windows. The glare sensation was possibly due to the high luminance of windows with Venetian blinds, which were not correctly adjusted. Hedge, McCrobie, and Corbett (1996) looked at the effects of a computer screen glare filter on reducing glare and specular reflections, and found that it improved both display quality and visual health.

A few studies have been done on large-area glare sources such as windows. In a survey of office workers, Osterhaus (2005) found that most preferred daylight over electric lighting, and rated their office window as highly important. However, Osterhaus found that existing discomfort glare prediction methods were not useful when dealing with large windows. Kim and Koga (2004) looked at discomfort glare in the presence of windows, and found that the glare sensation was determined more by the immediate background luminance, rather than the average background luminance. Kim, Ahn, and Kim (2008) investigated simulated windows with uniform and non-uniform surface luminance, such as would occur with a view of an obstructed sky. They found that participants rated discomfort glare higher for uniform compared to non-uniform

windows, when their average luminance was the same. Osterhaus and Bailey (1992) looked at the effects of large area glare sources on computer users doing a letter-counting task. Similar to the current research, participants adjusted the luminance of a large glare source to different target thresholds. They found that participants preferred a luminance from the surrounding glare source of 25 cd/m², in comparison to a display luminance of 12.5 cd/m².

Driving a vehicle is another context in which discomfort glare has been investigated. Lockhart, Atsumi, and Ghosh (2004) had young and old participants perform a driving simulation in daytime and nighttime conditions. Elderly participants had less visual acuity and experienced more glare than younger participants. Most discomfort glare studies have participants rate their discomfort for a particular lighting situation, or require them to adjust the brightness of a light to some threshold. With both methods, there is a judgement call made by the participant. Murray, Plainis, and Carden (2002) investigated a more objective approach, and created a new device called the ocular stress monitor. It measured the electrical activity from muscle contractions around the eye when exposed to a glare source, and was found to predict subjective ratings of glare during a driving simulation. Sivak, Flannagan, Traube, and Kojima (1999) looked at discomfort glare while driving at night for people with and without corrected vision. They found that duration and illuminance of the glare source both had an effect on reported discomfort glare. Discomfort glare was found to be about the same with and without glasses or contact lenses.

Chapter 3

METHOD

The purpose of this experiment was to determine the point at which a telepresence fill light produced discomfort glare (discomfort threshold), as well as the point at which it sufficiently filled the shadows of another person's face (required fill level), as judged by participants. These thresholds were investigated for different amounts of ambient light in the room (dim, moderate, bright) and for different vertical placements of a fill light (low, high). The main question was whether the amount of fill light required to produce a pleasing portrayal was enough to cause discomfort glare for the participants.

The research was conducted in two simulated home family rooms: one for the participant and one for the moderator of the test session. Each room had a telepresence system with an adjustable fill light. The participant controlled both fill lights with two dimmer switches, but only the moderator saw the voltage levels. A telepresence session was started between the two rooms, which allowed the participant and moderator to see and hear each other. After some initial preparation, the moderator adjusted the amount of ambient light in each room. For each ambient light condition, participants adjusted the moderator's fill light until they judged it produced a well-lit appearance. They then adjusted their own fill light (starting with the light off) until they felt a sense of discomfort. After a brief conversation, they were asked if they felt the need to lower the light. They then made a second adjustment (starting with the light on high) until they felt a sense comfort. At the end of the session, participants completed a survey.

Participants

There were a total of 30 participants in this study: 23 males and 7 females. Participants were between the ages of 22 and 53 years, with a mean age of 37.3 years. Based on a screening process, they had no corrective vision (contact lenses or eye glasses), no eye-related medical problems, and no previous eye surgery (for example, laser-assisted in situ keratomileusis, or LASIK). Most had brown eyes, had never or rarely used telepresence, and had no or very little experience with lighting. See Appendix M for distributions of participant age, gender, eye color, telepresence experience, and lighting experience.

Human Subjects Institutional Review Board approval was obtained from San Jose State University in October of 2008 (see Appendix A). Participants were asked to voluntarily sign a consent form at the start of the study (see Appendix B). They were assigned a unique identifier to remain anonymous and all data were kept confidential.

Recruiting

Participants were drawn from a population of over 11,000 employees at a technology company in San Jose, California. Assuming a 10% response rate, 1,000 names were randomly selected using simple random sampling from a subset of the company's employee list: employees working in San Jose. E-mail messages were sent to each randomly selected employee, inviting them to participate and describing the purpose of the study. To encourage participation, employees were told that participants would be entered into a raffle for one of three iPod Shuffle portable music players (1GB, \$49 each).

They were told they could withdraw from the study at any time but would not be entered into the raffle without full attendance and a complete set of data.

Screening

The e-mail message directed employees to complete an online survey if they were interested in participating (see Appendices C and D). The survey was constructed using the WebEffective tool from Keynote Systems. It screened people based on their age (must be between the ages of 18 and 55 years), corrective vision (must not use eye glasses or contact lenses), and eye problems (must have healthy eyes and no surgery, including LASIK). It also asked for demographics, familiarity with telepresence, familiarity with lighting (either photography or video), and eye color.

The screening criteria or survey questions were selected for the following reasons:

1. Age was a screening criterion because most people over 60 years are unable to effectively change the accommodation of their eyes and require correction (IESNA, 2000). Although this research was focused on discomfort glare, disability glare has been found to increase rapidly over the age of 60 years (Vos, 2003a).
2. Eye color was not a screening criterion but was a survey question so that its effects could be identified if needed. Light blue eyes have been found to be more sensitive to disability glare when the glare source is at a large angle (Vos, 2003a).
3. Corrective vision was a screening criterion because eye glasses and contact lenses can be a source of light scatter. As a result, a number of studies on discomfort glare have

excluded (or explicitly focused on) people with corrected vision (Sivak, Flannagan, Traube, & Kojima, 1999; Murray, 2002; Kim, Ahn, & Kim, 2008).

Group Assignment

Of the 94 people that responded to the survey, 36 people were selected as possible participants based on the screening criteria. Of the 36 possible participants, 30 random names were assigned to one of two groups based on random assignment: 15 in the high light height group and 15 in the low light height group. They were contacted by e-mail and phone to schedule the initial session. The remaining six participants were kept on standby and randomly replaced participants that had to drop out of the study.

Design

This experiment was a mixed factorial design with two independent factors: a between-groups factor and a within-group factor. The independent variable light height was a between-groups factor with two levels (low, high). The independent variable ambient light was a within-group factor with three levels (dim, moderate, bright). There were 15 participants in each light height group. This produced a two-by-three factorial design with six conditions (see Figure 7). Two dependent variables were directly measured in each condition: discomfort threshold and required fill level. After random assignment to one of the two groups, participants worked under each level of ambient light (counterbalanced to produce a different sequence), with all dependent variable measurements occurring in each ambient light condition (see Figure 8).

		Ambient Light Within-Group					
		Dim		Moderate		Bright	
Light Height Between-Groups	Low	p1	p9	p1	p9	p1	p9
		p2	p10	p2	p10	p2	p10
		p3	p11	p3	p11	p3	p11
		p4	p12	p4	p12	p4	p12
		p5	p13	p5	p13	p5	p13
		p6	p14	p6	p14	p6	p14
		p7	p15	p7	p15	p7	p15
		p8		p8		p8	
	High	p16	p24	p16	p24	p16	p24
		p17	p25	p17	p25	p17	p25
		p18	p26	p18	p26	p18	p26
		p19	p27	p19	p27	p19	p27
		p20	p28	p20	p28	p20	p28
		p21	p29	p21	p29	p21	p29
		p22	p30	p22	p30	p22	p30
		p23		p23		p23	

Figure 7. Participant allocation in the experimental design. Light height was a between-groups factor, with 15 participants in each group. All 30 participants experienced all three levels of ambient light, a within-group factor.

Group Assignment		Dim Ambient Light		Moderate Ambient Light		Bright Ambient Light	
Low Light Height	R	X_1	$O_{1,2}$	X_2	$O_{1,2}$	X_3	$O_{1,2}$
High Light Height	R	X_1	$O_{1,2}$	X_2	$O_{1,2}$	X_3	$O_{1,2}$

Figure 8. The experimental design over time. Participants were randomly assigned (R) to two groups. They then received three counterbalanced treatments (X) of ambient light. After each treatment, observations (O) were made of discomfort threshold and required fill level.

Independent Variables

The low level of light height consisted of a long horizontal lamp placed directly on top of the telepresence display. For the participant, this was 26.04 cm above their focal point on the display (where the moderator's eyes were located). This produced an angle of 8.72° above the line of sight. The high level consisted of the same fill light source placed 30.48 cm higher, for an angle of 15.53° above the participant's line of sight. This angle is part of the position index for the glare source, which is a component of the UGR formula used to predict discomfort glare. See Table 1 for a summary of the light height factor level differences between the participant and moderator rooms.

Table 1

Light Height Factor Level Definitions

Light Height Level	Distance Above Focal Point	Angle Above Line of Sight
Participant Room		
High	56.52 cm	15.53°
Low	26.04 cm	8.72°
Moderator Room		
High	59.06 cm	16.44°
Low	28.58 cm	9.64°

Note. Distance was measured from the physical environment. Angle was modeled in a computer program.

Table 2 shows a summary of the ambient light factor level differences. The dim level of ambient light consisted of an arrangement of floor and ceiling lamps turned on to produce a low level of average horizontal room illuminance and vertical illuminance at the eye, and a high maximum possible glare. The moderate and bright levels increased the average horizontal room illuminance and vertical illuminance at the eye, and decreased the maximum possible glare. This research investigated low light situations, therefore the illuminance values were kept intentionally low. Although there were differences in the illuminance of the participant and moderator rooms, the most equivalent settings were selected for the factor levels.

Dependent Variables

Discomfort threshold was the amount of voltage displayed on a multimeter after a participant adjusted a dimmer switch (controlling the fill light in front of them) until they perceived the luminance to be on the border of comfort and discomfort. For each ambient light level, participants made two measurements while focusing on the moderator's eyes. Starting with the light in an off position, participants were instructed to adjust the light up until it was "just uncomfortable, without going into the uncomfortable region." Starting with the light in a fully on position, participants were instructed to adjust the light down until it was "just comfortable." To help with their assessment, participants were asked to imagine having the light at that luminance for a five-minute telepresence conversation. The starting position was counterbalanced across different sessions and within each participant's session. Average discomfort threshold

Table 2

Ambient Light Factor Level Definitions

	Average	Vertical	Indirect		Local
Factor	Horizontal	Illuminance	Illuminance	Background	Background
Level	Illuminance ^a	at Eye ^b	at Eye ^c	Luminance ^d	Luminance ^e
Participant Room					
Dim	48 lux	19 lux	12 lux	3.82 cd/m ²	6.10 cd/m ²
Moderate	118 lux	33 lux	23 lux	7.32 cd/m ²	8.14 cd/m ²
Bright	269 lux	140 lux	32 lux	10.19 cd/m ²	12.36 cd/m ²
Moderator Room ^f					
Dim	71 lux	24 lux	—	—	—
Moderate	130 lux	39 lux	—	—	—
Bright	281 lux	206 lux	—	—	—

Note. For all measurements, an illuminance meter with cosine-corrected photodisc was used. The fill light was off, but the display, floor lamps, and front ceiling light were on at their respective settings.

^aMeasured with the illuminance meter oriented horizontally on a tripod 0.76 m above floor. Readings from the center of six equal grid squares were averaged (IESNA, 2000).

^bMeasured with the illuminance meter oriented vertically on a tripod 1.14 m high in the position of the person's eyes facing the display (Cuttle, 2008). Represents direct and indirect illuminance.

^cMeasured with the illuminance meter in the same vertical orientation. Direct views of the floor lamps and front ceiling light were blocked with cardboard shields (Cuttle, 2008). Represents indirect illuminance.

^dDerived by dividing indirect illuminance at the eye (in lux) by pi (CIE, 1995).

^eApproximated by measuring luminance of display (average of six grid-based readings), luminance of wall around display, and luminance of furniture below display. Luminance values were weighted based on their size in relation to 0.5 sr around focal point (0.24 for display, 0.60 for wall, 0.16 for furniture). Past research found the sensation of glare to be primarily affected by local background luminance (Kim & Koga, 2004).

^fDiscomfort glare was not evaluated in the moderator room, so some measurements are not provided.

was computed as the average of the two readings, forming a third set of data. The intention was to find the mid-point between the two up and down settings, which might be influenced by the direction of movement or the eye's response to the initial fill light luminance (either off, or on high). Participants were given clear definitions on the meaning of "just uncomfortable" in relation to other values on a discomfort glare scale.

Required fill level was the amount of voltage displayed on a multimeter after a participant adjusted a dimmer switch (controlling a second fill light in front of the moderator, who they saw on the telepresence display in front of them) to a level that illuminated the moderator's face and upper body enough to sufficiently fill in the shadows and produce a well-lit, pleasing portrayal. This was a subjective judgement call, and intentionally so, as it can help determine user expectations for facial illumination. Participants were given an overview of how a fill light worked, and given definitions for "well lit" in comparison to "over lit" and "under lit."

Materials

Room Layout

The research was conducted in two rooms that had been decorated like home family rooms. The general layout of the research equipment within these rooms is shown in Figures 9, 10, and 11. Curtains were drawn across all windows to block out the effect of daylight. Each room had two banks of recessed ceiling lights and four three-way floor lamps. Although the rooms were similar, they were not identical. They differed in size,

Figure 9. The distance between the participant and moderator rooms. See Figures 10 and 11 for larger views of the two rooms.

paint color, and decorations. The light settings that corresponded to the levels of each ambient light factor were made as similar as possible.

Each room had a pre-installed telepresence system placed by one of the walls. In the participant room, it was mounted on the wall and oriented at an angle. In the moderator room, it was placed on top of a piece of furniture and oriented vertically straight. On either side of the display were wooden stands with adjustable shelf brackets. These were used to place the fill light at the appropriate height. A multimeter was attached to each fill light to measure voltage. Both multimeters were connected to the moderator's laptop with USB cables and a USB-to-ethernet extension that ran through an

Figure 10. The participant room layout for the research. In front of the participant was a control box with two dimmer switches: one to control the fill light in this room, and one to control the fill light in the moderator's room. The scale is approximate.

Figure 11. The moderator room layout for the research. In front of the moderator was a laptop showing the voltage readings of two fill lights: one in front of the participant, and one in front of the moderator. The scale is approximate.

intervening room. A table and seat were placed 2.42 m away from the display in each room. Both the participant and moderator were situated with their eyes about 2.42 m from the focal point of the display and about 1.14 m high. In the participant room, a control box was placed on the table that had two dimmer switches. One controlled the fill light in front of the participant and one controlled the fill light in front of the moderator in the other room. Next to the dimmer switches were the relevant scales: a discomfort glare scale for the participant's fill light, and an appearance scale for the moderator's fill light. Power lines ran from this control box to both fill lights (one cable was run through an intervening room). In the moderator room, a laptop was placed on the table, along with a script, schedule, and the discomfort glare scale. The laptop was running software that logged and showed the voltage levels (as recorded by the multimeters) for each light as the participant made their adjustments throughout the session. Dependent variables were recorded on the laptop using SAS JMP software.

Room Cross-Section

Illustrated in figures 12 and 13 are cross-sections of the participant and moderator rooms as they were setup for this experiment. Both the participant and moderator are shown sitting on the edge of a couch. The participant is facing a wall-mounted telepresence display that is 2.42 m away, while the moderator is facing a table-top mounted display that is 2.43 m away. Both the participant's and moderator's eyes are 1.14 m above the floor and focused approximately 0.22 m down from the top of the display (0.66 or two thirds the vertical height of 0.65 m) at the eyes of the other

Figure 12. Distances and angles for the fill light positions. Cross-sections illustrate (a) the participant room and (b) the moderator room.

Figure 13. Distances and angles for the ceiling and floor lamp positions. Cross-sections illustrate (a) the participant room and (b) the moderator room. For the floor lamp, α is the angle from the vertical, and β is the angle from the line of sight.

telepresence user. The participant's line of sight has a greater upward angle due to the pre-existing wall mount. In the low light height condition, the fill light is placed directly on top of the display, or approximately 26.04 cm (28.58 cm in the moderator room) above the focal point on the display, for an angle of 8.72° (9.64° in the moderator room) above the line of sight. In the high light height condition, it is placed 30.48 cm higher, for an angle of 15.53° (16.44° in the moderator room) above the line of sight. There are a number of other dimensions outlined in these diagrams, such as the distance and angles of the fill light, floor lamps, and ceiling lights. The visible dimensions of the lights are outlined in Figure 14. All of these values were factored into the UGR formula (see Figure 15) to predict discomfort glare for the different room configurations. Maximum possible UGR values are shown in Table 3, with the calculation details in Appendix H.

Ambient Lighting

The three levels (dim, moderate, bright) of the ambient light factor had to be well-defined for each room. To determine which combination of floor lamps and ceiling lights

Ceiling Light

Fill Light

Floor Lamp

Figure 14. Dimensions of the visible glare sources used to calculate UGR values.

Brightness
of background

Brightness, size,
and position of lights

$$UGR = 8 \log_{10} \left(\frac{0.25}{L_b} \right) \sum_i \frac{L_i^2 \omega_i}{P_i^2}$$

L_b = luminance of the field of view, in cd/m²,
not including luminair luminance,
 L = luminance of a luminaire in the direction
of the observer,
 ω = solid angle of a luminaire subtended to the
observer,
 P = position index of luminaire.

Figure 15. An explanation of the Unified Glare Rating (UGR) formula. This equation is adapted from IESNA (2000).

produced an equivalent amount of room illumination, the following steps were taken.

Each room was measured and divided into a three-by-three grid of nine squares. The recessed ceiling lights were then set to the lowest level, and the average horizontal room illuminance was calculated by placing an illuminance meter in the center of each grid square, oriented horizontally 0.76 m above the floor on a tripod. Nine measurements were taken to cover the grid and an average was computed. This was done for each room, for all seven dimming levels of the recessed ceiling lights.

During this exercise, the front ceiling light was found to be a large source of direct illuminance in the participant's field of view. This was subjectively identified as a competing glare source and a possible confound. The moderator room was also observed to be generally brighter, due to the lighter paint color and a greater illuminance from the

Table 3

Maximum Possible UGR Values for Participant Room

Ambient Light Factor Level	Maximum Possible UGR (Fill, Floor, Ceiling) ^a	Maximum Possible UGR (Fill, Floor) ^b	Maximum Possible UGR (Fill Only) ^c
Low Light Height			
Dim	32.83	32.83	32.78
Moderate	30.64	30.64	30.52
Bright	30.17	29.57	29.37
High Light Height			
Dim	30.58	30.58	30.48
Moderate	28.45	28.45	28.22
Bright	28.48	27.44	27.07

Note. Maximum possible UGR represents the maximum possible glare sensation for each experimental condition. For these calculations, the fill light was on maximum (22.5 V, 4,731.66 cd/m²), settings for the floor lamps and ceiling lights changed with each ambient light condition, and the front ceiling light was only on in the bright condition.

^aUGR values based on calculations that sum the glare from the fill light, the two front floor lamps, and the front ceiling light.

^bUGR values based on calculations that sum the glare from the fill light and the two front floor lamps.

^cUGR values based on calculations of the glare from the fill light alone.

recessed ceiling lights at their lowest level (compared to the same setting in the participant room). In response to this, eight 1.85-m Mainstays floor lamps (see Figure 16) with three-way rotary switches were purchased. These were placed two on each side of the participant and moderator, with the intention of keeping the front ceiling light off except for the bright level of the ambient light factor. Satco S7342 compact fluorescent light bulbs with three-way settings (12 W, 20 W, and 26 W) were purchased for use in the floor lamps. The color temperature of the light bulbs was 4,100° K, which was the best

Figure 16. Photos showing (a) the recessed ceiling lights and (b) floor lamps. The two ceiling lights had 4,000° K fluorescent tubes, and the four floor lamps had 4,100° K compact fluorescent bulbs. Different combinations of light switch settings were used to set the room to the appropriate ambient light factor levels.

match to the 4,000° K temperature of the ceiling lights and the approximately 4,500° K temperature of the Light Emitting Diodes (LEDs) used in the fill light. With this new lighting environment setup, another round of measurements were made with different combinations of the ceiling lights and floor lamps.

In addition to average horizontal room illuminance, vertical illuminance at the eye was calculated for each configuration. This represents the amount of light reaching the participant's or moderator's eyes from both direct and indirect sources (floor lamps, ceiling light, and display, but not the fill light). Vertical illuminance was measured by orienting the illuminance meter vertically on a tripod at a height of 1.14 m, with the sensor facing forward 2.42 m from the display. For the participant room, the indirect vertical illuminance at the eye was also measured by blocking direct light from the light sources with cardboard cut-outs (Cuttle, 2008). Background luminance was derived from this value by dividing by pi (CIE, 1995). Background luminance is a component of the UGR formula used to predict discomfort glare. After performing these additional measurements, the most equivalent settings (factoring in both horizontal and vertical illuminance) were identified as the ambient light factor levels (see Table 4).

Telepresence Systems

The telepresence systems used in this research were already installed in the rooms, with approximately 1.32-m plasma displays tuned to a color temperature of 4,000° K. The cameras produce an optimal picture with 300-400 lux of vertical illuminance on the person's face. Given that the dim and moderate ambient light factor

Table 4

Ambient Light Luminaire Settings

	Average	Vertical	Front	Rear	Four
Factor	Horizontal	Illuminance	Ceiling	Ceiling	Floor
Level	Illuminance ^a	at Eye ^b	Light	Light	Lamps
Participant Room					
Dim	48 lux	19 lux	Off	Position 1	12 W
Moderate	118 lux	33 lux	Off	Position 4	20 W
Bright	269 lux	140 lux	Position 3	Position 6	26 W
Moderator Room					
Dim	71 lux	24 lux	Off	Position 1	12 W
Moderate	130 lux	39 lux	Off	Position 2(3)	20 W
Bright	281 lux	206 lux	Position 1	Position 4	26 W

Note. For all measurements, an illuminance meter with cosine-corrected photodisc was used. The fill light was off, but the display, floor lamps, and front ceiling light were on at their respective settings.

^aMeasured with the illuminance meter oriented horizontally on a tripod 0.76 m above floor. Readings from the center of six equal grid squares were averaged (IESNA, 2000).

^bMeasured with the illuminance meter oriented vertically on a tripod 1.14 m high in the position of the person's eyes facing the display (Cuttle, 2008). Represents direct and indirect illuminance.

levels far were below this range, the picture quality in those conditions was reduced. In those conditions, the image of the moderator on the participant's display was slightly pixelated and dim. However, the details of the moderator's face and upper body (and the effects of the fill light) could still be seen by the participant. Because the displays were different, the image of the participant was darker than the image of the moderator in the dim and moderate conditions. The room with the best picture quality in dim light was chosen for the participant.

Variable Fill Light

A variable fill light prototype was created to give the user control of the light output for both of the telepresence systems (see Figures 17 and 18). A number of iterations were made to improve the size, brightness, and color temperature of the light. When viewed from the front, the final light fixture was 1.21 m wide by 0.17 m high. The visible light source seen by participants was approximately 1.21 m wide by 0.10 m high. A curved reflector was created by cutting a piece of 0.15-m white PVC pipe in half. To make the light brighter, a sheet of Furukawa MCPET reflective material was ordered, which has a 99% reflectance (96% diffused). This flexible sheet was sanded slightly to produce a matte surface, and cut to fit over the interior of the curved piece of PVC. A wooden frame was created to hold the reflector upright, provide an angled surface to point the Light Emitting Diodes (LEDs) at the reflector, and shield the LEDs from the participant's direct view. The LED light source was four 1.02-m bars of "LED Dimmable Undercabinet Light (Neutral White)" (11 W, 376 lumens, 4,500° K, 110° viewing angle,

48 LEDs/bar, 2.08-cm LED spacing, 24 V DC). The power supply (60 W, 12-24 V DC) was paired with a Leviton magnetic dimmer. All of the LED parts and equipment were ordered from EnvironmentalLights.com. Due to time constraints on the final iteration of the fill light, the wooden frame was not redesigned to house the LED light bars, which

Figure 17. A photo of the telepresence system with fill light and stands. This example shows the fill light on maximum, at low light height, as seen in the participant room. The display shows a view of the moderator room.

were substantially thicker than the original LED flexible ribbon. The light bars were taped together to form a curve, and this was placed on top of the wooden frame and pointed at the reflector. The final prototype was substantially brighter than earlier versions, with an average maximum luminance of $4,731.66 \text{ cd/m}^2$, an average maximum illuminance of 76.38 lux at 2.42 m , and a maximum possible UGR of 32.78 for the participant in the low light height condition.

(a)

(b)

Figure 18. Photos showing side views of the variable fill light. The light is shown (a) with the power off, and (b) with the power on. The color temperature is $4,500^\circ \text{ K}$.

Control Box

The power supply and dimmer switch required electrical wiring and were designed to be mounted inside or on a building surface. A wooden control box was constructed to house both of the power supplies (one for the participant light and one for the moderator light). Holes were drilled on the sides to allow for ventilation, a handle was added to make it easy to carry, and the dimmer switches were mounted on the top surface (see Figure 19). Participants used one dimmer switch to adjust the light in front of them to the borderline of discomfort, and the other dimmer switch to adjust the light in front of the moderator to the point that produced a well-lit, pleasing appearance. To reduce the chance of the discomfort glare dimmer switch settings having an impact on the appearance dimmer switch settings (or vice versa), the switches were given different vertical orientations and mounted in opposing corners on the box surface (one was in the lower left corner, one was in the upper right corner). There were no markings on the dimmer switches.

Multimeters

Two V&A VA18B digital multimeters with USB interfaces were purchased to record the voltage across the light as the discomfort threshold and required fill level dependent variables (see Figure 20). The multimeters came with PC-Link software for Windows, which allowed the readings on the multimeter to be sent over a USB cable to a computer, where they were displayed in real time, logged and charted. Multimeter test leads tapped the positive and negative power wires at their point of entry into the first

Figure 19. A photo of the control box surface as seen by the participant. The “My Light” switch on the left controls the participant’s light and is associated with the discomfort glare scale. The “Remote Light” switch on the right controls the moderator’s light and is associated with the appearance scale. All scales are oriented in a compatible direction with their switches. To reduce the chance of one setting influencing the other, one switch was flipped and mounted in the opposite corner.

LED light bar (four of the 1.02-m LED light bars were chained together in total). The battery-powered multimeters were placed next to the fill light behind the telepresence display, where they were outside the participant’s field of view. In the participant’s room, a USB cable then ran to a USB-to-ethernet extension, which allowed the USB data to travel the large distance between the participant and moderator rooms. At the other end of this extension, another USB cable continued the connection to the moderator’s laptop. This enabled the moderator to see the voltage readings on the participant’s light in the other room in real time. In the moderator’s room, a USB extension cable connected the

Figure 20. The multimeter, test leads, and software display. Photos show (a) the multimeter with USB connection on top and test leads below, and (b) the tap points on the fill light for the test leads. Also shown is (c) a screen shot of the software that logged and charted the multimeter voltage readings in real time.

other multimeter to the laptop. The net result is that the moderator had two instances of the PC-Link software running, one showing the data from the participant's fill light, and one showing the data from the moderator's fill light (both of which were controlled by the participant in the other room). The dependent variables were read from this display and recorded in JMP.

Voltage Correlations

Voltage was chosen as the primary measure for the discomfort threshold and required fill level dependent variables for two reasons. First, it was more affordable to purchase two multimeters than two illuminance/luminance meters (it would have been impractical to run back and forth between each room with only one). And second, the USB connections and software enabled the readings to appear on the moderator's laptop in real time where they could be quietly logged without the participant's awareness. The alternative would have been to run between rooms to get the readings, or ask the participant to verbalize them, which would have biased their results. Although volts were recorded and used for statistical calculations, the attributes of real interest were the luminance (or brightness) of the light and the illuminance (or amount of light being cast) on a person 2.42 m away.

To ensure voltage had a strong correlation to luminance and illuminance, a series of voltage readings were taken while observing the luminance and illuminance values on a light meter. Appendix J shows the setup used to take these measurements. A Spectra Cine Candela II-A illuminance meter (see Figure 21) with a one-degree spot attachment

was purchased and calibrated to U.S. National Institute of Standards Technology (NIST) standards representing the human photopic response. The certification for this calibration is shown in Appendix I. For luminance measurements, the light meter was mounted on a tripod (1.14 m high, 2.42 m away, the same position as the participant's eyes) with the one-degree spot attachment aimed at the center of the fill light. The light was in a low light height position for these measurements, as preliminary tests showed no change in luminance for the high light height position while using the one-degree spot attachment. Starting from an off position, the dimmer switch was slowly moved up, and luminance readings (in footlamberts) were taken at every 0.5-V increment. Upon reaching the maximum setting for the light, the same readings were taken while moving the dimmer switch down. This entire sequence was done two more times. An analysis of bivariate

Figure 21. Photos of the light meter. A Spectra Cine Candela II-A illuminance meter is shown (a) with cosine-corrected photo disc, and (b) with one-degree spot attachment.

association in JMP produced a near-perfect positive Pearson correlation of 0.99 ($p = < .0001$, $N = 298$). See Appendix J for a plot of this data. A linear line of best fit was drawn, as well as one based on a four-degree polynomial. The equations for these lines were used to create a luminance predictor unique to this experimental setup (based on the input voltage, it estimates the footlamberts). See Appendix J for the equations.

For illuminance measurements, the light meter with a cosine-corrected photodisc was mounted on a tripod (1.14 m high, 2.42 m away) and pointed at the focal point on the telepresence display. Rounds of measurements were taken with the fill light in both the low and high light height positions. The same measurement procedure was used, but this time illuminance readings (in lux) were taken at every 0.5-V increment. An analysis of bivariate association in JMP produced a near-perfect positive Pearson correlation of 0.99 ($p = < .0001$, $N = 384$). A plot of the correlation data is shown in Appendix J. Two distinct lines can be seen in this chart, for the low and high light height readings. Because the lines did not have the same slope, an analysis of covariance (ANCOVA) was not possible without some type of data transformation. In lieu of this, a simple t-test was performed to compare the data values comprising each line (readings of “0” and missing values were first discarded). The low light height readings had a mean of 39.44 lux, and the high light height readings had a mean of 36.07 lux. No significant difference was found with this analysis, $t(334) = 1.41$, $p = .16$. However, Appendix J summarizes the differences in average illumination readings between the low and high light heights, which range from 1.13 to 6.5 lux over the 15.00 to 23.00 V range. There is clearly less

light reaching the participant and moderator as the power is increased in the high light height condition. Two linear lines of best fit were drawn, and the equations for these lines were used to create an illuminance predictor unique to this experimental setup (based on the input voltage, it estimates the lux for both high and low light heights). The equations for these lines are shown in Appendix J.

Discomfort Glare Scale

In this experiment, participants were asked to adjust the fill light in front of them to the borderline between comfort and discomfort. If starting with the fill light off, this would be the point that it becomes “just uncomfortable” (without going into the uncomfortable region) as they slide the dimmer switch up. If starting with the fill light on high, this would be the point that it becomes “just comfortable” as they slide the dimmer switch down. This transition point corresponds to the “just acceptable” (5) level of the 9-point de Boer discomfort glare scale (de Boer, 1967). To help participants understand how this relates to the wide range of glare experiences, the discomfort glare scale was explained to participants at the beginning of the session, and they had a copy of it on the table in front of them (see Figure 22).

Appearance Scale

Participants were also asked to adjust the remote fill light to the point that it produced a “well lit, pleasing portrayal” of the moderator, as viewed on the telepresence display in front of them. An appearance scale was created to guide their assessment (see Figure 23). In the middle of the scale, a “well-lit” assessment was given a score of five

Scale Value	Qualifier	Adjusting from "Off"	Adjusting from "On High"
1	Just noticeable		Comfortable region
2			
3	Satisfactory		
4			
5	Just acceptable	"Just uncomfortable"	"Just comfortable"
6		Uncomfortable region	
7	Disturbing		
8			
9	Unbearable		

Figure 22. The discomfort glare scale. A modified de Boer (1967) discomfort glare scale provided a reference to participants as they adjusted the fill light. The scale was oriented to be compatible with the dimmer switch on the control box.

Scale Value	Qualifier	Criteria
1	Very over-lit	Washed out, large hot spots, narrow tonal range
3	Slightly over-lit	Some hot spots, limited tonal range
5	Well-lit	Wide tonal range, no harsh shadows, no hot spots
3	Slightly under-lit	Some harsh shadows, limited tonal range
1	Very under-lit	Very dark, no detail, narrow tonal range

Figure 23. The appearance scale. An appearance scale was created to help guide participants in identifying a "well-lit" portrayal. The scale values represent point totals (not levels), and were not used in any analysis. The scale was oriented to be compatible with the dimmer switch on the control box.

and described as having a “wide tonal range, no harsh shadows, no hot spots.” This is followed by “slightly over-lit” and “slightly under-lit” having scores of three, and “very over-lit” and “very under-lit” having scores of one. These different conditions were explained to the participants at the start of the session.

Procedure

Each participant was scheduled for a one-hour session. After the introductory activities, the participant and moderator were in different locations during most of the session (see Figure 24). Each participant experienced all three levels of ambient light in a counterbalanced manner. In addition, there were two readings of discomfort threshold for each ambient light level. One went in an upward direction (starting with the light off), and one went in a downward direction (starting with the light on high). The starting direction of these measurements was also counterbalanced, and then alternated back and forth across all ambient light levels for that participant. To simplify the administration of

Figure 24. The location of the participant and moderator during the research. Ambient light conditions were counterbalanced for each participant.

this procedure to each participant, a number of schedules were created (see Appendix E), along with a detailed script (see Appendix F).

Preparation

Before the participant arrived, the moderator set the room lighting in both rooms to the moderate ambient light level. A new telepresence session was started if there was not already one established between the two rooms. If the telepresence fill light heights had to be changed, the moderator moved them to the appropriate positions on the light stands. Both of the fill lights were turned off. In the participant room, a new video tape was inserted into the high-definition video camera, and two copies of the consent form were placed on the table with a pen. In the moderator room, the multimeter log files were reset on the laptop, and a new entry was created for the participant in the moderator's data log. Participants were contacted by phone or instant message to confirm their attendance, and provided with instructions on how to access the lab. Because the moderator was the subject for the required fill level measurements, the same grey shirt was worn to each session. In addition, oil and perspiration were cleaned from the moderator's face before participants arrived.

Introduction (22 minutes)

Participants were greeted at the door, given a high-level description of the purpose of the study, and asked to read and sign the consent form. The moderator then adjusted the participant's seat height so that their eyes were 1.14 m above the floor. Participants were given instructions on how to communicate through the telepresence system, and

shown how to adjust the fill light controls (for both their light, and the moderator's light).

The moderator explained the discomfort glare and appearance scales, and gave the participants a chance to get familiar with the controls before the actual measurements.

Ambient Light: Dim (10 minutes)

Each participant experienced all three levels of ambient light (dim, moderate, bright) according to the counterbalanced sequence in their assigned schedule. The following five steps occurred during this 10-minute interval:

1. *Set Ambient Light Level (1 minute)*. For each ambient light level, the moderator set the room lights in both rooms to the appropriate levels. He then sat down before the telepresence display in the moderator's room with a previously adjusted seat height.
2. *Measure Required Fill Level (2 minutes)*. The moderator then directed the participant to turn their fill light labeled "My Light" off (if it was already on) by sliding the dimmer switch to the off position. He then asked them to use the other dimmer switch to adjust the moderator's fill light, labeled "Remote Light," to a level that produced a "well-lit, pleasing portrayal." The participant was allowed to adjust the light repeatedly until they were satisfied with the setting, at which point they said they were done. Upon hearing this, the moderator noted the voltage level displayed in the multimeter software running on the laptop (which only he could see). This value was then recorded as the dependent variable in the JMP data log. By having the participants adjust the fill light on the moderator first, it allowed their eyes to adapt to the ambient room lighting before making the discomfort threshold measurements.

3. *Measure Discomfort Threshold Up (2 minutes)*. The moderator then instructed the participant to turn the remote light off, and to turn the fill light in front of him or her to either the off or fully on position, depending on the counterbalanced schedule. If adjusting up from an off position, the participant was asked to focus on the moderator's face while adjusting the fill light to the point it became "just uncomfortable (without going into the uncomfortable region)." If adjusting down from a fully on position, the participant was asked to adjust the light to the point it became "just comfortable." During this, participants were allowed to reference the printed discomfort glare scale on the control box. They were allowed to adjust the light repeatedly until they were satisfied with the setting, at which point they said they were done. Upon hearing this, the moderator noted the voltage level displayed on the laptop, and recorded it as the dependent variable in the JMP data log. See Figure 25 for a photo of this part of the session.
4. *Conversation and Question (3 minutes)*. After the first discomfort threshold measurement, the moderator had a brief, casual discussion with the participant for about three minutes. The purpose of this was to have the participant experience a real telepresence conversation with the light in their field of view. At the end of the conversation, the moderator asked the participant if they felt the need to adjust the light lower, and their response was recorded.
5. *Measure Discomfort Threshold Down (2 minutes)*. The moderator then asked the participant to make another discomfort threshold measurement but with a starting

Figure 25. A photo showing a session in progress in the participant room. The experimental equipment is highlighted. The participant is looking at the eyes of the moderator, who is visible on the telepresence display. At the same time, the participant is using the control box to adjust the brightness of the fill light in front of him to a level perceived as just uncomfortable.

position opposite that of the first measurement. The same process was followed, and this second voltage level was recorded in the JMP data log.

Ambient Light: Moderate (10 minutes)

The same process repeated for a second counterbalanced condition (not necessarily in this order).

Ambient Light: Bright (10 minutes)

The same process repeated for a third counterbalanced condition (not necessarily in this order).

Wrap-up (8 minutes)

When measurements were obtained for all three ambient light conditions, the moderator sat next to the participant and asked them to complete a post-test survey. He then asked them if they had any questions, indicated when he would be following up with them, thanked them for their help, and escorted them out the door.

Analysis

All data were analyzed using SAS JMP 7, SPSS Statistics 17, and Minitab 15 software for redundant verification. Before evaluating the hypotheses, a few calculations were required to produce additional data sets. An average discomfort threshold data set was created by averaging the up and down values for each participant. Descriptive statistics were then calculated. For the overall analysis, mixed within-subjects factorial ANOVAs ($\alpha = .05$) were run to identify significant main or interaction effects for the levels of each factor on each dependent variable: average discomfort threshold, discomfort threshold up, discomfort threshold down, and required fill level.

The hypotheses were tested as follows:

1. Light height will not affect discomfort threshold.

Analysis: Two-way ANOVAs ($\alpha = .05$) on average discomfort threshold, discomfort threshold up, and discomfort threshold down. Look for main effects for light height.

Reject H_{01} if $p < .05$. Compare means for direction.

2. Light height will not affect required fill level.

Analysis: Two-way ANOVA ($\alpha = .05$) on required fill level. Look for main effects for light height. Reject H_{02} if $p < .05$. Compare means for direction.

3. Ambient light will not affect discomfort threshold.

Analysis: Two-way ANOVAs ($\alpha = .05$) on average discomfort threshold, discomfort threshold up, and discomfort threshold down. Look for main effects for ambient light. Reject H_{03} if $p < .05$. Conduct planned comparisons between dim and moderate, moderate and bright, and dim and bright. Compare means for direction.

4. Ambient light will not affect required fill level.

Analysis: Two-way ANOVA ($\alpha = .05$) on required fill level. Look for main effects for ambient light. Reject H_{04} if $p < .05$. Conduct planned comparisons between dim and moderate, moderate and bright, and dim and bright. Compare means for direction.

5. Light height and ambient light will not affect discomfort threshold.

Analysis: Two-way ANOVAs ($\alpha = .05$) on average discomfort threshold, discomfort threshold up, and discomfort threshold down. Look for interaction effects. Reject H_{05} if $p < .05$.

6. Light height and ambient light will not affect required fill level.

Analysis: Two-way ANOVA ($\alpha = .05$) on required fill level. Look for interaction effects. Reject H_{06} if $p < .05$.

Chapter 4

RESULTS

Participant data can be found in Appendix G. Descriptive statistics were calculated for each dependent variable: discomfort threshold up, discomfort threshold down, average discomfort threshold, and required fill level. Mixed within-subjects factorial ANOVAs ($\alpha = .05$) were then conducted to identify significant main effects, interaction effects, and planned comparisons. The stated hypotheses were evaluated based on these results.

Descriptive Statistics

The distributions of each dependent variable (see Figures 26 through 28) were examined for shape and the presence of outliers that might affect the statistical analysis. Means, standard deviations, and sample sizes are summarized in Tables 5 through 8.

Discomfort Threshold

All of the discomfort threshold distributions (up, down, and average) were positively skewed, with more low values than high values. They also exhibited positive kurtosis, with taller peaks. Shapiro-Wilk goodness-of-fit tests on discomfort threshold up ($W = 0.85, p = < .0001$), discomfort threshold down ($W = 0.87, p = < .0001$), and average discomfort threshold ($W = 0.90, p = < .0001$) showed the distributions were not normally distributed.

There were five outliers in the discomfort threshold down distribution and three in the discomfort threshold up distribution. Four participants are associated with these

Figure 26. Discomfort threshold distributions. Histograms show the counts of participant voltage settings for each 0.5-V range for all values ($N = 90$) of (a) discomfort threshold up, (b) discomfort threshold down, and (c) average discomfort threshold.

Figure 27. Required fill level distribution. A histogram shows the counts of participant voltage settings for each 0.5-V range for all values ($N = 90$) of required fill level.

outliers: P8, P17, P19, P31. A review of participant attributes showed no commonality other than very little experience with lighting. They had different genders, ages, and eye colors, and had sessions at different days and times. Five of eight outliers represented the first experimental condition in the participant's counterbalanced session schedule.

Removing participants with outlier data points reduced the skewness and means but did not result in a normally distributed distribution. Without a compelling reason to remove the outliers, they were included in statistical analysis.

The difference between each participant's discomfort threshold down and up settings for the same ambient light condition was calculated (see Figure 29). The mean difference was 0.44 V with a standard deviation of 1.78. The maximum difference was 4.97 V, which represents discomfort threshold down being greater than the up direction. The minimum difference was -3.07, which represents discomfort threshold down being less than the up direction.

Figure 28. Discomfort threshold and required fill level factorial distributions. Histograms are shown for each factorial condition ($n = 15$) of (a) average discomfort threshold, and (b) required fill level. Unlike the average discomfort threshold distributions, there are shifting means and shapes in the required fill level distributions. There is also evidence of a possible ceiling effect in the dim-high and moderate-high conditions.

Figure 29. Distribution of discomfort threshold down and up differences. A histogram shows the differences between discomfort threshold down and up settings in the same ambient light condition for each participant ($N = 90$). The mean difference is 0.44 V.

Required Fill Level

Unlike the discomfort threshold distributions, required fill level clearly had different peaks that might be representative of the experimental manipulations. In addition, a possible ceiling effect was found in the dim-high and moderate-high conditions, most likely due to participants turning the light on maximum.

There were three outliers in the dim-low distribution. Three participants are associated with these outliers: P14, P20, P29. A review of participant attributes showed no commonality other than brown eyes. They had different genders, ages, experiences, session schedules, session dates, and session times. Given the subjective nature of the required fill level measurement, the outliers may be due to individual differences in judgement or interpretation of instructions. Without a compelling reason to remove the outliers, they were included in statistical analysis.

Table 5

Discomfort Threshold Up

Factor Level	Mean	Standard Deviation	Sample Size
Grand Mean			
	13.67 V	1.16	90
Ambient Light			
Dim	13.70 V	1.26	30
Moderate	13.68 V	1.20	30
Bright	13.64 V	1.03	30
Light Height			
High	13.72 V	1.34	45
Low	13.62 V	0.96	45
Factorial Combinations			
Dim – Low	13.63 V	1.01	15
Dim – High	13.76 V	1.51	15
Moderate – Low	13.50 V	0.75	15
Moderate – High	13.86 V	1.54	15
Bright – Low	13.74 V	1.13	15
Bright – High	13.54 V	0.95	15

Table 6

Discomfort Threshold Down

Factor Level	Mean	Standard Deviation	Sample Size
Grand Mean			
	14.11 V	1.48	90
Ambient Light			
Dim	14.18 V	1.44	30
Moderate	14.07 V	1.71	30
Bright	14.08 V	1.31	30
Light Height			
High	14.09 V	1.52	45
Low	14.13 V	1.45	45
Factorial Combinations			
Dim – Low	14.33 V	1.37	15
Dim – High	14.03 V	1.54	15
Moderate – Low	13.92 V	1.64	15
Moderate – High	14.22 V	1.82	15
Bright – Low	14.14 V	1.40	15
Bright – High	14.01 V	1.26	15

Table 7

Average Discomfort Threshold

Factor Level	Mean	Standard Deviation	Sample Size
Grand Mean			
	13.89 V	1.19	90
Ambient Light			
Dim	13.94 V	1.20	30
Moderate	13.87 V	1.36	30
Bright	13.86 V	1.03	30
Light Height			
High	13.90 V	1.31	45
Low	13.88 V	1.07	45
Factorial Combinations			
Dim – Low	13.98 V	1.10	15
Dim – High	13.90 V	1.33	15
Moderate – Low	13.71 V	1.05	15
Moderate – High	14.04 V	1.63	15
Bright – Low	13.94 V	1.10	15
Bright – High	13.77 V	0.98	15

Note. Average discomfort threshold was calculated by averaging discomfort threshold up and down values for each participant in each experimental condition, resulting in a new data set. It represents the mid-point between a participant's discomfort threshold up and down settings.

Table 8

Required Fill Level

Factor Level	Mean	Standard Deviation	Sample Size
Grand Mean			
	18.12 V	3.35	90
Ambient Light			
Dim	19.78 V	2.36	30
Moderate	19.45 V	2.56	30
Bright	15.13 V	2.90	30
Light Height			
High	18.98 V	3.22	45
Low	17.26 V	3.28	45
Factorial Combinations			
Dim – Low	18.85 V	2.85	15
Dim – High	20.70 V	1.22	15
Moderate – Low	18.22 V	2.70	15
Moderate – High	20.68 V	1.74	15
Bright – Low	14.72 V	2.81	15
Bright – High	15.54 V	3.02	15

Unified Glare Rating

UGR values were calculated for the voltage settings made by participants in each experimental condition (see Figure 30 and Table 9). The UGR values represent the predicted glare sensation for the participant's entire field of view. The UGR formula takes into account the brightness of the fill light (based on the participant's setting), the height of the fill light (based on the participant's group), and the background luminance (based on the ambient light condition for that measurement). Therefore, the distribution of UGR values should be centered around the rating that best represents the borderline of comfort and discomfort.

The UGR values were calculated using three different models. One model sums the glare from the fill light, the two front floor lamps, and the front ceiling light. A second model sums the glare from the fill light and the two front floor lamps. And a third model factors in glare from just the fill light alone. Two peaks appeared in the distribution for the first model, which included the ceiling light. The presence of two peaks might suggest two different glare sensation targets. This does not fit the protocol of the experiment, as all users were instructed to find the border between comfort and discomfort. The second peak disappeared when the ceiling light was not factored into the glare sensation. This suggests that the ceiling light (only on during bright ambient light) was not a factor when participants assessed their discomfort threshold. Without the ceiling light, the mean UGR for all the participant discomfort threshold settings is 20.57. This is about halfway between the 10 to 30 practical range of UGR values.

Figure 30. Distribution of Unified Glare Ratings (UGR). A histogram shows the distribution of calculated UGR values for all discomfort threshold settings across all experimental conditions ($N = 180$). The mean is 20.57, which is about halfway between the 10 to 30 practical range. UGR calculations did not include glare from the ceiling light. Including the ceiling light created a second peak of all the values in the bright ambient light condition. Because this would represent a second target for participants other than the borderline of comfort and discomfort, it suggests the ceiling light did not affect the participant's glare sensation in this experiment.

Table 9

UGR Calculations of Discomfort Threshold

Lights in UGR Model	Mean	Standard Deviation	Sample Size
Fill, Floor, Ceiling ^a	22.06	2.69	180
Fill, Floor ^b	20.57	1.85	180
Fill ^c	14.77	5.36	180

Note. Calculations were made using three different glare source models, to see which lights may be affecting the participant's sensation of glare.

^aRepresents the sum of the glare from the fill light, two front floor lamps, and front ceiling light.

^bRepresents the sum of the glare from the fill light and two front floor lamps (no ceiling light).

^cRepresents the sum of the glare from the fill light only.

Desire to Change Discomfort Threshold

After chatting for three minutes with the fill light at their initial discomfort threshold setting, participants said they felt the need to adjust the light lower in 16 out of 90 measurement conditions (17.78%). When the second discomfort threshold setting was made in the opposite direction, 13 of 16 voltage readings (81.25%) were lower than the first. So most of the participants that said they felt the need to adjust the light lower actually did so. The mean difference was -0.81 V, which suggests that even though they lowered their discomfort setting, it was not by a large amount.

Analysis of Variance

Mixed within-subjects factorial ANOVAs were conducted to identify significant main or interaction effects on each dependent variable: discomfort threshold up, discomfort threshold down, average discomfort threshold, and required fill level. Planned comparisons were made between all permutations of the ambient light factor levels for each dependent variable. Because the means appeared different, a post-hoc t-test was run between discomfort threshold up and discomfort threshold down. An alpha level of .05 was used for all statistical tests.

Discomfort Threshold

No significant effects were found for discomfort threshold up, discomfort threshold down, or average discomfort threshold. Summaries of the ANOVAs are shown in Tables 10 through 12, and plots of the means are shown in Figures 31 through 33.

Starting Position and Discomfort Threshold

A post-hoc t-test on discomfort threshold up ($M = 13.67$ V, $N = 90$) and discomfort threshold down ($M = 14.11$ V, $N = 90$) revealed a significant difference for starting position, $t(178) = 2.20$, $p = .03$.

Required Fill Level

Significant effects were found for required fill level. The ambient light by light height interaction was not significant. However, the main effect of light height was significant, $F(1,28) = 5.94$, $p = .02$. The main effect of ambient light was also significant, $F(2,56) = 54.60$, $p = < .0001$. Three planned contrasts were performed. Ambient light dim to moderate was not significant. However, ambient light dim to bright was significant, $F(1,56) = 87.63$, $p = < .0001$. And ambient light moderate to bright was also significant, $F(1,56) = 75.72$, $p = < .0001$. A summary of the ANOVA is shown in Table 13, and a plot of the means is shown in Figure 34.

Hypotheses Testing

Light Height and Discomfort Threshold

The H_{01} null hypothesis states that “Light height will not affect discomfort threshold.” No significant main effects were found for light height on discomfort threshold up, discomfort threshold down, or average discomfort threshold. Therefore, the hypothesis is accepted. The data do not support an effect of light height on discomfort threshold.

Figure 31. Discomfort threshold up plot of means.

Table 10

Discomfort Threshold Up Analysis of Variance

Source	<i>df</i>	<i>F</i>
Between Groups		
Light Height (LH)	1	0.07
Error	28	(2.83)
Within Group		
Ambient Light (AL)	2	0.04
LH X AL	2	0.88
AL Dim to Moderate	1	0.01
AL Dim to Bright	1	0.08
AL Moderate to Bright	1	0.03
Error	56	(0.68)

Note. Values enclosed in parentheses are mean square errors.

Figure 32. Discomfort threshold down plot of means.

Table 11

Discomfort Threshold Down Analysis of Variance

Source	<i>df</i>	<i>F</i>
Between Groups		
Light Height (LH)	1	0.01
Error	28	(5.46)
Within Group		
Ambient Light (AL)	2	0.17
LH X AL	2	1.02
AL Dim to Moderate	1	0.26
AL Dim to Bright	1	0.24
AL Moderate to Bright	1	0.001
Error	56	(0.72)

Note. Values enclosed in parentheses are mean square errors.

Figure 33. Average discomfort threshold plot of means.

Table 12

Average Discomfort Threshold Analysis of Variance

Source	<i>df</i>	<i>F</i>
Between Groups		
Light Height (LH)	1	0.004
Error	28	(3.56)
Within Group		
Ambient Light (AL)	2	0.13
LH X AL	2	1.20
AL Dim to Moderate	1	0.15
AL Dim to Bright	1	0.23
AL Moderate to Bright	1	0.01
Error	56	(0.45)

Note. Values enclosed in parentheses are mean square errors.

Figure 34. Required fill level plot of means.

Table 13

Required Fill Level Analysis of Variance

Source	df	F
Between Groups		
Light Height (LH)	1	5.94 *
Error	28	(11.11)
Within Group		
Ambient Light (AL)	2	54.60 **
LH X AL	2	1.39
AL Dim to Moderate	1	0.43
AL Dim to Bright	1	87.63 **
AL Moderate to Bright	1	75.72 **
Error	56	(3.69)

Note. Values enclosed in parentheses are mean square errors. * $p < .05$. ** $p < .01$.

Light Height and Required Fill Level

The H_{02} null hypothesis states that “Light height will not affect required fill level.” A significant main effect was found for light height on required fill level, $F(1,28) = 5.94, p = .02$. Therefore, we reject the null hypothesis, and conclude that there is an effect of light height on required fill level. A comparison of the means shows that low light height ($M = 17.26$ V, which correlates to 33.86 lux at 2.44 m) does indeed have a lower mean required fill level than high light height ($M = 18.98$ V, which correlates to 42.75 lux at 2.44 m).

Ambient Light and Discomfort Threshold

The H_{03} null hypothesis states that “Ambient light will not affect discomfort threshold.” No significant main effects were found for ambient light on discomfort threshold up, discomfort threshold down, or average discomfort threshold. Therefore, we cannot reject the null hypothesis. The data do not support an effect of ambient light on discomfort threshold.

Ambient Light and Required Fill Level

The H_{04} null hypothesis states that “Ambient light will not affect required fill level.” A significant main effect was found for ambient light on required fill level, $F(2,56) = 54.60, p = < .0001$. Therefore, we reject the null hypothesis, and conclude that there is an effect of ambient light on required fill level.

Planned contrasts revealed no significant difference between required fill level in dim and moderate ambient light. However, a significant difference was found between

required fill level in dim and bright ambient light, $F(1,56) = 87.63, p = < .0001$. A comparison of the means shows that dim ambient light ($M = 19.78$ V, which correlates to 52.87 lux at 2.44 m for low and 48.19 lux for high light height) does indeed have a higher mean required fill level than bright ambient light ($M = 15.13$ V, which correlates to 17.79 lux at 2.44 m for low and 16.52 lux for high light height).

A significant difference was also found between required fill level in moderate and bright ambient light, $F(1,56) = 75.72, p = < .0001$. A comparison of the means shows that moderate ambient light ($M = 19.45$ V, which correlates to 50.38 lux at 2.44 m for low and 45.95 lux for high light height) does indeed have a higher mean required fill level than bright ambient light ($M = 15.13$ V, which correlates to 17.79 lux at 2.44 m for low and 16.52 lux for high light height).

Light Height and Ambient Light on Discomfort Threshold

The H_{05} null hypothesis states that “Light height and ambient light will not affect discomfort threshold.” No significant interaction effects were found on discomfort threshold up, discomfort threshold down, or average discomfort threshold. Therefore, we cannot reject the null hypothesis. The data do not support an interaction effect on discomfort threshold.

Light Height and Ambient Light on Required Fill Level

The H_{06} null hypothesis states that “Light height and ambient light will not affect required fill level.” No significant interaction effects were found on required fill level.

Therefore, we cannot reject the null hypothesis. The data do not support an interaction effect on discomfort threshold.

Survey Results

In the post-test survey, 87% of the participants said the fill light had a positive effect on picture quality, and the rest were neutral. Most felt the dim and moderate ambient light conditions benefitted the most from the fill light. Regarding their personal experience, 53% said the fill light had a positive effect, 30% said they were neutral, and 17% said it had a negative effect. However, 83% said it was important for a telepresence product to have a fill light. Most participants said they wanted a fill light that automatically adjusted based on ambient light but still allowed them to manually control it. See Appendix L for more post-test survey results.

Chapter 5

DISCUSSION

In general, the results suggest that the factor levels of ambient light and light height were not different enough to produce significant effects on discomfort threshold. This may be due to the background luminance (relevant to the sensation of glare) not changing as much as the overall room illuminance. However, light height and ambient light did produce significant effects on required fill level. This may be because the amount of illumination on a face is directly affected by these factors. Ultimately, the results seem to support the idea of a conflict between presence and portrayal in low-light environments. Required fill level was greater than discomfort threshold in all conditions. Understanding the relationship between these variables has practical implications for product design.

Effects of Variables

Ambient Light and Discomfort Threshold

Changes in ambient light did not result in any significant differences among average discomfort threshold, discomfort threshold up, or discomfort threshold down. This is possibly due to the background luminance not being different enough between each ambient light condition. Changing the ambient light by adjusting the light settings in the room affects a number of properties: average horizontal illuminance at the task plane, vertical illuminance at the eye, indirect illuminance at the eye, and background luminance (see Table 14). But of all these, the property that directly impacts a person's

Table 14

Ambient Light in Participant Room and Discomfort Threshold

Factor	Average Horizontal Illuminance	Vertical Illuminance at Eye	Background Luminance	Local Background Luminance	Average Discomfort Threshold
Dim	48 lux	19 lux	3.82 cd/m ²	6.10 cd/m ²	13.94 V
Moderate	118 lux	33 lux	7.32 cd/m ²	8.14 cd/m ²	13.87 V
Bright	269 lux	140 lux	10.19 cd/m ²	12.36 cd/m ²	13.86 V

sensation of discomfort glare is the background luminance (Cuttle, 2008; Boyce, 2003).

It is the background luminance that is mostly responsible for the eye's adaptation, and to which the glare sources are contrast. Although there was a large change from dim to bright ambient light in average horizontal illuminance (48 to 269 lux) and vertical illuminance at the eye (19 to 140 lux), the background luminance did not change as much (3.82 to 10.19 cd/m²).

There is some evidence that the local background (within 0.5 steradian of the focal point) has more of an effect on discomfort glare than the average background luminance (Kim & Koga, 2004). In the experiment reported here, the local background consisted of the telepresence display, the wall paint surrounding the display, and the entertainment center below it. The luminance of these items was measured, multiplied by

the portion of 0.5 steradian they occupied, and then averaged to produce an estimate of local background luminance. Although the local background luminance was brighter than the average background luminance, the range of difference was about the same. The difference in background luminance from dim to bright is 6.37 cd/m^2 , while the difference in local background luminance is 6.26 cd/m^2 , which is slightly less but effectively equal. A greater difference in these levels might have produced a significant effect on discomfort glare.

For example, consider the participant room with the fill light in the low position set to 13.89 V, the grand mean of average discomfort threshold. The predicted glare sensation in UGR is 21.14 for dim ambient light, 20.46 for moderate, and 20.50 for bright (not counting glare from the ceiling light). The difference in UGR values between dim and bright is 0.68. However, the minimum noticeable difference in glare sensation is represented by an increment of one UGR value (CIE, 1995). So a difference of 0.68 is not likely to have an effect on discomfort threshold. But if the background luminance in the bright condition is increased from 10.19 cd/m^2 to 30 cd/m^2 , the UGR for bright ambient light would drop to 16.74 (a reduction in glare sensation). This produces a difference between dim and bright of 3.76 UGR values, which should be enough for a noticeable difference. If the participant's eyes adapt to this brighter background luminance, they might set the fill light voltage to a higher discomfort threshold.

Ambient Light and Required Fill Level

For required fill level, it may be that the differences between dim and moderate ambient light were also not large enough to produce a significant effect. However, bright ambient light was significantly different from both dim and moderate ambient light. Of all the properties affected by ambient light, the significant effects may be best explained by vertical illuminance at the eye. Vertical illuminance at the eye represents the amount of light reaching the participant's face in each ambient light condition (without the fill light). It increased by 14 lux from dim to moderate, but there was a 107-lux difference from moderate to bright. This latter increase is partly due to the front ceiling light being turned on in the bright ambient light condition.

Required fill level is the voltage that produced a well-lit, pleasing appearance of the moderator, as judged by the participant. If there was less light on the moderator's face for a particular ambient light condition, then more light would be required to reach the "well-lit" target. This means that required fill level would drop as vertical illuminance increased with each ambient light condition. This relationship is shown in Figure 35, which is a bivariate linear fit of vertical illuminance at the eye and mean required fill level for the moderator room. An analysis of bivariate association produced a near-perfect negative Pearson correlation of -0.99 ($p = .007$, $N = 3$). This strong correlation may explain why there was a significant difference between dim and bright, between moderate and bright, but not between dim and moderate light.

Figure 35. Bivariate fit of vertical illuminance at the eye and mean required fill level. Plotted points represent dim, moderate, and bright ambient light.

Light Height and Discomfort Threshold

When looking at the effects of light source height, no significant effects were found in discomfort threshold. With the fill light in the low position (8.72° above the line of sight) at 13.89 V, the UGR values are 21.14 for dim ambient light, 20.46 for moderate, and 20.50 for bright (not counting glare from the ceiling light). With the fill light in the high position (15.53° above the line of sight) at the same voltage, the UGR values are 20.04 for dim ambient light, 19.80 for moderate, and 20.04 for bright. The only

difference that is greater than one UGR value is the dim condition. Raising the light source higher to 30° above the line of sight would produce approximate UGR values of 18.82 for dim ambient light, 19.17 for moderate, and 19.64 for bright light. Although it is more of a difference, it still is less than one in some conditions. It may be that a larger change in height or angle would produce a significant effect. However, it may also be that height of the light source does not have as great an effect on discomfort glare as some other components of the UGR formula.

Light Height and Required Fill Level

Light height did have a significant effect on required fill level. The voltage-to-illuminance correlation revealed a gradually increasing drop in lux between low and high light height. The 17.26 V mean for low light source height corresponds to about 33.86 lux at 2.44 m. However, that same amount of voltage for high light height would produce about 31.03 lux (less illuminance), based on the equations for lines of best fit. Similarly, the 18.98 V mean for high light height corresponds to about 42.75 lux at 2.44 m. However, that same amount of voltage for low light source height would produce about 46.83 lux (more illuminance). It is important to note that for high light height, the larger angle makes it harder to fill a person's shadows (for example, under the chin). It might create shadows if the light were bright enough and at a high enough angle. A few participants made comments during their session that they could not fill the shadows or could not cast enough light onto the moderator when they were in the high light height condition.

Starting Position and Discomfort Threshold

A significant difference was found between discomfort threshold up and discomfort threshold down. These variables represent the different starting positions of the dimmer switch (either off or fully on) when the participants made their two discomfort threshold measurements. The mean of discomfort threshold down was higher than the mean of discomfort threshold up. This is possibly the result of three factors. First, when participants turned their fill light up to its brightest setting, their eyes adapted to the increased light. This adaptation to the bright light in front of them would affect their perceived threshold of discomfort. Second, different instructions were given to the participants. When moving up (starting from an off position), participants were told to set the light to the “point at which it becomes just uncomfortable, without going into the uncomfortable region.” When moving down (starting from a fully on position), participants were told to set the light to the “point at which it becomes just comfortable.” Although they were told it was the same target approached from different directions, the change in wording may have influenced their settings.

And third, participants were observed using different strategies to arrive at the discomfort threshold setting on the dimmer switch. Some moved the switch quickly from the starting point and passed their discomfort threshold, then reversed the direction and passed the discomfort threshold again (but by less, more slowly, and in the opposite direction). They continued this oscillation around the discomfort threshold until they settled on it. Others moved the switch quickly from the starting point and also passed

their discomfort threshold but then started over and adjusted the distance (and reduced the speed) they moved the switch on their next attempt. They continued this pattern until they felt they settled on their discomfort threshold. Finally, some participants moved the dimmer switch slowly from the starting point until they felt they reached the discomfort threshold, at which point they stopped (they did not try to refine it). Participants adopting this last strategy would likely have higher discomfort threshold readings for a down movement compared to an up movement, as they stopped as soon as they felt a sense of discomfort or comfort.

Discomfort Threshold vs. Required Fill Level

Ultimately, this research investigated the conflict between presence and portrayal. The results suggest that this conflict exists in low-light environments. For all ambient light conditions, the mean required fill level was greater than the mean average discomfort threshold (see Figure 36). This means that a telepresence fill light set to produce the best appearance (as judged by the remote user) would likely cause a sensation of discomfort glare for the local user. And once a person becomes aware of the technology (in this case, a bright fill light), his or her sense of presence may be disrupted.

Implications

Based on these results, a few recommendations can be made to enhance a telepresence experience in an environment that requires a supplemental fill light (due to low light or back-lit, side-lit, or top-lit scenes) and has a similar configuration to those used in this research:

- × — Mean Discomfort Threshold Up (V)
- — Mean Discomfort Threshold Down (V)
- ◇ — Mean Required Fill Level (V)

Figure 36. Discomfort threshold and required fill level. The chart shows average horizontal illuminance in relation to mean discomfort threshold up, discomfort threshold down, and required fill level. Discomfort threshold values are mapped to participant room illuminance, while required fill level values are mapped to moderator room illuminance. Average horizontal illuminance is used for comparison because it was a shared measurement between the two rooms. Note that the results of this research suggest that discomfort threshold is affected more by background luminance, and required fill level is affected more by vertical illuminance at the eye.

1. *Collocate the fill light.* If it helps from a manufacturing cost perspective (and does not conflict with the industrial design), collocate the fill light with the telepresence camera unit on top of the display. No effect was found for light height on discomfort threshold, so there is no benefit (regarding discomfort glare) to increasing the distance of the fill light above the display. Required fill level was greater for the high light height condition, which would require more energy, for less of an effect. And participants made comments that they could not fill the shadows of the remote person in the high condition, so the low condition is preferred.

2. *Limit fill light luminance.* In general, avoid producing a fill light luminance greater than 663.46 cd/m^2 (corresponding to 13.89 V, the grand mean for average discomfort threshold). If more light is required, prompt the user to adjust the room lighting by changing lamp settings. Note that the discomfort threshold distribution was positively skewed, with more low values than high values. See Table 15 for a list of the distribution's quantiles. Since this is a threshold of discomfort, it may be best to use the 25% or 10% quantiles as the limit, to avoid discomfort for 75% or 90% of the population.

3. *Detect background luminance.* If a product wanted to determine the discomfort threshold by sampling light in the room, it should focus on the background luminance instead of room illuminance. As this research showed, you can have large changes in room illumination that do not produce as great a change in background luminance. And background luminance is the property used to predict the discomfort glare sensation. The brightness of the background depends on the reflective properties of

Table 15

Discomfort Threshold Quantiles

Quantile	Voltage	Luminance
Maximum	19.23 V	3,170.95 cd/m ²
90%	15.44 V	1,348.76 cd/m ²
75%	14.57 V	949.67 cd/m ²
Median	13.61 V	554.92 cd/m ²
25%	12.73 V	261.42 cd/m ²
10%	12.58 V	220.05 cd/m ²
Minimum	12.44 V	184.08 cd/m ²

the different surfaces. In some cases, there may be a strong correlation between room illuminance and background luminance. But this would not always apply when you have dark, non-reflective surfaces.

Limitations

There were a number of limitations with this research. The ambient light range was limited to sub-optimal conditions. To fully understand the relationship between discomfort threshold and required fill level, optimal and super-optimal conditions need to be included. In addition, background luminance did not change enough between ambient light conditions to produce an effect. Two separate rooms were used to conduct the experiment. They differed in shape and size, had different paint colors and decorations,

and the light output from the recessed ceiling lights was greater in the moderator room. However, many steps were taken to compensate for these differences, such as defining the ambient light factor levels based on the closest corresponding light configurations. Note that the front ceiling light was only turned on in the bright ambient light condition.

Within each room, the two pre-installed telepresence displays were not identical, with the one in the moderator room being clearly darker. Regardless, the participant sat in the room with the brightest picture, and the moderator was clearly visible on the participant's display in all ambient light conditions. In addition, the cameras used with the telepresence systems were not tuned for low light, and thus produced an image that was slightly dim and pixelated in the low and medium ambient light conditions.

The power supply for the participant's fill light started to emit a gradual buzz from the control box, roughly between the 15- to 17-V range. In addition, there was an intermittent flicker in the fill light, perhaps in a similar range. Some participants mentioned the buzzing sound and flicker were distracting, so the moderator began to instruct participants to disregard the sound and flicker, and to just focus on the brightness of the light. Nevertheless, this may have had some impact on the results by causing some participants to avoid the unpleasant regions.

Future Research

Future research should try to address some of the deficiencies in this experiment. For example, a repeat of this experiment with larger differences in background luminance may produce significant differences on discomfort threshold. It would also be valuable to

know how much the discomfort threshold is determined by the average background luminance, the local background luminance, or the luminance of the display at the user's focal point.

Ideally, any follow-up experiments should make sure that the telepresence cameras will perform well in low light conditions. This research focused on a telepresence fill light placed directly on top of the display, but various fill light styles and placements could also be explored. In addition, this research focused on low lighting without a strong direction. A good follow-up study would investigate the effects of different lighting situations (back-lit, side-lit, top-lit). Different color temperatures could also be explored. Perhaps the discomfort threshold would be different for a perceptually warmer light. Other factors that could be explored include: longer periods of time for better adaptation, experienced compared to novice telepresence users, biometric measures of discomfort glare, and comparisons of the UGR to other glare prediction models.

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APPENDICES

Appendix A – IRB Approval

San José State
UNIVERSITY

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Associated Vice President
Graduate Studies & Research**

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To: Jim Beno

From: Pamela Stacks, Ph.D.
Associate Vice President
Graduate Studies and Research

Date: October 13, 2008

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

**"Balancing Presence and Portrayal: Effects of Telepresence Fill
Light Height and Ambient Light on Discomfort Glare and
Appearance"**

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Pamela Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subject's portion of your project is in effect for one year, and data collection beyond October 13, 2009 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

Protocol # S0804037

cc: Louis Freund, 0085

The California State University:
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Bakersfield, Channel Islands, Chico,
Dominguez Hills, East Bay, Fresno,
Fullerton, Humboldt, Long Beach,
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Appendix B – Consent Form

San José State
UNIVERSITY

Graduate Studies
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San José, CA 95192
<http://www.sjsu.edu>

Agreement to Participate in Research

Responsible Investigator: Jim Beno

Title of Protocol: *Balancing Presence and Portrayal: Effects of Telepresence Fill Light Height and Ambient Light on Discomfort Glare and Appearance*

You have been asked to participate in a research study investigating the use of a supplemental fill light for a telepresence product. You will be asked to participate in a telepresence session connecting two simulated home family rooms, through which you will communicate with the investigator. During the session, the lighting in the room will be adjusted to different levels, and you will be asked to adjust the amount of light coming out of the fill light in front of you to the point at which it becomes "just uncomfortable" (or "just comfortable") by adjusting a dimmer switch. You will also be asked to adjust the amount of light being cast on the moderator's face to the point at which it produces a pleasing portrayal. The session will be recorded with a video camera, the investigator will make observational notes, and you will be asked to complete a survey at the end.

There will not be any risks present in this study outside of what are present in daily life. You may experience a slight, temporary eye discomfort from viewing the fill light in low light. But the light is much less than what you'd see from a car headlight at night, and you control the light at all times.

The research will be conducted in San Jose, CA. The participant is responsible for their own transportation. All materials and equipment will be provided by the investigator or San Jose State University. The study is expected to last one hour. Upon successful completion of the research, participants will be entered into a drawing for one of three iPod Shuffle portable music players (\$49 value, 1-in-10 chance of winning). No other benefits will be provided to you for your participation by the investigator or by San José State University.

Although the results of this study may be published, no information that could identify you will be included. The data collected from your participation will be stored in password-protected computer files, with access granted only to the investigator.

Questions about this research may be addressed to the investigator, Jim Beno, SJSU Graduate Student, at (408) 569-6892 or jim@jimbeno.net. Complaints about the research may be presented to Dr. Louis Freund, Ph.D., Director, Graduate Program in Human Factors / Ergonomics, SJSU, at (408) 924-3890. Questions about research participants' rights or research-related injury may be presented to Dr. Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, SJSU, at (408) 924-2488.

No service of any kind, to which you are otherwise entitled, will be lost or jeopardized if you choose to "not participate" in the study. Your consent to participate is being given voluntarily. You may refuse to participate in the entire study or in any part of the study. You have the right to not answer questions you do not want to answer. You are free to withdraw from the study at any time, without any negative effect on your relations with San José State University.

At the time that you sign this consent form, you will receive a copy of it for your records, signed and dated by the investigator.

- Your signature on this document indicates agreement to participate in the study.
- The signature of an investigator on this document indicates agreement to include the below named participant in the research, and attestation that the participant has been fully informed of the participant's rights.

The California State University:
Chancellor's Office
Bakersfield, Chico, Dominguez Hills,
Fresno, Fullerton, Hayward, Humboldt,
Long Beach, Los Angeles, Maritime
Academy, Monterey Bay, Northridge,
Pomona, Sacramento, San Bernardino,
San Diego, San Francisco, San José,
San Luis Obispo, San Marcos, Sonoma,
Stanislaus

Participant's Signature _____

_____ Date

Investigator's Signature _____

_____ Date

Appendix C – Screening Survey

Thank you for your interest in this research study, which is investigating the use of a fill light for telepresence. To participate in this study, please read the [Agreement to Participate in Research](#) and answer the following questions. Eligible participants will be contacted to schedule a one-hour session in the telepresence research lab.

1. Email address: _____

2. Are you able to attend a one-hour in-person meeting in San Jose, as scheduled based on your availability?

- ☐ Yes
☐ No

3. What is your age? _____

4. What is your gender?

- ☐ Male
☐ Female

5. What color is the iris of your eyes?

- ☐ Amber (solid color with strong yellowish/golden and russet/copper tint)
☐ Blue
☐ Brown
☐ Gray
☐ Green
☐ Hazel (mixed or shifting color, from light brown to medium golden-green)
☐ Other: _____
☐ I'm not sure

6. Do you wear eye glasses or contact lenses to correct your vision? Check all that apply:

- ☐ I wear eye glasses or spectacles
☐ I wear contact lenses
☐ Although my vision needs correction (blurry vision), I do not wear eye glasses or contact lenses
☐ My vision does not need correction

7. Do you have any medical conditions that affect your eyes?

- ☐ Yes, I have the following condition(s): _____
☐ No
☐ I'm not sure (Please explain: _____)

8. Have you had any surgery on your eyes (including LASIK)?

- ☐ Yes, I had the following surgery: _____
☐ No
☐ I'm not sure (Please explain: _____)

9. How much experience do you have with telepresence?

- ☐ I have never heard of telepresence
☐ I have heard of telepresence, but never used it
☐ I use it a couple of times a year
☐ I use it monthly
☐ I use it weekly
☐ I use it daily

10. How much experience do you have with lighting for photography or video (setting up studio lighting, portraiture, evaluating lighting on a subject)?

- ☐ No experience with lighting
☐ Very little experience with lighting
☐ Some experience with lighting (for example, a hobbyist)
☐ A lot of experience with lighting (for example, as a professional)

Appendix D – Recruitment E-mail

From: Jim Beno

Subject: Help with Telepresence Research?

We're investigating the use of a supplemental fill light for telepresence, and would like your help! Just come to a **1-hour session** in the telepresence lab in San Jose. As an incentive, participants will be entered into a raffle for an **iPod Shuffle**. But more importantly, your participation will help inform telepresence product design.

To participate in this research study:

1. Read the [Agreement to Participate in Research](#)
2. Complete the [Participant Survey](#)
3. If eligible, you will be contacted to schedule a session

What: Telepresence Lighting Research (one 1-hour session)

When: Scheduled based on your availability

Where: San Jose, California

Why: Help inform telepresence product design, increase our understanding of lighting

Incentive: Participants will be entered in a raffle to win 1 of 3 iPod Shuffle portable music players (\$49 value, 1-in-10 chance of winning)

Jim Beno

Appendix E – Session Schedules

The following schedules reflect the following changes in the sequence of the procedure.

Ambient Light Counterbalancing

The Ambient Light independent variable has three levels: Dim (D), Moderate (M), and Bright (B). There are 6 schedule variations to reflect all possible combinations of this sequence:

Schedule A: D-M-B	Schedule B: M-D-B
Schedule C: D-B-M	Schedule D: B-D-M
Schedule E: B-M-D	Schedule F: M-B-D

Discomfort Threshold Adjustment Counterbalancing

The Discomfort Threshold dependent variable is measured twice for each Ambient Light level: once when a person adjusts the light Up from an off position (U), and once when a person adjusts the light Down from an on position (D). There are 2 variations within each schedule to reflect a different starting position:

Variation 1: UD-DU-UD	Variation 2: DU-UD-DU
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Resulting Schedule Variations

The result is 12 different schedule variations:

Schedule A1: D (UD) – M (DU) – B (UD)
Schedule A2: D (DU) – M (UD) – B (DU)
Schedule B1: M (UD) – D (DU) – B (UD)
Schedule B2: M (DU) – D (UD) – B (DU)
Schedule C1: D (UD) – B (DU) – M (UD)
Schedule C2: D (DU) – B (UD) – M (DU)
Schedule D1: B (UD) – D (DU) – M (UD)
Schedule D2: B (DU) – D (UD) – M (DU)
Schedule E1: B (UD) – M (DU) – D (UD)
Schedule E2: B (DU) – M (UD) – D (DU)
Schedule F1: M (UD) – B (DU) – D (UD)
Schedule F2: M (DU) – B (UD) – D (DU)

Participant Assignments

These schedule variations are distributed among the 30 participants as follows:

Schedule A1: 3 participants
Schedule A2: 2 participants
Schedule B1: 2 participants
Schedule B2: 3 participants
Schedule C1: 3 participants
Schedule C2: 2 participants
Schedule D1: 2 participants
Schedule D2: 3 participants
Schedule E1: 3 participants
Schedule E2: 2 participants
Schedule F1: 2 participants
Schedule F2: 3 participants

Schedule A

Category	Event	A1	A2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Schedule B

Category	Event	B1	B2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Schedule C

Category	Event	C1	C2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Schedule D

Category	Event	D1	D2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Schedule E

Category	Event	E1	E2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Schedule F

Category	Event	F1	F2	Time
Introduction	Welcome			10 minutes
Introduction	Consent Form			2 minutes
Introduction	Seat Adjustment			5 minutes
Introduction	Familiarization			5 minutes
Ambient Light: Moderate	Adjust Room Lighting			1 minute
Ambient Light: Moderate	Adjust to Fill Level			2 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Moderate	Brief Conversation			3 minutes
Ambient Light: Moderate	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Bright	Adjust Room Lighting			1 minute
Ambient Light: Bright	Adjust to Fill Level			2 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Down	Up	2 minutes
Ambient Light: Bright	Brief Conversation			3 minutes
Ambient Light: Bright	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Adjust Room Lighting			1 minute
Ambient Light: Dim	Adjust to Fill Level			2 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Up	Down	2 minutes
Ambient Light: Dim	Brief Conversation			3 minutes
Ambient Light: Dim	Adjust to Discomfort Threshold	Down	Up	2 minutes
Wrap-Up	Post-Test Survey			5 minutes
Wrap-Up	Departure			3 minutes

Participant Schedule Assignments

Participant ID	Session Schedule	DT Counterbalancing	Light Height
P01	A	A1	Low
P02	A	A2	Low
P03	A	A1	Low
P04	A	A2	High
P05	A	A1	High
P06	B	B2	High
P07	B	B1	High
P08	B	B2	High
P09	B	B1	Low
P10	B	B2	Low
P11	C	C1	Low
P12	C	C2	Low
P13	C	C1	Low
P14	C	C2	High
P15	C	C1	High
P16	D	D2	High
P17	D	D1	High
P18	D	D2	High
P19	D	D1	Low
P20	D	D2	Low
P21	E	E1	Low
P22	E	E2	Low
P23	E	E1	Low
P24	E	E2	High
P25	E	E1	High

Participant ID	Session Schedule	DT Counterbalancing	Light Height
P26	F	F2	High
P27	F	F1	High
P28	F	F2	High
P29	F	F1	Low
P30	F	F2	Low

Appendix F – Session Script

Welcome (10 minutes)

Participant: *Arrives at door.*

Moderator: *Greets participant at door.*

Hi, my name is Jim and I'll be working with you in today's session.

Please have a seat over here on the couch.

Directs participant to sit.

Participant: *Sits on couch, in front of coffee table.*

Moderator: *Sits on couch, at an angle to participant.*

So let me explain what we'll be doing here today.

We're investigating the use of a supplemental fill light on a telepresence product, and would like your help. In case you're not familiar these terms, telepresence is a technology that delivers realistic face-to-face communication experiences in an immersive environment through high-definition video, surround-sound audio, high-bandwidth networks, and carefully controlled environments. A fill light is designed to provide additional lighting to the main light on a person or a scene, primarily by filling in the shadows. It's not meant to be the primary light, but in a really dim room, it could become that. So we'll be looking at how one of these fill lights affects a home telepresence experience.

To start off, I'll go over the plan for today's session, answer any questions you have, and then ask you to sign a consent form. Once that's taken care of, I'll start a telepresence session connecting two simulated home family rooms, and adjust your seating to the appropriate level. I'll then make some adjustments to this room's lighting, go into the other room, adjust that room's lighting, and continue our conversation through the telepresence connection.

We'll have a light conversation about our jobs, hobbies, or things we do for fun. We can really talk about anything you want. The goal is to have a real and meaningful discussion during a telepresence session.

Along the way, I'll ask you to adjust the output of the fill light in front of you by moving the dimmer switch on the table marked "My Light." While focusing on my face (not staring directly at the light), I'll have you set the light to the "border between comfort and discomfort," or the point at which it just starts to become distracting and annoying for you. Below this point, the light wouldn't bother you during a 5-minute telepresence call. But at this point and above, you'd want to adjust the light down (or turn it off) to continue the call. I'll ask you to make this adjustment twice for each level of room lighting.

In addition, I'll ask you to adjust the output of the fill light in front of me (in the other room) by moving the dimmer switch on the table marked "Remote Light." When you're making this adjustment, you won't be focusing on discomfort, but on how well-lit my face appears. Your task will be to set the light to the point that produces

the most pleasing portrayal of my face and upper body, where the shadows are filled and the face is not overexposed (too bright) or underexposed (too dark). You'll only make this adjustment once for each level of room lighting.

We'll repeat this process for three different levels of room lighting, and then we'll wrap up with a small survey at the end.

This session is expected to last about one hour. It will be recorded with the video camera you see over there in the corner, and I'll be taking some observational notes along the way. Although the results of this study may be published, no information that could identify you will be included. The data collected from your participation will be stored in password-protected computer files, with access granted only to myself.

Now, given that we'll be working with a light in low light, you may experience some slight, temporary eye discomfort. But keep in mind that the brightness of this light is much less than what you'd see from a car headlight at night, and you will be in control of the light at all times.

Once you complete this session, you'll be entered into a drawing for one of three iPod Shuffle portable music players, which are worth about \$50. Since there are 30 participants in this study, you'll have a 1-in-10 chance of winning one. I'll do the drawings after everyone has completed their sessions.

Do you have any questions so far?

Participant: *Asks questions.*

Moderator: *Answers questions.*

Consent Form (2 minutes)

Moderator: *Hands participant two copies of "Agreement to Participate in Research" paper and pen.*

Okay, to get started, you just need to read and sign this consent form. It covers much of what I just shared with you, as well as contact information in case you have questions or complaints. Note that your participation is entirely voluntary, and you can refuse to participate, or withdraw at any time, without any negative effect. If you choose to participate, please sign and date both copies of this form, one of which you'll take back with you for your own records.

Participant: *Signs form, or declines, in which case the moderator thanks them and escorts them out.*

Moderator: *Checks both copies of the consent form, hands one to the participant.*

Seat Adjustment (5 minutes)

Moderator: Before we start the telepresence conversation, we'll have to adjust your seat to the appropriate height. Please take a seat on the edge of the couch with your hands over the dimmer switches on the control box. Focus on the top center of the

display.

Directs participant to sit on the couch in front of telepresence display.

Participant: *Sits on chair or stool.*

Moderator: I'm now going to measure the height of your eyes from the floor. Based on this height, we'll need to adjust the height of your seat, either up or down.

Grabs tape measure.

Measures vertical height of participant's eyes.

Asks participant to stand up, and adjusts the couch the appropriate distance with pillows.

Checks vertical measurement again, and adjusts if necessary.

Familiarization (5 minutes)

Moderator: What you now see on the display is the other room where I'll be sitting.

On top of the display is the fill light. You control the output of this light with the dimmer switch on the control box labeled "My Light." Right now, it's off. But if I slide this switch, the light turns on and gets brighter the more that I move it.

Slides the "My Light" dimmer switch on the control box.

Now it's your turn. Try adjusting the light up and down a little bit.

Gestures to the "My Light" dimmer switch on the control box.

Participant: *Slides the "My Light" dimmer switch on the control box.*

Moderator: There is another fill light in the other room, on top of the telepresence display that I will be looking at. You control the output of that light with this other dimmer switch, which is labeled "Remote Light." It behaves in a similar manner.

Slides the "Remote Light" dimmer switch on the control box.

You can't really see the effect without a person sitting there, so I'll now go into the other room, and have you adjust the light up and down so you can see the effect it will have on my face and upper body.

Leaves the participant's room and enters the moderator's room.

Sits down on the couch in front of the moderator's telepresence display and fill light.

Okay, now we're talking to each other through Telepresence! What do you think?

Participant: *Responds to the question.*

Great. Now try adjusting the remote light up and down a little bit. Do you see the effect on my face?

Participant: *Slides the "Remote Light" dimmer switch on the control box.*

Responds to the question.

Moderator: Do you have any questions about how to communicate over telepresence, or how to operate the lights?

Participant: *Asks questions.*

Moderator: *Answers questions.*

Ambient Lighting (10 minutes, repeats 3 times to cover each Ambient Light condition)

Adjust Room Lighting (1 minute, counter-balanced for each Ambient Light condition)

Moderator: I'm now going to adjust the room lighting in both our rooms.

Adjusts the room lighting in the moderator's room (to Dim, Moderate, or Bright).

Moves to the participant's room.

Adjusts the room lighting in the participant's room (to either Dim, Moderate, or Bright).

I'll now go back to the other room.

Moves to the moderator's room.

Sits down on the couch in front of the moderator's display and fill light.

Adjust to Fill Level (2 minutes)

Moderator: To start off, you'll now adjust the amount of light being cast on my face to the point that it produces the most pleasing portrayal, where the shadows are filled and the face is not overexposed (too bright) or underexposed (too dark).

Go ahead and adjust the "Remote Light" dimmer switch now. Say "I'm done" when you're ready.

Participant: *Slides the "Remote Light" dimmer switch and adjusts the amount of fill light on the moderator.*

I'm done.

Moderator: *Records voltage reading on multimeter USB software display.*

Moderator: Okay, please turn the "Remote Light" completely off.

Participant: *Slides the “Remote Light” dimmer switch to the off position.*

Moderator: *Verifies “off” setting by reading voltage on multimeter USB software display.*

Adjust Up to Discomfort Threshold (2 minutes, counter-balanced up and down)

Moderator: *If it's the first adjustment for this Ambient Light condition, say:
Okay, now you'll adjust the amount of light coming out of your light, marked as “My Light” on the control box.*

*If it's the second adjustment for this Ambient Light condition, say:
Okay, now you'll make another adjustment of your fill light, marked as “My Light” on the control box.*

First, please turn your light completely off.

Participant: *Slides the “My Light” dimmer switch to the off position.*

Moderator: *Verifies “off” setting by reading voltage on multimeter USB software display.*

On the control box in front of you is a discomfort glare scale. Look at the “Adjusting Up” column. You're now going to adjust the light up to the point at which it just starts to become uncomfortable, without going into the uncomfortable region.

Go ahead and adjust your light now, while you continue to focus on my face. Say “I'm done” when you're ready. If you see a flicker or hear a buzz, please try to ignore that and focus only on the brightness.

Participant: *Slides the “My Light” dimmer switch and adjusts the amount of fill light.*

I'm done.

Moderator: *Records voltage reading on multimeter USB software display.*

Brief Conversation (3 minutes)

Moderator: *In between the light adjustments, we'll have some time to chat about things.*

Asks the participant some of the following questions to allow time for adaptation, and to give the glare source more time to become a distraction or annoyance. This will be a two-way conversation, involving both asking and sharing information. Conversations will span across the different Ambient Light conditions.

*So what do you do for a living? My role is...
What do you think of telepresence? I know, I'm amazed...
What do you do for fun outside of work? I like to...
Do you have any hobbies? I like to...*

Moderator: *We've been chatting for about three minutes now with the fill light at your setting. Do you feel the need to adjust it lower?*

Participant: *Responds with a yes or no, and perhaps some comments.*

Moderator: *Records response.*

Adjust Down to Discomfort Threshold (2 minutes, counter-balanced up and down)

Moderator: *If it's the first adjustment for this Ambient Light condition, say:*
Okay, now you'll adjust the amount of light coming out of your light, marked as "My Light" on the control.

If it's the second adjustment for this Ambient Light condition, say:
Okay, now you'll make another adjustment of your fill light, marked as "My Light" on the control box.

First, please turn your light completely on.

Participant: *Slides the "My Light" dimmer switch to the fully on position.*

Moderator: *Verifies "fully on" setting by reading voltage on multimeter USB software display.*

On the control box in front of you is a discomfort glare scale. Look at the "Adjusting Down" column. You're now going to adjust the light down to point at which it just starts to become comfortable.

Go ahead and adjust your light now, while you continue to focus on my face. Say "I'm done" when you're ready. If you see a flicker or hear a buzz, please try to ignore that and focus only on the brightness.

Participant: *Slides the "My Light" dimmer switch and adjusts the amount of fill light.*

I'm done.

Moderator: *Records voltage reading on multimeter USB software display.*

Post-Test Survey (5 minutes)

Moderator: Okay, we're done with the lighting adjustments. I'll now come over there to wrap up the session.

Adjusts the room lighting in the moderator's room to Moderate.

Moves to the participant's room.

Adjusts the room lighting in the participant's room to Moderate.

Sits down next to participant.

Hands participant a copy of the "Post-Test Survey" paper and pen.

This is a one-page survey that asks a few questions about your experience with the fill light, and about your home family room environment. Please answer these questions, and let me know if you're not sure how to answer them.

Participant: *Completes survey.*

Alright, I'm done with the survey now.

Moderator: *Checks the post-test survey.*

Departure (3 minutes)

Moderator: Thank you so much for your participation in this research study. The results of this research may help inform the design of lighting solutions for telepresence products. At the very least, it will provide useful information on the effects of one particular style of fill light in a variable environment, which further research can then build upon.

Since you've completed this session, you'll be entered into the drawing for one of three iPod Shuffle portable music players. I'll do the drawings after everyone has completed their sessions. I will follow-up with you then, whether you have won the drawing or not.

Do you have any questions for me?

Participant: *Asks questions.*

Moderator: *Answers questions.*

Well thank you again. Let me show you how to exit the lab before I prepare for the next session.

Escorts participant to the door.

Appendix G – Participant Data

Participant	Light Height	Required Fill Level - Low	Discomfort Threshold - Dim (Up)	Discomfort Threshold - Dim (Down)	Change Discomfort Threshold - Dim	Required Fill Level - Moderate	Discomfort Threshold - Moderate (Up)	Discomfort Threshold - Moderate (Down)	Change Discomfort Threshold - Moderate	Required Fill Level - High	Discomfort Threshold - High (Up)	Discomfort Threshold - High (Down)	Change Discomfort Threshold - High
P22	Low	19.19	12.54	12.46 N		16.32	12.77	12.79 N		17.73	12.58	13.44 N	
P13	Low	19.94	14.62	14.6 Y		18.88	13.86	13.6 N		11.76	12.58	13.53 N	
P19	Low	18.99	15.05	17.89 N		18.3	13.96	18.93 N		13.24	14.94	18.33 Y	
P01	Low	20.63	12.93	14.02 N		17.48	12.72	13.02 N		12.41	12.72	13.39 N	
P29	Low	13.18	14.09	14.2 N		14.05	12.89	14.81 N		13.16	14.19	13.99 N	
P04	High	22.28	13.32	12.91 N		22.3	12.58	12.49 Y		18.08	12.69	13.17 N	
P10	Low	21.7	14.18	14.17 N		20.26	14.57	14.58 N		19.14	13.17	14.11 N	
P30	Low	18.95	15.36	15.54 N		20.61	13.03	12.58 N		15.1	14.57	12.85 N	
P08	High	20.32	15.18	14.42 Y		19.49	16.91	16.23 N		17.62	15.57	15.59 N	
P23	Low	18.72	12.47	12.71 N		14.14	12.47	12.68 Y		12.71	12.51	12.57 N	
P15	High	21.03	13.41	13.98 N		21.41	13.43	13.69 N		11.41	12.75	12.6 N	
P18	High	20.15	12.7	12.58 Y		21.11	12.6	12.63 N		15.18	12.57	12.45 N	
P27	High	18.98	13.34	16.37 N		18.24	14.24	15.37 N		14.51	12.79	15.27 Y	
P26	High	20.39	12.44	12.52 N		21.1	12.67	12.44 N		14.41	13.23	12.58 Y	
P36	Low	19.2	13.86	14.98 N		20.49	14.46	12.86 N		17.48	13.55	14.33 N	
P05	High	18.75	13.88	13.78 N		20.39	13.49	14.26 N		16.56	14.73	15.81 N	
P24	High	22.25	12.91	12.59 N		22.25	14.28	12.55 Y		12.92	14.99	13.76 N	
P16	High	19.49	12.47	13.34 N		17.52	12.6	12.7 N		13.07	12.49	12.66 N	
P17	High	19.47	14.5	17.76 Y		16.68	13.9	14.16 N		13.62	13.88	13.55 Y	
P02	Low	19.01	14.25	15.55 Y		18.4	14.76	15.24 N		18.73	15.44	14.69 N	
P09	Low	20.75	12.61	14.6 N		21.24	13.46	13.77 N		11.64	15.02	15.43 N	
P31	High	20.77	18.47	15.4 N		22.21	17.78	19.23 N		18.72	13.5	15.82 N	
P32	High	22.31	14.11	15.03 N		22.3	13.6	14.72 N		11.53	13.93	14.54 N	
P33	Low	21.73	13.07	14.36 N		19.65	13.59	13.6 N		13.82	12.85	14.44 N	
P35	High	21.46	12.64	12.63 N		18.52	12.8	13.28 Y		14.85	12.76	13.32 N	
P34	High	22.29	13.66	13.87 Y		22.41	13.61	15.02 N		18.42	13.6	15.2 N	
P11	Low	22.41	12.7	12.61 N		22.44	12.6	12.59 Y		18.71	12.69	12.71 N	
P20	Low	14.7	12.44	13.65 Y		14.05	13.31	13.15 N		12.88	15.63	13.75 N	
P03	High	20.63	13.42	13.29 N		22.25	13.35	14.56 N		22.25	13.61	13.8 N	
P14	Low	13.62	14.37	13.64 N		17	13.99	14.54 N		12.31	13.69	14.57 N	

Appendix H – UGR Calculations

Fill Light (Maximum), Front Floor Lamps, Front Ceiling Light

Property	Unit of Measure	Variable	Participant Room (Low, Dim)	Participant Room (Low, Moderate)	Participant Room (Low, Bright)	Participant Room (High, Dim)	Participant Room (High, Moderate)	Participant Room (High, Bright)
CONFIGURATION								
Ambient Light Factor Level			Dim Low Participant	Moderate Low Participant	Bright Low Participant	Dim High Participant	Moderate High Participant	Bright High Participant
Light Height Factor Level								
Room								
AMBIENT LIGHT			Participant Room (Low)			Participant Room (High)		
r_1 – Horiz. Illum. 30-in Front-Left	lux	r_1	42	49	87	42	49	87
r_2 – Horiz. Illum. 30-in Front-Center	lux	r_2	34	62	111	34	62	111
r_3 – Horiz. Illum. 30-in Front-Right	lux	r_3	43	77	128	43	77	128
r_4 – Horiz. Illum. 30-in Middle-Left	lux	r_4	39	76	228	39	76	228
r_5 – Horiz. Illum. 30-in Middle-Center	lux	r_5	42	89	295	42	89	295
r_6 – Horiz. Illum. 30-in Middle-Right	lux	r_6	50	100	280	50	100	280
r_7 – Horiz. Illum. 30-in Back-Left	lux	r_7	53	179	372	53	179	372
r_8 – Horiz. Illum. 30-in Back-Center	lux	r_8	68	226	487	68	226	487
r_9 – Horiz. Illum. 30-in Back-Right	lux	r_9	65	201	434	65	201	434
E_{hor} – Average Horizontal Illuminance	lux	E_{hor}	48	118	269	48	118	269
E_{vert} – Vertical Illuminance at Eye	lux	E_{vert}	19	33	140	19	33	140
E_i – Indirect Illuminance at Eye	lux	E_i	12	23	32	12	23	32
L_b – Luminance of Background	candela per meter ² (cd/m ²)	L_b	3.82	7.32	10.19	3.82	7.32	10.19
L_{a-est} – Est. Avg. Lum. of Local BG (0.5 sr)	candela per meter ² (cd/m ²)	L_{a-est}	5.59	7.22	10.52	5.59	7.22	10.52
FILL LIGHT			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β – Angle from horizontal to source	degrees (°)	β	8.72	8.72	8.72	15.53	15.53	15.53
P – Gutz position index of light	index	P	1.37	1.37	1.37	1.78	1.78	1.78
w – Width of light	meters (m)	w	1.21	1.21	1.21	1.21	1.21	1.21
h – Height of light	meters (m)	h	0.08	0.08	0.08	0.08	0.08	0.08
d – Viewing distance	meters (m)	d	2.50	2.50	2.50	2.60	2.60	2.60
θ^* – Viewing angle (in degrees)	degrees (°)	θ in °	8.72	8.72	8.72	15.53	15.53	15.53
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.15	0.15	0.15	0.27	0.27	0.27
ω – Solid angle of light	steradians (sr)	ω	0.018	0.016	0.016	0.014	0.014	0.014
L_{fi} – Luminance of light (in ft)	footlamberts (f)	L in ft	1381	1381	1381	1381	1381	1381
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	4731.66	4731.66	4731.66	4731.66	4731.66	4731.66
UGR – Unified Glare Rating	index	UGR	32.78	30.52	29.37	30.48	28.22	27.07
UGR Difference			-	2.26	1.15	-	2.26	1.15
CEILING LIGHT			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β – Angle from horizontal to source	degrees (°)	β	44.00	44.00	44.00	44.00	44.00	44.00
P – Gutz position index of light	index	P	6.70	6.70	6.70	6.70	6.70	6.70
w – Width of light	meters (m)	w	5.84	5.84	5.84	5.84	5.84	5.84
h – Height of light	meters (m)	h	0.10	0.10	0.10	0.10	0.10	0.10
d – Viewing distance	meters (m)	d	2.39	2.39	2.39	2.39	2.39	2.39
θ^* – Viewing angle (in degrees)	degrees (°)	θ in °	44.00	44.00	44.00	44.00	44.00	44.00
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.77	0.77	0.77	0.77	0.77	0.77
ω – Solid angle of light	steradians (sr)	ω	0.073	0.073	0.073	0.073	0.073	0.073
L_{fi} – Luminance of light (in ft)	footlamberts (f)	L in ft	0	0	1410	0	0	1410
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	0.00	0.00	4831.03	0.00	0.00	4831.03
UGR – Unified Glare Rating	index	UGR	32.78	30.52	30.00	30.48	28.22	26.21
UGR Difference			-	2.26	0.52	-	2.26	0.01
FLOOR LAMP 1			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β – Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P – Gutz position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w – Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h – Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d – Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ^* – Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω – Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L_{fi} – Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR – Unified Glare Rating	index	UGR	32.80	30.56	30.09	30.53	28.34	26.35
UGR Difference			-	2.23	0.49	-	2.19	-0.01
FLOOR LAMP 2			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β – Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P – Gutz position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w – Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h – Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d – Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ^* – Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω – Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L_{fi} – Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR – Unified Glare Rating	index	UGR	32.83	30.84	30.17	30.58	28.45	26.48
UGR Difference			-	2.19	0.47	-	2.13	-0.03
DIFFERENCE			0.05	0.12	0.80	0.10	0.23	1.41
UGR with fill light compared to UGR with fill light, ceiling and floor lamps.			Higher	Higher	Higher	Higher	Higher	Higher

Fill Light (Mean Discomfort), Front Floor Lamps, Front Ceiling Light

Property	Unit of Measure	Variable	Participant Room (Low, Dim)	Participant Room (Low, Moderate)	Participant Room (Low, Bright)	Participant Room (High, Dim)	Participant Room (High, Moderate)	Participant Room (High, Bright)
CONFIGURATION								
Ambient Light Factor Level			Dim	Moderate	Bright	Dim	Moderate	Bright
Light Height Factor Level			Low	Low	Low	High	High	High
Room			Participant	Participant	Participant	Participant	Participant	Participant
AMBIENT LIGHT			Participant Room (Low)			Participant Room (High)		
r ₁ - Horiz. Illum. 30-in Front-Left	lux	r ₁	42	49	87	42	49	87
r ₂ - Horiz. Illum. 30-in Front-Center	lux	r ₂	34	62	111	34	62	111
r ₃ - Horiz. Illum. 30-in Front-Right	lux	r ₃	43	77	128	43	77	128
r ₄ - Horiz. Illum. 30-in Middle-Left	lux	r ₄	39	76	226	39	76	226
r ₅ - Horiz. Illum. 30-in Middle-Center	lux	r ₅	42	89	295	42	89	295
r ₆ - Horiz. Illum. 30-in Middle-Right	lux	r ₆	50	100	280	50	100	280
r ₇ - Horiz. Illum. 30-in Back-Left	lux	r ₇	53	179	372	53	179	372
r ₈ - Horiz. Illum. 30-in Back-Center	lux	r ₈	68	226	487	68	226	487
r ₉ - Horiz. Illum. 30-in Back-Right	lux	r ₉	65	201	434	65	201	434
E _{hor} - Average Horizontal Illuminance	lux	E _{hor}	48	118	269	48	118	269
E _{ver} - Vertical Illuminance at Eye	lux	E _{ver}	19	33	140	19	33	140
E _i - Indirect Illuminance at Eye	lux	E _i	12	23	32	12	23	32
L _b - Luminance of Background	candela per meter ² (cd/m ²)	L _b	3.82	7.32	10.19	3.82	7.32	10.19
L _a - Est. Avg. Lum. of Local BG (0.5 sr)	candela per meter ² (cd/m ²)	L _a	5.59	7.22	10.52	5.59	7.22	10.52
FILL LIGHT			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β - Angle from horizontal to source	degrees (°)	β	8.72	8.72	8.72	15.53	15.53	15.53
P - Guth position index of light	index	P	1.37	1.37	1.37	1.78	1.78	1.78
w - Width of light	meters (m)	w	1.21	1.21	1.21	1.21	1.21	1.21
h - Height of light	meters (m)	h	0.08	0.08	0.08	0.08	0.08	0.08
d - Viewing distance	meters (m)	d	2.50	2.50	2.50	2.60	2.60	2.60
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	8.72	8.72	8.72	15.53	15.53	15.53
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.15	0.15	0.15	0.27	0.27	0.27
ω - Solid angle of light	steradians (sr)	ω	0.018	0.018	0.018	0.014	0.014	0.014
L _{fl} - Luminance of light (in ft)	footlamberts (ftl)	L in ft	204.19	171.94	199.48	194.8	191.32	190.16
L _{cd/m²} - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	699.81	589.11	683.47	667.44	655.51	651.54
UGR - Unified Glare Rating	index	UGR	19.49	18.04	15.92	16.87	14.49	13.30
UGR Difference			-	3.45	0.12	-	2.39	1.19
CEILING LIGHT			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β - Angle from horizontal to source	degrees (°)	β	44.00	44.00	44.00	44.00	44.00	44.00
P - Guth position index of light	index	P	6.70	6.70	6.70	6.70	6.70	6.70
w - Width of light	meters (m)	w	5.84	5.84	5.84	5.84	5.84	5.84
h - Height of light	meters (m)	h	0.10	0.10	0.10	0.10	0.10	0.10
d - Viewing distance	meters (m)	d	2.39	2.39	2.39	2.39	2.39	2.39
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	44.00	44.00	44.00	44.00	44.00	44.00
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.77	0.77	0.77	0.77	0.77	0.77
ω - Solid angle of light	steradians (sr)	ω	0.073	0.073	0.073	0.073	0.073	0.073
L _{fl} - Luminance of light (in ft)	footlamberts (ftl)	L in ft	0	0	1410	0	0	1410
L _{cd/m²} - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	0.00	0.00	4831.03	0.00	0.00	4831.03
UGR - Unified Glare Rating	index	UGR	19.49	18.04	24.12	16.87	14.49	23.94
UGR Difference			-	3.45	-8.08	-	2.39	-9.45
FLOOR LAMP 1			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β - Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P - Guth position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w - Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h - Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d - Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω - Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L _{fl} - Luminance of light (in ft)	footlamberts (ftl)	L in ft	592	900	1150	592	900	1150
L _{cd/m²} - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR - Unified Glare Rating	index	UGR	20.54	18.70	24.55	18.82	18.06	24.39
UGR Difference			-	1.85	-5.85	-	0.76	-6.33
FLOOR LAMP 2			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β - Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P - Guth position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w - Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h - Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d - Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω - Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L _{fl} - Luminance of light (in ft)	footlamberts (ftl)	L in ft	592	900	1150	592	900	1150
L _{cd/m²} - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR - Unified Glare Rating	index	UGR	21.35	20.18	24.93	20.05	19.78	24.79
UGR Difference			-	1.16	-4.74	-	0.27	-5.01
DIFFERENCE			Participant Room (Low)			Participant Room (High)		
UGR with fill light compared to UGR with fill light, ceiling and floor lamps.			1.85	4.14	9.00	3.18	5.30	11.49
			Higher	Higher	Higher	Higher	Higher	Higher

Fill Light (Maximum), Front Floor Lamps

Property	Unit of Measure	Variable	Participant Room (Low, Dim)	Participant Room (Low, Moderate)	Participant Room (Low, Bright)	Participant Room (High, Dim)	Participant Room (High, Moderate)	Participant Room (High, Bright)
CONFIGURATION			Dim Low Participant	Moderate Low Participant	Bright Low Participant	Dim High Participant	Moderate High Participant	Bright High Participant
Ambient Light Factor Level								
Light Height Factor Level								
Room								
AMBIENT LIGHT			Participant Room (Low)			Participant Room (High)		
r ₁ – Horiz. Illum. 30-in Front-Left	lux	r ₁	42	49	87	42	49	87
r ₂ – Horiz. Illum. 30-in Front-Center	lux	r ₂	34	62	111	34	62	111
r ₃ – Horiz. Illum. 30-in Front-Right	lux	r ₃	43	77	128	43	77	128
r ₄ – Horiz. Illum. 30-in Middle-Left	lux	r ₄	39	76	226	39	76	226
r ₅ – Horiz. Illum. 30-in Middle-Center	lux	r ₅	42	89	295	42	89	295
r ₆ – Horiz. Illum. 30-in Middle-Right	lux	r ₆	50	100	280	50	100	280
r ₇ – Horiz. Illum. 30-in Back-Left	lux	r ₇	53	179	372	53	179	372
r ₈ – Horiz. Illum. 30-in Back-Center	lux	r ₈	68	226	487	68	226	487
r ₉ – Horiz. Illum. 30-in Back-Right	lux	r ₉	65	201	434	65	201	434
E _{amb} – Average Horizontal Illuminance	lux	E _{amb}	48	118	269	48	118	269
E _{amb} – Vertical Illuminance at Eye	lux	E _{amb}	19	33	140	19	33	140
E _i – Indirect Illuminance at Eye	lux	E _i	12	23	32	12	23	32
L _b – Luminance of Background	candela per meter ² (cd/m ²)	L _b	3.82	7.32	10.19	3.82	7.32	10.19
L _s – Est. Avg. Lum. of Local BG (0.5 sr)	candela per meter ² (cd/m ²)	L _s	5.59	7.22	10.52	5.59	7.22	10.52
FILL LIGHT			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β – Angle from horizontal to source	degrees (°)	β	8.72	8.72	8.72	15.53	15.53	15.53
P – Gutz position index of light	index	P	1.37	1.37	1.37	1.78	1.78	1.78
w – Width of light	meters (m)	w	1.21	1.21	1.21	1.21	1.21	1.21
h – Height of light	meters (m)	h	0.08	0.08	0.08	0.08	0.08	0.08
d – Viewing distance	meters (m)	d	2.50	2.50	2.50	2.60	2.60	2.60
θ° – Viewing angle (in degrees)	degrees (°)	θ in °	8.72	8.72	8.72	15.53	15.53	15.53
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.15	0.15	0.15	0.27	0.27	0.27
ω – Solid angle of light	steradians (sr)	ω	0.016	0.016	0.016	0.014	0.014	0.014
L ft – Luminance of light (in ft)	footlamberts (f)	L in ft	1381	1381	1381	1381	1381	1381
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	4731.68	4731.68	4731.68	4731.68	4731.68	4731.68
UGR – Unified Glare Rating	index	UGR	32.78	30.52	29.37	30.48	28.22	27.07
UGR Difference			–	2.26	1.15	–	2.26	1.15
+ FLOOR LAMP 1			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β – Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P – Gutz position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w – Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h – Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d – Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° – Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω – Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L ft – Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR – Unified Glare Rating	index	UGR	32.80	30.58	29.47	30.53	28.34	27.26
UGR Difference			–	2.23	1.11	–	2.19	1.07
+ FLOOR LAMP 2			Participant Room (Low)			Participant Room (High)		
α – Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β – Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P – Gutz position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w – Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h – Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d – Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° – Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads – Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω – Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L ft – Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² – Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR – Unified Glare Rating	index	UGR	32.83	30.64	29.57	30.58	28.46	27.44
UGR Difference			–	2.19	1.07	–	2.13	1.01
DIFFERENCE			0.05	0.12	0.20	0.10	0.23	0.37
UGR with fill light compared to UGR with fill light, ceiling and floor lamps.			Higher	Higher	Higher	Higher	Higher	Higher

Fill Light (Mean Discomfort), Front Floor Lamps

Property	Unit of Measure	Variable	Participant Room (Low, Dim)	Participant Room (Low, Moderate)	Participant Room (Low, Bright)	Participant Room (High, Dim)	Participant Room (High, Moderate)	Participant Room (High, Bright)
CONFIGURATION			Dim Low Participant	Moderate Low Participant	Bright Low Participant	Dim High Participant	Moderate High Participant	Bright High Participant
Ambient Light Factor Level								
Light Height Factor Level								
Room								
AMBIENT LIGHT			Participant Room (Low)			Participant Room (High)		
r_1 - Horiz. illum. 30-in Front-Left	lux	r_1	42	49	87	42	49	87
r_2 - Horiz. illum. 30-in Front-Center	lux	r_2	34	62	111	34	62	111
r_3 - Horiz. illum. 30-in Front-Right	lux	r_3	43	77	128	43	77	128
r_4 - Horiz. illum. 30-in Middle-Left	lux	r_4	39	76	226	39	76	226
r_5 - Horiz. illum. 30-in Middle-Center	lux	r_5	42	89	295	42	89	295
r_6 - Horiz. illum. 30-in Middle-Right	lux	r_6	50	100	280	50	100	280
r_7 - Horiz. illum. 30-in Back-Left	lux	r_7	53	179	372	53	179	372
r_8 - Horiz. illum. 30-in Back-Center	lux	r_8	68	226	487	68	226	487
r_9 - Horiz. illum. 30-in Back-Right	lux	r_9	65	201	434	65	201	434
E_{hor} - Average Horizontal Illuminance	lux	E_{hor}	48	118	269	48	118	269
E_{vert} - Vertical Illuminance at Eye	lux	E_{vert}	19	33	140	19	33	140
E_i - Indirect Illuminance at Eye	lux	E_i	12	23	32	12	23	32
L_b - Luminance of Background	candela per meter ² (cd/m ²)	L_b	3.82	7.32	10.19	3.82	7.32	10.19
L_a - Est. Avg. Lum. of Local BG (0.5 sr)	candela per meter ² (cd/m ²)	L_a	5.59	7.22	10.52	5.59	7.22	10.52
FILL LIGHT			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	0.00	0.00	0.00	0.00	0.00	0.00
β - Angle from horizontal to source	degrees (°)	β	8.72	8.72	8.72	15.53	15.53	15.53
P - Gush position index of light	index	P	1.37	1.37	1.37	1.78	1.78	1.78
w - Width of light	meters (m)	w	1.21	1.21	1.21	1.21	1.21	1.21
h - Height of light	meters (m)	h	0.08	0.08	0.08	0.08	0.08	0.08
d - Viewing distance	meters (m)	d	2.50	2.50	2.50	2.60	2.60	2.60
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	8.72	8.72	8.72	15.53	15.53	15.53
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.15	0.15	0.15	0.27	0.27	0.27
ω - Solid angle of light	steradians (sr)	ω	0.016	0.016	0.016	0.014	0.014	0.014
L ft - Luminance of light (in ft)	footlamberts (f)	L in ft	204.19	171.94	199.48	194.8	191.32	190.16
L cd/m ² - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	699.61	589.11	683.47	667.44	655.51	651.54
UGR - Unified Glare Rating	index	UGR	19.49	16.04	15.92	16.87	14.49	13.30
UGR Difference			-	3.45	0.12	-	2.39	1.19
+ FLOOR LAMP 1			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β - Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P - Gush position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w - Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h - Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d - Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω - Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L ft - Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR - Unified Glare Rating	index	UGR	20.54	18.70	18.96	18.82	18.06	18.09
UGR Difference			-	1.85	-0.26	-	0.76	-0.03
+ FLOOR LAMP 2			Participant Room (Low)			Participant Room (High)		
α - Angle from vertical to source	degrees (°)	α	79.00	79.00	79.00	79.00	79.00	79.00
β - Angle from horizontal to source	degrees (°)	β	46.20	46.20	46.20	46.20	46.20	46.20
P - Gush position index of light	index	P	2.63	2.63	2.63	2.63	2.63	2.63
w - Width of light	meters (m)	w	0.23	0.23	0.23	0.23	0.23	0.23
h - Height of light	meters (m)	h	0.13	0.13	0.13	0.13	0.13	0.13
d - Viewing distance	meters (m)	d	2.89	2.89	2.89	2.89	2.89	2.89
θ° - Viewing angle (in degrees)	degrees (°)	θ in °	46.20	46.20	46.20	46.20	46.20	46.20
θ rads - Viewing angle (in radians)	radians (rads)	θ in rads	0.81	0.81	0.81	0.81	0.81	0.81
ω - Solid angle of light	steradians (sr)	ω	0.002	0.002	0.002	0.002	0.002	0.002
L ft - Luminance of light (in ft)	footlamberts (f)	L in ft	592	900	1150	592	900	1150
L cd/m ² - Luminance of light (in cd/m ²)	candela per meter ² (cd/m ²)	L in cd/m ²	2028.35	3083.63	3940.20	2028.35	3083.63	3940.20
UGR - Unified Glare Rating	index	UGR	21.35	20.18	20.55	20.05	19.78	20.03
UGR Difference			-	1.16	-0.37	-	0.27	-0.24
DIFFERENCE			1.85	4.14	4.63	3.18	5.30	6.73
UGR with fill light compared to UGR with fill light, ceiling and floor lamps.			Higher	Higher	Higher	Higher	Higher	Higher

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CALIBRATION CERTIFICATION

This is to certify that the subject instrument was tested and calibrated at Spectra Light Laboratories on this date, using standards that are traceable to the U.S. National Institute of Standards Technology, and was found to comply with all applicable specifications. Test records are on file and are available for examination and verification. Our calibration system requirements satisfy MIL-STD 45662 (A)

We also certify that these instruments and accessories were produced in conformance with all contractually applicable Spectra Light Laboratories specifications, as referenced in or furnished with your purchase order number: VERBAL

This instrument was specially calibrated for your application, and was found to be within its rated accuracy. The following is the pertinent calibration data:

CALIBRATION PARAMETER	ACCESSORIES	CALIBRATION LEVEL	CORRECTION <small>(READING MULTIPLIER)</small>
Illuminance, Cosine Corrected	Cosine Receptor	10.00 FC	1.0
Luminance	Photospot Attachment	10.00 FL	1.0
Luminance (back-lighted)	Fiber Optics Probe	N/A	
Luminance (back-lighted)	Micro Reader Probe	N/A	
Illuminance Level	White light	N/A	

All calibration and tests were accomplished at the following environmental conditions:
Laboratory Condition - 25°C +/- 2°C, 45% R. H.

Calibration and Test Equipment Used

Luminance - The equipment for determining luminance measurement was Photo Research PR-1980A Pritchard Photometer S/N: C909 in conjunction with a Spectralon Reflectance Standard traceable to SRS-99-020-REFL-51 (NIST). The photometer was calibrated prior to use using a NIST traceable luminous intensity standard lamp # 844-261021-99

Power and Voltage Standard: -- Summit Technology PowerSight PS 250 Power Analyzer S/N: 25395.
PowerSight PS 250 NIST to traceable standards.

In Charge of Testing

Certified by Gabriel Perez Date October 15, 2008
Gabriel Perez/Laboratory Supervisor/Photometric Testing

Report Reviewed by

Nasir J. Zaidi, Laboratory Director

NOTE: This certification is good for only six months

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CALIBRATION LAB

GENERAL NOTES ON THE ACCURACY OF PHOTOMETRIC CALIBRATIONS AND MEASUREMENTS

The absolute accuracy of any measurement is limited by the uncertainty of the calibrating standard. Spectra Light Laboratories (as well as all photometer manufacturers) is limited by the uncertainty of the calibration standards maintained by the National Institute of Standards Technology in Washington D.C.

The absolute uncertainty of the standard of luminous intensity ("candela") at NIST in 1972 was reported as follows¹:

I.	SUBSTITUTION CALIBRATION	
A.	Time dependant bias	1.0%
B.	Constant Bias	0.0%
C.	Random Variation	0.5%
II.	TRANSFER CHAIN	
A.	International intercomparison at 2856K (1/2 range)	.85%
B.	International intercomparisons, inconsistency in Realizing the candela at the platinum point and 2856K	3.5%
III.	PLATINUM POINT CALIBRATION	1.5%
	TOTAL UNCERTAINTY.....	7.35%

Therefore, no photometric measurement can be made with certainty to an absolute accuracy of less than 7.35%, however, relative measurements can be made with much greater accuracy. If the calibration of a photometer is checked periodically, the relative accuracy may be on the order of +/- 2.5 %.

In the use of any photometric instrument for maximum accuracy, particular care must be taken to exclude stray light. Other causes of error include the measurement of non-uniform sources and errors due to color differences. All calibrations performed by Spectra Light Laboratories are made by using 2854 Kelvin "white light" or measurement of color sources may result in serious errors unless the instrument was specifically calibrated with a similar source.

In addition to an absolute calibration, photometers calibrated by Spectra Light Laboratories generally include a linearity check on one range and a range-to-range tracking. On most new instruments, the spectral response, photodetector fatigue, focus variation, and line voltage regulation are also checked.

For photometers equipped with internal calibration reference sources, calibrations are made after the instrument has been carefully standardized with respect to the internal source. Calibration values and factors are given on the calibration report or in the instruction manual and must be used to achieve accurate results.

¹ V.I. Burns and D.A. MC Sparron, Optical Radiation Measurements: Photometric Calibration Procedures, NIST Technical Note 594-3, Washington, 1993.

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Appendix J – Voltage Correlations

Setup for Measurements

The following diagram shows how voltage, current, luminance, and illuminance were measured to collect data for the correlations.

Luminance-to-Voltage Correlation

The following diagram shows the luminance-to-voltage correlation. An analysis of bivariate association in JMP produced a near-perfect positive Pearson correlation of 0.99 ($p = < .0001$, $N = 298$).

— Linear Fit
— Polynomial Fit Degree=4

Linear fit equation

$$\text{Luminance} = -1535.859 + 127.72862 * \text{Voltage}$$

Polynomial fit equation

$$\text{Luminance} = -1809.881 + 142.59575 * \text{Voltage} + 0.0137233 * (\text{Voltage} - 16.7465)^2 - 0.6927033 * (\text{Voltage} - 16.7465)^3 + 0.099252 * (\text{Voltage} - 16.7465)^4$$

Illuminance-to-Voltage Correlation

The following diagram shows the illuminance-to-voltage correlation. An analysis of bivariate association in JMP produced a near-perfect positive Pearson correlation of 0.99 ($p = < .0001$, $N = 384$).

— Linear Fit Light Height=="Low"
 — Linear Fit Light Height=="High"

Linear fit equation (low light height)

$$\text{Illuminance} = -96.34264 + 7.5435065 \cdot \text{Voltage}$$

Linear fit equation (high light height)

$$\text{Illuminance} = -86.52143 + 6.8107143 \cdot \text{Voltage}$$

Illuminance-to-Voltage Data

The following table shows the overall average illuminance-to-voltage mappings, followed by separate mappings for the low and high light height conditions. The last column highlights the differences between the low and high averages.

Voltage	Avg. Illum.	Avg. Illum. L	Avg. Illum. H	L-H Diffs
11.50	1.00	1.00	1.00	0.00
12.00	1.00	1.00	1.00	0.00
12.50	1.00	1.00	1.00	0.00
13.00	2.94	2.63	3.25	-0.63
13.50	5.50	5.50	5.50	0.00
14.00	8.19	8.50	7.88	0.63
14.50	12.19	12.63	11.75	0.88
15.00	15.06	15.63	14.50	1.13
15.50	19.00	20.00	18.00	2.00
16.00	23.25	24.25	22.25	2.00
16.50	27.31	28.38	26.25	2.13
17.00	30.94	32.13	29.75	2.38
17.50	34.44	35.88	33.00	2.88
18.00	38.63	40.25	37.00	3.25
18.50	41.88	43.75	40.00	3.75
19.00	45.50	47.50	43.50	4.00
19.50	48.63	50.75	46.50	4.25
20.00	52.63	55.50	49.75	5.75
20.50	56.31	58.88	53.75	5.13
21.00	59.25	61.88	56.63	5.25
21.50	62.69	65.88	59.50	6.38
22.00	65.81	69.13	62.50	6.63
22.50	69.63	72.88	66.38	6.50
23.00	73.13	76.38	69.88	6.50

Appendix K – Post-Test Survey

The Fill Light

1. Which room lighting condition(s) benefitted from the fill light? Check all that apply:

- ☐ "Bright" room lighting
- ☐ "Moderate" room lighting
- ☐ "Dim" room lighting
- ☐ None of these conditions

2. How would you rate the fill light's overall effect on *picture quality*?

- ☐ 5 – Very positive
- ☐ 4 – Mostly positive
- ☐ 3 – Neutral
- ☐ 2 – Somewhat negative
- ☐ 1 – Very negative

3. How would you rate the fill light's overall effect on your *experience*?

- ☐ 5 – Very positive
- ☐ 4 – Mostly positive
- ☐ 3 – Neutral
- ☐ 2 – Somewhat negative
- ☐ 1 – Very negative

4. How *important* is it for TelePresence products to have a fill light?

- ☐ 5 – Very important
- ☐ 4 – Mostly important
- ☐ 3 – Neutral
- ☐ 2 – Somewhat unimportant
- ☐ 1 – Very unimportant

Your Family Room

5. What kind of light do you have in your home family room? Check all that apply:

- ☐ Daylight (from windows)
- ☐ Incandescent (typically a "warmer" light from traditional bulbs in lamps)
- ☐ Fluorescent (originally in long tubes, but now in a twisted compact design)
- ☐ Halogen (typically a "brighter" light in a very compact bulb)
- ☐ Other: _____
- ☐ I don't know

6. What kind of lamps do you have in your home family room? Check all that apply:

- ☐ Ceiling (recessed or hanging)
- ☐ Sconces (small lights attached to the walls)
- ☐ Down light from shade
- ☐ Table lamps
- ☐ Floor lamps
- ☐ Other: _____
- ☐ I don't know

7. What paint color(s) are used on the walls of your home family room?

8. How high is the ceiling in your home family room?

9. How is the TV positioned in your family room?

- ☐ Mounted to the wall
- ☐ Placed on a TV stand
- ☐ Placed inside an entertainment center
- ☐ Other: _____
- ☐ I don't have a TV

10. When you're sitting in front of your TV in your home family room, where are there light sources, and what kind? Check all that apply:

- ☐ In front of me, there is a: _____
- ☐ Behind me, there is a: _____
- ☐ To the left of me, there is a: _____
- ☐ To the right of me, there is a: _____
- ☐ I don't know

11. Which fill light placement(s) would you prefer in your family room? Check all that apply:

- ☐ Above the TV
- ☐ Below the TV
- ☐ On either side of the TV
- ☐ On a coffee table in front of me
- ☐ As small lamps on tables or shelves
- ☐ Other: _____
- ☐ None of these placements

12. How would you like to set the brightness of the fill light? Check all that apply:

- ☐ Fill light automatically adjusts based on the amount of room lighting
- ☐ I can manually control the amount of light coming out of the fill light
- ☐ Other: _____

Appendix L – Post-Test Survey Results

The Fill Light

1. Which room lighting condition(s) benefitted from the fill light? Check all that apply:

- 8: "Bright" room lighting
- 17: "Moderate" room lighting
- 24: "Dim" room lighting
- 0: None of these conditions

2. How would you rate the fill light's overall effect on *picture quality*?

- 7: 5 – Very positive
- 19: 4 – Mostly positive
- 4: 3 – Neutral
- 0: 2 – Somewhat negative
- 0: 1 – Very negative

3. How would you rate the fill light's overall effect on your *experience*?

- 5: 5 – Very positive
- 11: 4 – Mostly positive
- 9: 3 – Neutral
- 5: 2 – Somewhat negative
- 0: 1 – Very negative

4. How *important* is it for TelePresence products to have a fill light?

- 13: 5 – Very important
- 12: 4 – Mostly important
- 2: 3 – Neutral
- 3: 2 – Somewhat unimportant
- 0: 1 – Very unimportant

Your Family Room

5. What kind of light do you have in your home family room? Check all that apply:

- 28: Daylight (from windows)
- 22: Incandescent (typically a "warmer" light from traditional bulbs in lamps)
- 12: Fluorescent (originally in long tubes, but now in a twisted compact design)
- 9: Halogen (typically a "brighter" light in a very compact bulb)
- 2: Other:
 - 1: In-ceiling lights (halogen and fluorescent)
 - 1: CFL's - recessed lights and back-drop lights
- 0: I don't know

6. What kind of lamps do you have in your home family room? Check all that apply:

- 21: Ceiling (recessed or hanging)
- 2: Sconces (small lights attached to the walls)
- 3: Down light from shade
- 12: Table lamps
- 19: Floor lamps

- 2: Other:
 - 1: Natural light from windows
 - 1: Indirect floorlamp
- 0: I don't know

7. What paint color(s) are used on the walls of your home family room?

- 8: White
- 5: Off white
- 2: Beige
- 2: Light Yellow
- 1: Cream color
- 1: Pale green
- 1: Sage
- 1: Light cream
- 1: Light beige
- 1: Beige - light tan
- 1: Medium tan
- 1: Warm yellow tones
- 1: Brick color
- 1: Ivory
- 1: Light sand
- 1: Light green
- 1: Red on the lower part of the wall, and yellowish/mustard on top

8. How high is the ceiling in your home family room?

- 9: 10 feet
- 6: 8 feet
- 3: 12 feet
- 2: 11-12 feet
- 2: 9-10 feet
- 1: 9 feet
- 1: 11 feet
- 1: about 14 feet at peak (vaulted)
- 1: 9 feet, in India - 10 feet
- 1: 20 feet
- 1: Vaulted ceiling
- 1: 13 feet
- 1: Comfortable height

9. How is the TV positioned in your family room?

- 5: Mounted to the wall
- 19: Placed on a TV stand
- 6: Placed inside an entertainment center
- 0: Other
- 0: I don't have a TV

10. When you're sitting in front of your TV in your home family room, where are there light sources, and what kind? Check all that apply:

In front of me, there is a:

- 2: Floor lamp

- 1: Ceiling light
- 1: Ceiling hanging lamp
- 1: Light in the ceiling
- 1: Recessed lighting in ceiling
- 1: To the right - (fluorescent-twisted)
- 1: Hanging ceiling lamp
- 1: Table lamp (1 to the left plus 1 to the right)
- 1: Floor lamp next to the TV

Behind me, there is a:

- 2: Ceiling light
- 1: Table lamp
- 1: Natural light - windows
- 1: Natural light from a window
- 1: Windows
- 1: Hanging light / chandelier (small)
- 1: To the right (floor lamp)
- 1: Floor lamp

To the left of me, there is a:

- 6: Floor lamp
- 2: Table lamp
- 1: Ceiling light (3 spotlights - incandescent)
- 1: Windows
- 1: Ceiling light
- 1: Table, sconces
- 1: 2 sconces
- 1: Table lamp on a side coffee table
- 1: Floor light, ceiling light/fan

To the right of me, there is a:

- 8: Floor lamp
- 1: Window
- 1: Natural light windows, lamp
- 1: Floor lamp, natural light from window
- 1: Recessed lighting in ceiling
- 1: Sconces, table lamp
- 1: Deck door/window
- 1: Floor light, ceiling light
- 1: Recessed lights

Above me, there is a:

- 1: Ceiling fan with lights
- 1: Ceiling lights above
- 1: Also have lights in ceiling overhead
- 1: Lighting is on the ceiling

11. Which fill light placement(s) would you prefer in your family room? Check all that apply:

- 10: Above the TV

- 2: Below the TV
- 12: On either side of the TV
- 1: On a coffee table in front of me
- 10: As small lamps on tables or shelves
- 4: Other:
 - 1: All around me in general
 - 1: Behind
 - 1: On ceiling not flashing on me
 - 1: On both sides of the TV
- 4: None of these placements

12. How would you like to set the brightness of the fill light? Check all that apply:

- 21: Fill light automatically adjusts based on the amount of room lighting
- 19: I can manually control the amount of light coming out of the fill light
- 9: Other:
 - 1: Both. Don't want to adjust each time, but want ability to modify.
 - 1: Can move the fill light from the top to the sides and vice versa
 - 1: Automatically adjusting but with manual override
 - 1: Manual override
 - 1: Would be great for the product to adjust the light intensity and balance independent of the light conditions in the room
 - 1: Auto with override
 - 1: Both if possible (automatically by default but with the option to adjust manually)
 - 1: I prefer fill light automatically adjusted but I also would like to have power to control the level of fill light.
 - 1: Some intelligence to adjust fill light will be useful

Appendix M – Participant Demographics

*Distributions***Age** **Gender** **Eye Color**

Telepresence Experience

Lighting Experience

Participant Data

ID	Session Schedule	DT Start Position	Light Height	Age	Gender	Eye Color	TP Exp.	Lighting Exp.
P01	A	A1	Low	35	Male	Brown	Not used	Very little
P02	A	A2	Low	33	Male	Brown	Monthly	Very little
P03	B	B1	High	53	Male	Hazel	Yearly	Very little
P04	A	A1	High	38	Male	Not sure	Monthly	Some
P05	A	A2	High	52	Male	Green	Yearly	Some
P08	B	B2	High	25	Male	Hazel	Yearly	Very little
P09	B	B2	Low	36	Male	Other: Black	Not used	Very little
P10	B	B1	Low	22	Male	Brown	Yearly	Some
P11	C	C1	Low	29	Male	Other: Black	Not used	Very little
P13	C	C1	Low	37	Female	Brown	Not used	Some
P14	C	C2	Low	41	Male	Brown	Not used	Some
P15	C	C1	High	47	Male	Brown	Monthly	Very little
P16	D	D2	High	28	Male	Hazel	Weekly	None
P17	D	D1	High	39	Female	Brown	Not used	None
P18	D	D2	High	39	Male	Brown	Not used	Very little
P19	D	D1	Low	25	Female	Brown	Daily	Very little
P20	D	D2	Low	30	Male	Brown	Monthly	Some
P22	E	E2	Low	38	Male	Other: Black	Not used	Very little
P23	E	E1	Low	44	Male	Brown	Yearly	Some
P24	E	E2	High	38	Male	Brown	Not used	None
P25	E	E1	High	33	Male	Other: Black	Monthly	Very little
P27	F	F1	High	37	Male	Brown	Yearly	None
P29	F	F1	Low	35	Female	Brown	Weekly	None
P30	F	F2	Low	37	Female	Brown	Not used	Very little
P31	B	B2	High	49	Female	Hazel	Weekly	Very little
P32	F	F2	High	32	Male	Hazel	Monthly	Some
P33	A	A1	Low	50	Male	Brown	Yearly	Very little
P34	C	C2	High	36	Male	Brown	Not used	None
P35	F	F2	High	45	Male	Brown	Yearly	Very little
P36	E	E1	Low	36	Female	Green	Daily	None