Atmosphere creation in the living room

The freedom of light characteristics in atmosphere perception for the living room

By
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Master’s Thesis

August 2009

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Preface

This master's thesis represents my graduation project at the Man-Machine Interaction group of the Delft University of Technology. The study was carried out on behalf of the Visual Experiences Group at Philips Research Eindhoven. During my internship, I did research in the field of atmospheric lighting and conducted several visual experiments with regard to atmosphere perception in the living room.

My thanks and appreciation goes to prof. dr. Ingrid Heynderickx for giving me the opportunity to finish my master's thesis at Philips Research Eindhoven. Also, I wish to thanks dr. ir. Pieter Seuntiens for his excellent guidance and feedback throughout this project. I would also like to thank all my colleagues in the 'Perception Group' for giving me a great time during my internship. Last but not least, my deep gratitude to all my family and friends from whom I have all their support and prayers.

August 14th, 2009

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Summary

With the introduction of LED lighting, nowadays designers and architects have more flexibility to evoke emotions and create certain atmospheres in a space by means of artificial lighting. The perceived atmosphere in a space is an experience of the surroundings in relation to ourselves; it is an affective evaluation of the environment (Scholten et al., 2003; Vogels, 2008). Previous studies related to atmosphere perception have given valuable insight into the relation between white light and the perceived atmosphere (Vogels et al., 2008). Moreover, in (Seuntiens and Vogels, 2008) four atmospheres (cosy, relaxing, activating and exciting) were designed by professional lighting designer for a standard living room and verified by end users. This study found clear commonalities between the professional lighting designers with respect to the chosen light characteristics to evoke a certain atmosphere in the room. However, it was not clear how much variation in light characteristics was allowed before an initially perceived atmosphere disappears. In the present research three experiments were conducted to investigate the allowed variation in light characteristics (luminance, color temperature, hue and saturation) on two atmospheres, namely cosy and activating.

In the first study, a tuning experiment was conducted in order to investigate the allowed variation in light characteristics on the initially perceived “cosy” and “activating” atmosphere. In general, the results of the first experiment showed that participants allowed quite some variation in light characteristics in both atmospheres. On average participants allowed an increase in luminance of the white light sources of a factor two to four compared to the initial luminance level, and a decrease in luminance of at least a factor of two. Furthermore, a consistent change of about 800K was allowed for the increase in color temperature in the “cosy” atmosphere and the decrease in color temperature in the “activating” atmosphere. Due to technical limitations, the decrease in color temperature in the “cosy” atmosphere and the increase in color temperature in the “activating” atmosphere were not investigated in this study. Finally, the allowed change in hue and chroma of the colored luminaires was found to be larger in the “activating” atmosphere than in the “cosy” atmosphere.

In order to investigate the effect of a change in light characteristics on the perceived atmosphere, a difference scaling experiment was conducted. In this experiment, participants compared the average allowed change in light settings as obtained from the first study to the light settings corresponding to a “cosy” or “activating” atmosphere as reference. A short version of the original atmosphere questionnaire of Vogels (2008) was used to assess the perceived atmosphere in the room. The results showed that an increase in luminance of the white light sources reduced the *cosiness* and *tenseness* of the atmosphere, and enlarged its *liveliness* and *detachment* (with a reverse effect for a decrease in luminance). A decrease in color temperature was found to increase the *cosiness*, and to reduce the *liveliness* and *detachment* of the atmosphere. With regard to the colored luminaires, a change in hue was found to mainly affect the *cosiness* and *detachment*, whereas a decrease in chroma mainly affected the *liveliness* and *detachment*.

In a follow-up experiment participants assessed the perceived atmosphere for the allowed change in light settings without the initial “cosy” and “activating” atmosphere as a reference to compare with. In general, similar trends with respect to the changes in the atmosphere were found, however, the effects were considerably smaller. This indicates that participants found it more difficult to distinguish the atmosphere related to the different light settings when they could not directly compare them.

In this study, boundaries for the allowed variation in luminance, color temperature, hue and chroma were obtained for the “cosy” and “activating” atmosphere. In addition, the results gave further insight into the relation between light and perceived atmosphere. However, this research also has its limitations in the sense that some light characteristics, such as the spatial distribution of the light, and its dynamics, as well as the spatial configuration of the light sources, were not included. More research is needed to investigate the effect of these aspects on perceived atmosphere further.

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1. Introduction

The invention of artificial light has given people the ability to maintain clear visibility whilst staying indoors and thus acts as a support for their daily indoor activities. The relation between artificial light and visual performance has been investigated extensively by many researchers (e.g. Boyce, 2003; Baron et al., 1992 and Veitch, 2001). These studies were mainly focused on investigating the way people perceive different light characteristics and the way it affects the human cognition and task performance. Recently, designers and researchers realized that light should not only facilitate visibility, but can also accomplish an appropriate atmosphere and give people a pleasant feeling. With the introduction of LED lighting, nowadays designers and architects have more flexibility to evoke emotions and have the ability to create certain atmospheres in a room using artificial light. Nevertheless, despite the increased interest in atmosphere creation, to date not much is known about the effect of lighting on the perceived atmosphere.

In a previous study on atmosphere perception (Vogels, 2008), a questionnaire to assess and quantify the perceived atmosphere of an environment has been developed and verified. In a number of follow-up studies, the relation between white light and perceived atmosphere has been confirmed using the atmosphere questionnaire (Vogels et al., 2008). These studies found interesting relations between light characteristics of white light and the perceived atmosphere in an empty room. Furthermore, in a recent study it was shown that the influence of light characteristics (for white light) on the perceived atmosphere is independent of the contextual situation (Vogels and Bronckers, 2009).

In contrast to the controlled studies of Vogels et al. (2008) and Vogels and Bronckers (2009), a more practical approach was taken in Seuntiens and Vogels (2008). In that study, the relation between perceived atmosphere and light characteristics of white and colored light for a given contextual setting was investigated by asking fifteen professional lighting designers to design four atmospheres (cosy, relaxing, activating and exciting). The results of that study showed that all lighting designers were able to discriminate between atmospheres in terms of light characteristics for a given standard living room. In addition, similarities were found between the lighting designers with regard to the chosen light characteristics for the four atmospheres; no effect of gender, age or background was found. Finally, a follow-up study with end-users showed that people were able to clearly recognize the cosy, relaxing, activating and exciting atmospheres (Seuntiens, internal report 2008).

The atmosphere questionnaire of Vogels (2008) has shown its value in a number of follow-up studies. In addition, these studies gave insight into the relation between white light and context on perceived atmosphere. Furthermore, the study of Seuntiens and Vogels (2008) showed in a practical approach that there were clear commonalities for light settings to evoke a certain atmosphere. However, it was not clear what the tolerated variation in light characteristics was on an initially perceived atmosphere. Therefore, it was considered interesting to investigate how much variation in light characteristics is allowed before an initially perceived atmosphere disappears.

The aim of the current study is twofold. First, we investigate the allowed variation in light characteristics on the initially perceived atmosphere. Subsequently, the extent to which the perceived atmosphere changes for the allowed change in light settings is investigated. Consequently, the research question of this study is:

> *"What is the effect of variation in light characteristics on an initially perceived atmosphere?"*

In the rest of this report we present the results of three experiments that were conducted in order to answer the research question. This research question is further divided into the following sub questions:

- *What is the allowed variation in light characteristics on an initially perceived atmosphere?*
- *What is the effect of a change in light characteristics on an initially perceived atmosphere?*

Both research questions are answered for a variation in the light characteristics luminance, color temperature, hue and chroma starting from a "cosy" or "activating" atmosphere.

The structure of this report is as follows. First, a literature review is given in Chapter 2 in which we discuss a number of studies that are related to lighting and atmosphere perception. Next, the experimental conditions in which all three experiments took place are described in Chapter 3. Additionally, the characterization of the white and colored luminaires in the experimental room is described in the same chapter. Subsequently, the experimental design and results for the experiments are presented in the Chapters 4, 5 and 6. Next, in Chapter 7 a discussion of the results is provided in which we step back and take a broad look at our findings and study as a whole. Finally, recommendations for future work are also presented in the last chapter.

2. Literature review

While little is known about the effects of lighting on atmosphere perception, numerous studies have investigated topics that are strongly related to atmosphere perception. In this chapter we will discuss a number of studies that are closely related to lighting applied to atmosphere perception. First, an introduction to atmosphere perception is given. Next, studies with regard to the human perception of light characteristics are discussed. Finally, research concerning environmental appraisal and atmosphere creation can be found in the last section of this chapter.

2.1 Introduction to atmospheric lighting

According to Vogels (2008), an atmosphere is the experience of the surrounding in relation to ourselves. It is a subjective experience through the perception of external elements and internal sensation. Atmosphere differs from emotion and mood in the sense that it is not an affective state, but rather an experience of the surroundings in relation to ourselves. Therefore, the perception of an atmosphere is an affective evaluation of the environment (Scholten et al., 2003; Vogels, 2008). While people might have different opinions about the atmosphere of an environment, it is expected that the effect of light on perceived atmosphere will be more consistent than the effect on mood.

The need for pleasant and appropriate atmospheres has always existed. For example, people prefer to dim the light to create a suitable atmosphere for watching a movie with friends or light up some candles to create a more romantic atmosphere. While these simple light settings can be achieved by simple tasks such as dimming the light and lighting up some candles, the possibilities for creating different kinds of atmospheres are limited. So far, the creation of specific atmospheres to fit certain activities have been mainly the domain of experts such as stage/theatre experts, interior designers and lighting designers (Harkin et al., 2005). In the past few years, the need for personal customization to fit individual needs has increased. This trend can be found in different kinds of industries where the specific needs of individuals are taken into account (e.g. fragrance and car industries). In the same manner, research revealed that people are now also interested in getting more involved in creating their own atmospheres that support their own activities (Diederiks and Hoonhout, 2006).

While the current approach taken by experts to create specific atmospheres will continue to exist in professional and high-end consumer installations, we believe that there is significant value to be captured by providing an easy to use lighting solution with built-in expert knowledge. Such lighting solution will allow people to create their own atmosphere light scenes in a less time consuming and expensive way compared to the approach taken by experts. Besides the possibility of creating personal light scenes from scratch, it is important that such lighting solution provides users with a number of atmosphere presets to help them get started. In order to create atmospheres using artificial indoor lighting and understand how people experience lighted environments, we first need to understand how people perceive the characteristics of light, and how that can be linked to their internal sensation and mood.

2.2 Understanding characteristics of light

In this paragraph we first discuss studies that are related to the perception of light characteristics that are important for atmosphere creation. The effects of white light on performance and preference will be discussed subsequently. Finally, studies related to color preference and color association can be found in the last section.

2.2.1 Perception of light characteristics

In this section we discuss a number of studies that are related to human perception of light characteristics. Brightness, color temperature, color and spatial distribution of light are known as important factors in atmosphere light design (Seuntiens and Vogels, 2008). Therefore, these light characteristics are discussed in more detail in the rest of this section.

2.2.1.1 Brightness

Intensity is the amount of radiant energy transferred per unit area. While several measures of light are commonly known as intensity, in light engineering illuminance and luminance are often used to express the amount of light measured (Fairchild, 1998). Illuminance is defined as the luminance power per unit area falling on a surface; the unit is lumen per square meter ($lm\, m^{-2}$) and is called lux (lx). Luminance refers to the luminance power emitted or reflected from a surface per solid angle and per unit area of the surface; the unit of luminance is candela per square meter ($cd\, m^{-2}$) and is also called nit. Luminance is related to the visual perception of brightness.

Brightness is a perceptual subjective quantity defined by the Commission Internationale de L'Eclairage (CIE) as the visual sensation to which an area appears to emit more or less light. The apparent brightness of a surface depends not only on its luminance, but also on the luminance of its surroundings that constitutes our visual environment (Cayless and Marsden, 1983). While the sensation of brightness has no objective measure, it is useful for engineering purposes to understand the relationship between the actual luminance and the perceived brightness under different situations. Several experiments regarding that relationship have been conducted. For example, Stevens (1975, as cited in Cayless & Marsden, 1983) offered a method to create a ratio scale of perceived brightness using the magnitude estimation procedure. In another study, it was shown that the perceived brightness of any single surface in the room increases with the luminance according to a power law with an exponent of 0.35 (Boyce, 2003). Moreover, the brightness for a number of surfaces seen simultaneously follows a power law with an exponent of 0.6. However, due to differences between individual perceptions of brightness, the previously described relationships between luminance and brightness should be used for guidance only (Cayless and Marsden, 1983; Boyce, 2003).

In a research conducted by Loe et al. (1994) participants were presented with 18 different lighting patterns in a room that was furnished like a small conference room. By means of a traditional semantic differential scale technique, each of the light conditions was assessed by the participants from a fixed position at the side of the room. Loe et al. (1994) concluded that the average luminance in the range of 40 degrees vertical visual angle best explains the sensation of brightness. They suggest that there possibly exists an observation area which is closely related to the sensation of brightness. However, since the experiment was carried out by participants sitting in a fixed location in the room, it is interesting to know whether the findings are reproducible for subjects that are positioned at different locations in space.

In Bernecker and Mier (1985) and Akashi et al. (1995) the relation between brightness and the luminance of the visible portion of the luminaire was investigated. They found that the sensation of brightness increases when the luminance of the visible portion of the luminaire gets higher. The results of these studies suggest that by varying the emitting surface of a luminaire appropriately we can control the perceived brightness. However, since brightness is a subjective evaluation of the environment the findings from these studies do not represent the overall brightness impression in a room space.

While the above mentioned studies have investigated the sensation of brightness for different factors, the experiment in each study was controlled in such a way that only the influence of one factor on the sensation of brightness was investigated. In a study by Iwai et al. (2001) the sensation of brightness in a living room was quantitatively evaluated for a combination of different factors. In this study the effect of the psychophysical factors of the average luminance of specific areas and the luminance of the visible portion of the luminaire were investigated together. Also, in contrast to previous studies where the experiments were conducted in office spaces, this study was conducted in a space furnished as a living room. The study of Iwai et al. (2001) concluded that the average luminance of the front wall and the average luminance of the room corners contributed highly to the sensation of brightness in the living room with down lights. Although the results show similar trends to with the findings of Loe et al. (1994), they concluded that the average luminance within the 40 degree visual field alone cannot explain the sensation of brightness. This supports the finding of Nakamura and Karasawa (1997) who found that it was difficult to calculate the average luminance through analysis of the relation between average luminance within the 40 degree visual field and the sensation of brightness.

Studies related to the perception of brightness have also investigated the relationship between the illumination in a room and its impression of brightness (Iwai et al. 2001). Taking the future into account, it is important to establish a method to quantitatively evaluate the perceived brightness in a room; this in order to create an amount of brightness sensation with as less energy as possible. In addition, brightness is an important factor in the selection of lighting, since an illuminated space is perceived to be dark is not preferred (Iwai et al, 2001).

Many studies, for example Loe et al. (1994) and Ishida and Ogiuchi (2000), investigated the relation between illuminance and the sensation of brightness in a space where the visual direction was fixed. However, since people move in three-dimensional space, it can be expected that the eyes will move in various directions and will be hardly fixed to a single direction. In a recent study of Kato and Sekiguchi (2005) the relation between illuminance and the sensation of brightness was investigated for different patterns of illuminance. The experiment was conducted under two conditions: (1) with a fixed visual direction, and (2) with an unfixed visual direction. Furthermore, in contrast to the previous studies, the experiment was carried out in an experimental space which was large enough for the observer to be inside and move around. The results of the experiment showed that the evaluation of brightness becomes higher for illumination in the horizontal direction and lower for vertical direction. Furthermore, it is confirmed that the impressions of brightness vary depending on the visual direction of the observer.

2.2.1.2 Color of light

Most artificial light sources are a mixture of various wavelengths and intensities of light. Manufactures can influence the color of an artificial light source by controlling the different wavelength components of the light. Different colors can be created by producing different spectra. The color of light comprises two aspects. On one hand we have white light which can have different shades from cool to warm. On the other hand we have colored light which has different shades from saturated to pastel. Until recently, most of the studies related to the perception of the color of light were related to white light. More recently, numerous studies have investigated topics regarding color preference and color association in general. These studies can give us insight in choosing appropriate colors for colored light sources to enhance the perceived atmosphere. In the rest of this section we first discuss studies that are related to the perception of color of white light. Next, properties of colors in general are described. Studies relating to color preference and association are discussed later in section 2.2.4.

Color of white light

The color of white light is described by the color temperature (CT), which value is determined by the chromaticity coordinates of a hot object, called a black body radiator. The spectral power distribution of a black-body radiator can be specified using Planck's equation as a function of a single variable, the absolute temperature in Kelvin. However, since black-body radiators rarely exist outside laboratories, CT is not a useful quantity. Therefore, instead of CT the correlated color temperature (CCT) is used in general. The CCT of a light source is the color temperature of a black body radiator that has almost the same color as the source in question (Fairchild, 1998). As the CCT of the source increases, the color will become more bluish. On the other hand, as the CCT decreases the color of the light source will be become more reddish. The values of CCT can be estimated by using the CIE chromaticity diagram that is depicted in Figure 1.

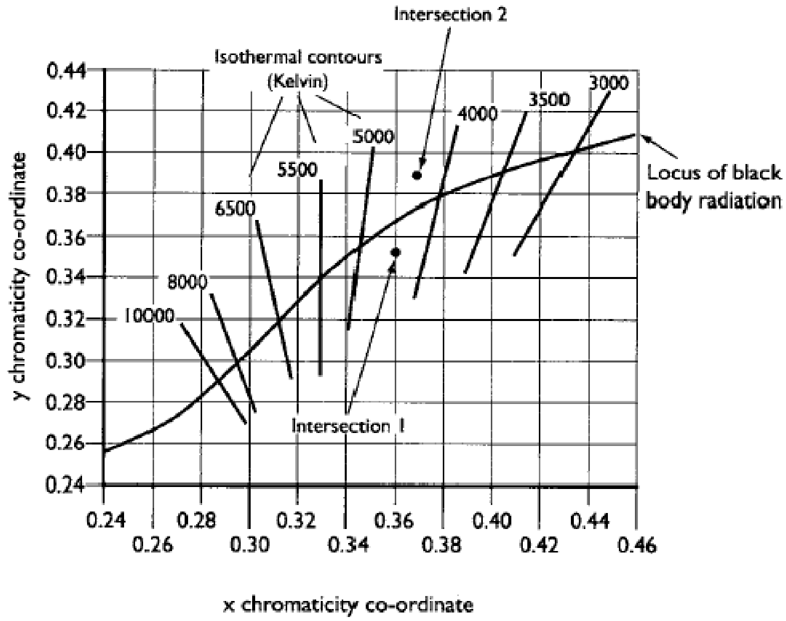


Figure 1: Isothermal contours on CIE chromaticity diagram

The diagram in Figure 1 shows the region of the black body radiation with several isothermal contours corresponding to a color temperature in Kelvin. An important point to mention is that identical CCT of light sources can be represented by different chromaticity coordinates. For example, the intersection points 1 and 2 depicted in Figure 1 while having different x, y chromaticity coordinates are sharing the same CCT of around 4500K. Therefore, care should be taken when one specifies a light source by CCT only which can be very misleading.

A research conducted by Davis and Githner (1990) investigated the effects of CCT and illuminance level on lighting perception. In this study, 40 subjects examined two light sources with a different color temperature at three different illuminance levels. One lamp with a CCT of 2750K and the other a CCT of 5000K. The result of the study showed that the subjects were able to clearly distinguish the two different color temperatures of the light sources being used. Furthermore, the color temperature changes were recognized by subjects as being distinct from the illuminance level changes. Hu et al. (2006) used three linear brightness models, two color appearance models, and two psychophysical experiments to investigate whether we could describe the perception of brightness as a function of CCT. The result from the experiments confirmed the observation Davis and Ginthner (1990) that the perception of CCT and brightness were not related.

Other studies suggested a possible relation between age and gender on perceived CCT. In Knez and Enmarker (1998), two levels of CCT, i.e. 2750K and 4000K at two different illuminance levels were presented to the subjects. Interestingly, the results of the experiments showed that females were less sensitive to high CCT compared to males. In another study, Knez and Kers (2000) found that younger people perceived the overall color temperature in a room as colder compared to older people. The difference in perceived color temperature between the younger and older people can be explained by the fact that the human eye deteriorates due to the aging process.

In van Erp (2008) the discrimination in color temperature has been investigated in a pilot experiment with five participants. The experiment followed a forced choice design with a fixed reference with CCT of 3469K; the reference and test stimuli were presented simultaneously. In total, eleven test stimuli varying from 3013K to 3986K with a step size ranging between 81K and 123K were selected. Participants were asked to judge whether the reference light was more bluish than the actual stimulus (yes or no). The results showed that the smallest difference in CCT that people could perceive was at least 75K. Obviously, it can be argued whether the findings of van Erp (2008) are reliable due to the small amount of subjects that participated.

Color properties

In order to describe a color, the following three visual qualities of color are used: (1) hue, (2) colorfulness and (3) lightness. The hue is often described by people using the words; “it’s the name of the color”. The colorfulness is related to the perceived intensity of a color. Other concepts that are related to the perceived intensity of a color are chroma and saturation. However, these concepts are not the same. Colorfulness refers to the perceived intensity of a color according to which the perceived color of an area appears to be more or less chromatic. On the other hand, saturation is the perceived intensity of a color compared to its brightness. Finally, with chroma we mean the perceived intensity of a color judged against the brightness of a similarly illuminated area that appears white. Lightness, the third property of a color, is the quality by which we distinguish a light color from a dark one. It is the brightness of an area compared to the brightness of a similarly illuminated area that appears white (Munsell, 1946; Fairchild, 1998).

The three visual qualities of color mentioned above represent the dimensions in which most of the color spaces are described. Many designs of color spaces exist. The CIE 1931 XYZ color space was one of first ones based on the human color perception. A great amount of color spaces are based on the CIE 1931 XYZ color space, for example the CIE 1976 LAB and CIE 1976 LUV color spaces. In contrast to the CIE 1931 XYZ color space, the CIE 1976 LAB and CIE 1976 LUV are appearance models that are designed to be more perceptually uniform. The CIE 1976 LAB and CIE 1976 LUV color appearance models enable people to predict and calculate color differences (Fairchild, 1998). The Euclidean distance (ΔE^*_{00}) between two points in these spaces can be taken as a measure of their color difference (Sharma et al., 2004). A huge amount of literature describes the properties of different color spaces extensively. For an in depth overview of the development of color spaces and colorimetry in general please refer to Wyszecki and Stiles (2000) and Fairchild (1998).

2.2.1.3 Spatial distribution and direction of light

The spatial distribution is formed by two aspects: (1) the distribution or pattern of the light, and (2) the location of the light source. By controlling the spatial distribution of light in a space we can control the degree of uniformity. Furthermore, it influences the way we perceive space. In order to create a uniform light effect in a space we can choose to illuminate the whole space evenly. Conversely, by spreading the light in a space unevenly we can create patterns and create zones within a space; thus achieving a non-uniform light effect. The amount of uniformity in a room can be controlled by the number of luminaires, their location, and their direction for emitting the light.

The direction of light refers to the angle in which the light is emitted by the luminaire; this can be directional or diffuse. Directional light results in spots with well defined edges. On the other hand, more diffuse light will result in shadows with softer edges to no shadows at all. People can control the direction of light by positioning the light source and choosing different beam angles. Directional lighting can be used to highlight something and makes it stand out. Furthermore, by emphasizing specific parts in a room, we can draw the attention of the observer.

According to Boyce (2003), it is widely believed that diffuse lighting is perceived as less bright compared to directional lighting with the same illuminance. However, this is dependent on the light distribution of the luminaire. For example, by narrowing down the luminous intensity distribution, the amount of light that reaches the wall decreases. As a result, the directional luminaire will have a low luminance from most viewing directions and produce a lower perceived brightness than indirect lighting.

In Tiller and Veitch (1995) the effects of illuminance level and luminance distribution on perceived brightness have been investigated. By means of a matching experiment, participants viewed one office and were asked to adjust the lighting in a second office to the same perceived brightness as the first office. Four rooms were used for this experiment, two with a uniform distribution of luminance and two with a non-uniform luminance distribution. While the distribution of luminance differed in all rooms, the average luminance across the subject's field of view was the same. The participants viewed all the four rooms through a viewport from a fixed location. The results of the experiment showed that the rooms with a non-uniform luminance distribution were perceived as brighter compared to the rooms with a uniform distribution. In other words, subjects required a higher illuminance when they were adjusting the room with uniform luminance distribution to make it as bright as the room with a non-uniform distribution. Contrary, when a room with a non-uniform luminance distribution was matched with a room with uniform luminance distribution, subjects required less illuminance.

The study of Loe et al. (1994) concluded that the luminance within a 40 degrees vertical angle about the line of sight was most important in determining the perception of brightness. However, a 40 degrees angle around the line of sight suggests that the luminance of the wall is emphasized more relative to the ceiling and the floor. This is in contrast with the findings of Miller et al. (1995, as cited in Boyce, 2003). They used different illuminance levels with direct lighting, with and without wall-washing and indirect lighting to find a relation between light distribution and the perceived brightness they concluded that the relation between the perceived brightness and the luminance distribution of different surfaces could be best explained by both the luminance of the wall and the ceiling. Despite this contradiction, both studies justified the of use wall-washing to enhance the perception of brightness in a room (Boyce, 2003).

2.2.2 Effects of white light on affective state and cognitive performance

The studies so far discussed mainly focused on the human visual perception of different light characteristics – mainly the brightness and color temperature. These studies were often restricted to finding the optimal lighting conditions for different perceptual tasks or finding threshold values for visual discomfort. While it might sound plausible that lighting has non-visual psychological effects on people, it is not until recent that studies investigated the impact of lighting on people's affective state and cognitive performance. In the rest of this section we discuss a number of studies that investigated the effect of indoor lighting on the human affective state and cognitive performance.

In Baron et al. (1992) the effect of indoor lighting on the affective state, performance of cognitive tasks and interpersonal behavior was investigated. In this study, three separate experiments were conducted where participants carried out a number of cognitive tasks under a specific light condition. The light condition differed in terms of illuminance and color temperature. Besides performing the cognitive tasks, subjects evaluated the experimental room on several dimensions. Some of these dimensions were related to affective reactions, while others directly referred to the lighting. In the first experiment, the participant's mood was assessed using the 5-point PANAS questionnaire (Watson et al., 1988). Since no significant effects were found for the positive and negative affect derived from the PANAS questionnaire, a second experiment was conducted using the Current Feelings Survey before and after the performed tasks.

The main conclusions that of this study were that lighting conditions could influence human behavior and task performance, but they were not able to demonstrate a direct relation between lighting conditions and the affective state. They concluded that there was no evidence that subjects experienced differential affective reactions to the various lighting conditions. They could only suggest that there was an effect of low illuminance (150 lux) and low color temperature on the positive affect. Observers were more likely to describe the experimental room as relaxing and pleasing when under warm CCT or low illuminance. The lack of significant effects of the lighting conditions on subjects' feelings could be caused by many factors. For example, one may argue whether the methods used to assess the subjects' feelings were sensitive enough. Furthermore, only a small number of lighting conditions were presented to the participants; it is possible that illuminance and color temperature needed to be varied over a wider range to cause a significant effect. Finally, they did not mention how long the subjects were exposed to the light conditions. There might be a possibility that the exposure time for the light conditions was not sufficient to cause a measurable emotional response using the PANAS.

In a range of studies, Knez and his colleagues (1995a; 1995b; 1997; 2000; 2001) investigated the effect of indoor lighting on mood. In addition, they investigated whether a possible change in mood caused by a luminous setting could affect the cognitive task performance of participants. In these studies, a number of experiments were conducted where participants had to perform a number of cognitive tasks, while being exposed to a certain lighting condition. In contrast to the study previously discussed (Baron et al., 1992), the mood was measured twice, i.e. in the beginning of the experiment and after the experiment using PANAS (Watson et al, 1988). Also, participants were exposed to the lighting conditions for a longer period of time. The main conclusions of these studies were that different combinations of illuminance and color temperature had a significant effect on people's mood. In contrast to Baron et al. (1992), the effects of illuminance and color temperature on mood were found to be significant. The positive affect in females was found to be higher in low color temperature, and decreased for higher color temperature. The reverse relation was found for the males. Furthermore, Knez (1995a; 1995b) showed that the performance of the cognitive tasks was improved when using a combination of light parameters (illuminance and color temperature) that best preserved the positive affect. This support the hypothesis that people's cognitive performance could be affected due to the change in positive and negative affect.

It is important to note that the studies of Baron et al. (1992) and Knez (1995a; 1995b; 1997; 2001) were all performed in a laboratory setting which was furnished like an office. Furthermore, the light settings presented to the participants in both studies were not common in daily residential spaces. Additionally, rather extreme values were chosen for the illuminance levels in both studies. It would be interesting to know whether similar findings could be found when people were presented with less extreme light conditions and under different contextual settings.

In McCloughan et al. (1999), the impact of lighting on mood was investigated using four less extreme lighting conditions. The participants were presented randomly with one of the four lighting conditions in which they performed some simple tasks. The mood was assessed twice using the Multiple Affect Adjective Checklist Revised scale (MAACL-R) (Zucker and Lubin, 1985). The following five major mood components were measured by the MAACL-R scale: (1) anxiety, (2) depression, (3) hostility, (4) positive affect and (5) sensation seeking. The first mood measure took place five minutes after the experiment started, and the second one at the end of the experiment. The result of this study showed that the components of the MAACL-R questionnaire could be grouped into two factors: (1) Dysphoria (negative mood; anxiety, depression and hostility) and (2) PASS (positive mood; positive affect and sensation seeking). McCloughan et al. (1999) found that there was a difference in short and long term effects of illuminance and color temperature on the measured mood. Short term effects showed that sensation seeking was higher in low illuminance, and hostility was significantly higher under warm color temperature. Long term effects, on the other hand, showed that positive mood appeared to be more stable compared to the negative mood. This could be due to the fact that when people were exposed to a lighting condition for a longer period they got used to the environment and the sensation seeking was not affected by the lighting condition anymore. In general, the findings of McCloughan et al. (1999) were in line with the findings of Knez (1995a; 1995b) with regard to the interaction effects between illuminance, CCT and gender influencing negative mood. However, McCloughan et al. (1999) was not able to explain the increase in negative mood for males under a warm CCT condition.

2.2.3 Preference of white light

Numerous studies investigated the relation between illuminance, color temperature and light preference. The research of Kruithof (1941) is recognized as one of the classic studies that investigated the relation between illuminance and preferred color temperature. This study showed the upper and lower limits of preferred illuminance levels depending on the color temperature of the light source. The results are summarized in Figure 2. According to this study, the atmosphere is calm and warm in a room of low color temperature in combination with low illuminance. On the other hand, the use of a high color temperature in combination with low illuminance creates an unpleasant atmosphere; in that case, a high illuminance is more appropriate.

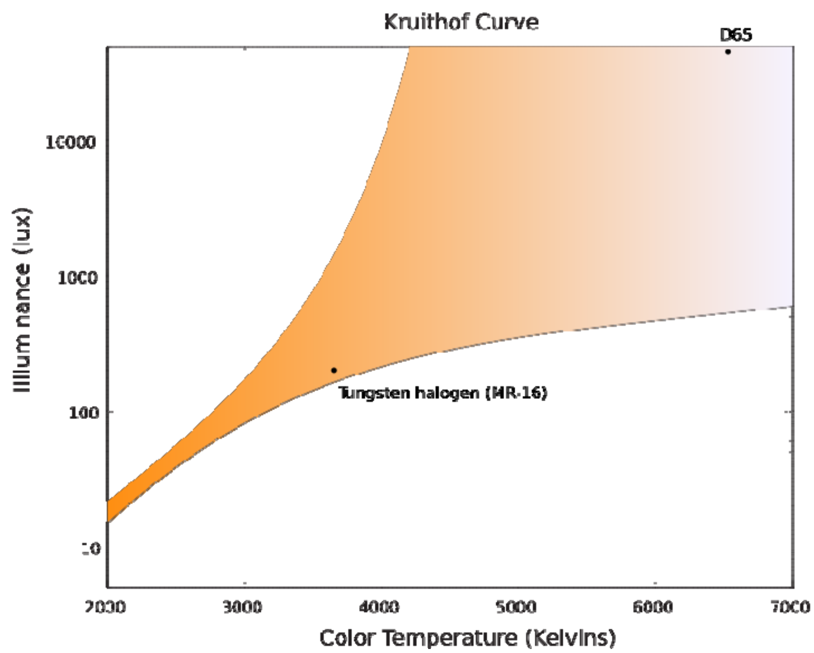


Figure 2: The results of the study of Kruithof (1941) are summarized above in the so called "Kruithof curve". The colored (orange) region relates to the combinations of illuminance and color temperature levels that are perceived as pleasing.

While the study of Kruithof (1941) has gathered quite some recognition, other studies related to the preference of illuminance and correlated color temperature were inconsistent in either supporting or contradicting the results found by Kruithof. One problem with the study of Kruithof was that he did not consider the influence of activities on the preference of lighting conditions (Oi and Takahashi, 2007; Nakamura and Karasawa, 1999). Furthermore, a problem with the setup of the experiment was that the diffuse properties of the light changed simultaneously with the change in color temperature (Nakamura and Karasawa, 1999).

Davis and Ginthner (1990) evaluated the appropriateness of the "Kruithof curve" while taking into account that the diffuse properties of the light remained stable while the color temperature was changed. In contrast to the study of Kruithof (1941), the primary finding of this experiment was that the subjective ratings for preference were influenced only by light level and not by color temperature. This finding was further strengthened by the fact that subjects participating in the experiment were able to recognize color temperature changes as being distinct from light level changes. However, we have to emphasize that this does not mean that color temperature has no influence on the preference of lighting. The findings of Davis and Ginthner (1990) were established a given experimental setup: i.e. with luminaires with a high color rendering index and a small conference room as contextual situation. In other words, it might be possible that in a different contextual situation, for example a living room, the correlated color temperature has an influence on the preference of light. Furthermore, Davis and Ginthner (1990) suggested that there may be an important effect of color rendering index on the preference of color temperature.

In another study by Nakamura and Karasawa (1999), the relationship between illuminance, color temperature and preference of atmosphere was investigated for the living room as contextual setting. In addition, the possible effect of activities on lighting preference was considered. The experiment consisted of two sessions in which the participants were presented with 16 light conditions. In the first session the participants were asked to evaluate the atmosphere of the overall space, while imagining a communal state where they conversate cheerfully with their family. In the second session, participants were asked to evaluate the atmosphere of the overall space while imagining a solitary state in which they relax and drink a cup of coffee alone. The study of Nakamura and Karasawa (1999) concluded that in the communal state, the preference of light increased in parallel with an increase in illuminance in the range from 100 lx to 400 lx. On the other hand, in the solitary state, the relation between illuminance and preference of light was less strong. In both the communal and solitary condition, a lower color temperature was preferred for all illuminance levels of the experiment. This suggests that illuminance had a larger influence on the preference than color temperature, which supported the findings of David and Ginthner (1990). Additionally, a comparison with the results of Kruithof (1941) showed that only the results for the communal state were similar. Thus, the results of Nakamura & Karasawa (1999) indicated that the preferred illuminance and color temperature vary by the activities of the users. These findings were further supported by Oi and Takahashi (2007).

The previous studies found interesting factors that might affect the preference of illuminance and color temperature when designing atmospheres, such as the contextual setting and the activities of people in the room. Other studies also found a relationship between gender and the preference of color temperature. For example, Knez (1995a; 1995b; 1997) and Knez and Kners (2000) found that males rated cool lighting as less negative, while females rated warm lighting as less negative using the PANAS questionnaire (Watson et al., 1988). In other words, the results of the study showed that males preferred lighting with a higher color temperature, while females preferred lighting with a lower color temperature. In McCloughan et al. (1999) where the impact of lighting on mood was investigated, the same relation between color temperature and negative mood was found for the female participants only. The study could not confirm the increase in negative mood for males when the color temperature was low. It is interesting to note that, the findings of Knez (1995a) were not reproducible for lamps with a low color rendering index (i.e. CRI = 55). This may confirm the influence of color rendering properties on color temperature as mentioned by (Davis and Ginthner, 1990).

2.2.4 Color emotion, association and preference

Many studies investigated the preference of color and the way people associate colors. Furthermore, it is known that color may influence human emotions or feelings (Gao et al., 2007). However, a majority of these studies are based on experiments using color patches and the findings may not apply to colored light. Nevertheless, it is worthwhile to investigate to what extent the findings of those studies are useful when considering colored light to create a certain atmosphere.

In two recent studies conducted by Gao and Xin (2006) and Goa et al. (2007), the human emotional response to colors for people from seven regions (four Asian regions and three western regions) was investigated extensively. They stated that the evaluation of the emotional response to color could be divided in two categories. The first category dealt with the evaluative dimensions of colors such as “comfortable” or “uncomfortable”, “good” or “bad”. The second category concerned descriptive dimensions of color such as “warm” or “cool”, “brighter” or “dark”, “heavy” or “light”. The second approach was taken in their study. By means of a psychophysical experiment, participants were asked to evaluate 214 color patches based on 12 descriptive variables formulated in subject’s native language. In addition, it was found that the 12 descriptive variables could be divided into four categories that could be used for the color emotion description. The four categories were defined as: (1) activity index, (2) potency index, (3) definition index and (4) temperature index. An overview of the descriptive variables for each category is shown in Table 1.

Table 1: Overview of the four categories and their corresponding descriptive variable(s)

Activity index	Potency index	Definition index	Temperature index
vague – distinct	soft – hard	turbid - transparent	warm – cool
vivid – somber	deep – pale	-	-
passive – dynamic	heavy – light	-	-
gaudy – plain	light – dark	-	-
striking – subdued	strong – weak	-	-

According to the results, Gao and Xin (2006) concluded that the meaning of a color was mainly influenced mainly by its lightness and saturation and little by its hue. The results showed that the hue only had an effect on the “warm-cool” descriptive. In general, little difference among the seven regional groups was found. This might suggest that some inherent or biological relationship existed between color and the human’s emotional response, regardless of the individual participants (Gao et al., 2007). The experiment, however, was conducted in different countries at a different time, and sometimes even under different experimental conditions, which might have affected the results. Additionally, one might argue the validity of the method using semantic descriptives such as “light-dark”, “soft-hard” etc. to relate color to the human’s emotional response Using a questionnaire based on an emotion model might be more appropriate to investigate and the human's emotional response to color.

In a similar study by Valdez and Mehrabian (1994), the human emotional response to color was investigated by means of the Pleasure-Arousal-Dominance emotion model (PAD) Mehrabian and Russell, 1974). Interestingly, the results in these studies were similar to the findings of Gao and Xin (2006) and Goa et al. (2007). The studies of Valdez and Mehrabian (1994) showed a consistent effect of color brightness and saturation on the emotional reactions. Conversely, the relation between hue and emotion was weak. Pleasure was found to be a joint positive function of brightness and saturation, where brightness played a more important than saturation. Arousal was found to increase linearly with saturation. Dominance was found to increase linearly with saturation, but decreased with increasing brightness. While the overall emotional reaction regarding the hue was weak, a consistent relation was found between hue and pleasure. It was found that blue-purple and blue-green colors were found to be most pleasant. Contrary, green-yellow and red-yellow colors were found to be less pleasant. Finally, the study also showed that there was no difference between genders.

The studies of Gao and Xin (2006), Goa et al. (2007), and Valdez and Mehrabian (1994) mainly focused on the human's emotional response to the color attributes hue, saturation and brightness. Other studies have investigated more specifically the association and preference of particular colors. In Manav (2007) color association and color preference were investigated as a case study for residential spaces. It was found that the colors blue and green received a high number of positive responses. Green was associated with feelings of relaxation, purity and vividness. However, some people also associated green with negative feelings such as depressive. Blue was associated with calmness, peaceful and cold. Other colors such as pink, yellow and orange received a positive response in general and were associated with vivid, cheerful enjoyment and warm. Furthermore, the participants suggested light blue as a preferred color for the living room area; which they related with emotional reactions like calm, peaceful, modern and relaxing. The hue effects and impressions were similar to the classification described by Mahnke (1996) except for the blue. Mahnke (1996) found that blue was associated with depression. Supportive results for the positive responses to the colors blue and green were also found in the studies of Ou et al. (2004) and Luckiesh (1915). Additionally, these studies found that warm colors such as yellow-red were preferred by people since it elicit a warm, relaxing and vivid feeling. Finally, yellow-green colors were associated with sickness and disgust and received the highest number of negative responses from people.

The findings of the studies discussed above suggest that the colors purple-blue, blue-green and yellow-red are generally accepted as positive. However, all of the above mentioned studies emphasized that color preference and association is highly dependent on personal preference and past experience. Furthermore, color conventions differ from one society to another (Ou et al., 2004) and thus affect the way people associate colors. Finally, the study of Manav (2007) showed that people assign different colors to areas depending on the contextual setting and the type of activities that are expected to be performed in that area. Thus, when one considers adding color for atmosphere creation, one should consider the implications mentioned previously in order to choose appropriate colors that agree with the end-users cultural background, activities and preferences.

2.3 Environmental appraisal and perceived atmosphere

In the previous chapters we discussed studies that investigated the perception of different light characteristics and how it is related to the human affective state, performance and light preference. Another approach to assess a light setting in a room is to measure the perceived atmosphere. It should be emphasized that atmosphere differs from emotion and mood in the sense that it is not an affective state, but rather an experience of the surroundings in relation to ourselves. In contrast to mood, the perceived atmosphere of an environment is expected to be a more stable concept. This makes atmosphere a more useful concept than mood to determine the psychological effect of environments (Vogels, 2008).

In order to understand how a certain light setting can elicit a particular atmosphere in a space, it is important to understand how people judge their environment with regard to the presented light setting, which consists of a combination of different types of luminaires and light characteristics. In the first two sections of this chapter we discuss several studies that investigated with different approaches how people's environmental experience can be evaluated. Finally, studies related to atmosphere creation can be found in the third section of this paragraph.

2.3.1 Environmental appraisal models

In order to understand how people evaluate their environment, it is important to determine the dimensions in which they make aesthetic judgments (Veitch, 2001). The research of Flynn (1977a), and Flynn and Spencer (1977b) is considered by many (e.g. Veitch, 2001; Ginthner, 2008; Loe et al., 1994) as one of the first in which the appraisal of various luminous conditions was investigated. In an experiment, Flynn presented participants with six light configurations and asked their subjective response. This initially resulted in 34 semantic differential scales. Additionally, the participants were asked to rate the similarity or difference between pairs of light configurations separately. By means of a factor analysis the semantic differential scales were reduced to three factors: (1) perceptual clarity, (2) evaluative impressions and (3) spaciousness. Furthermore, multidimensional scaling was applied to the ratings which resulted in an appraisal model for lighting of a space consisting of three environmental: (1) Uniform/non-uniform distribution of light, (2) Bright/dim levels of illumination, and (3) overhead/peripheral lighting. Flynn concluded that people preferred lit environments that were perceived as bright. Furthermore, spaces that were lit non-uniformly were perceived as interesting and relaxed. On the other hand, uniform lighting is positively correlated with the perceived spaciousness in a room, and higher horizontal illuminance was said to increase the perceptual clarity.

In another recent study by Durak et al. (2007), similar results as in Flynn's study were found. Additionally, the results of this study confirmed the hypothesis that differences in lighting arrangements and illuminance affected the impression in a space. They found that wall washing and spot lights could be used to create different impressions. For example, using wall washing to create uniform lighting was perceived as clear, spacious, pleasant and order. Directional lighting (e.g. spot lights), on the other hand, resulted in non-uniform lighting that was associated with relaxation, privacy and pleasantness. Furthermore, it was found that a high luminance was preferred for the uniform wall wash lighting, with a low luminance was preferred for the non-uniform spot lights. Thus, the findings of Flynn and Spencer (1977b), and Durak et al. (2007) suggest that if we want to create a lighted environment which is perceived as relaxed, private, intimate and pleasant, we should use non-uniform light with a low illuminance.

2.3.2 Evaluating perceived atmosphere in lighted environment

As mentioned in the beginning of this chapter, one can also evaluate the experience environment by means of perceived atmosphere. According to Vogels (2008), "the atmosphere of an environment is a subjective experience of the surrounding in relation to ourselves. The atmosphere of an environment is a subjective experience through the perception of external elements and internal sensations, but it does not necessarily give rise to a particular feeling. An environment only has the *potency* of changing people's mood in accordance with its atmosphere". In contrast to mood, which can be affected by many environmental factors, the perceived atmosphere is expected to be independent on people's mood. Therefore, atmosphere can be expected to be a more stable concept to use for measuring people's experiences in a lighted environment.

In Atmosphere Metrics (Vogels, 2008), a questionnaire has been developed to evaluate the perceived atmosphere in lighted environment. By means of a questionnaire, two hundred Dutch people were asked to imagine different kinds of locations and describe the atmosphere of that environment with as many terms as possible. This resulted in a list of 184 terms which was reduced to a practical list consisting of 38 terms by means of a PCA. The atmosphere questionnaire was evaluated by Vogels (2008) in two experiments. The results of the first experiment showed that people were able to distinguish between atmospheres in different locations using the atmosphere questionnaire. Similar results were found in a second experiment in which different light settings were presented in a room that resembled a fashion shop. Furthermore, by means of a factor analysis, it was found that the perceived atmosphere in an environment could be described by at least two factors: *cosiness* and *liveliness*.

In Vogels et al. (2008), the atmosphere questionnaire of Vogels(2007) was used to investigate whether and how the atmosphere of a room could be changed with light. The study consisted of two experiments conducted in an empty room. In the first experiment, four extreme light setting were designed using different combinations of values for the intensity, color temperature, color and type of luminaire. The results of the first experiment showed that the different light settings had a significant effect on the perceived atmosphere in a room. Also, in addition to the factors *cosiness* and *liveliness* as found in Vogels (2008), the results of the experiments revealed two additional factors: *tenseness* and *detachment*. Thus, the studies of Vogels (2008) and Vogels et al. (2008) showed similar results, however different underlying factors that described the perceived atmosphere in a room were found. It should be noted that, the experiment in both studies took place in a different room, and in Vogels et al. (2008) only extreme light settings were used. Hence, it might be possible that this affected the amount and type of factors found. The previous experiments only confirmed that the atmosphere tool of Vogels (2008) was able to discriminate atmospheres between different light settings. The underlying relation between individual light characteristics and perceived atmosphere was not investigated yet. Thus, in a second experiment seven light settings were designed in which the light characteristics were varied independently from each other. The result of the second experiment showed that moderate variations in color temperature and intensity had a large effect on the perceived atmosphere.

The studies of Vogels (2008) and Vogels et al. (2008) showed that light had an influence on the perceived atmosphere of a space. However, both studies were conducted in an empty room. As discussed in the previous chapters, research has shown that the preference of indoor lighting may depend on the contextual situation and activities. This suggests that the evaluation of the perceived atmosphere in a space, elicited by lighting, may also differ depending on the contextual situation of a space. In Vogels and Bronckers (2009), the effect of context and light characteristics on perceived atmosphere of a space was investigated. In this experiment, the same seven light settings as in the second experiment of Vogels et al. (2008) were used as independent variables. The light settings were presented in three different contexts: (1) empty room, (2) furnished living room, and (3) office. In order to evaluate the perceived atmosphere in the room, a shortened version of the atmosphere questionnaire of Vogels (2008), consisting of twelve terms, was used. The results of this study were found to be similar to those found by Vogels et al. (2008). Furthermore, no main effect for both the living room and office context on the perceived atmosphere was found. This suggests that the evaluation of the perceived atmosphere in a space is mainly affected by the illumination and is independent of the contextual setting. However, it should be stressed that the findings of Vogels and Bronckers (2009) might only be true for the given light conditions and experimental condition of the room. Furthermore, the studies of Vogels et al. (2008) were all based on light settings using white light sources only. It would be interesting to investigate the effect of colored light on perceived atmosphere.

2.3.3 Creating atmospheres

In the previous sections we discussed studies that investigated the way people assess their environment and how a space can be evaluated in terms of perceived atmosphere. In this section we discuss studies concerning atmosphere creation. The experience of a certain atmosphere in space is influenced by combining a number of elements within a context (e.g. interior and lighting) in such a way that they have meaning (Harkin et al., 2005). Furthermore, the way people are influenced by the combination of different elements that elicit a certain experience in a space is further dependent on personal preferences and cultural background. Currently, there are no easy and affordable (lighting) solutions available that allow users to experience a certain atmosphere in residential spaces such as a living room. At present, professional lighting and interior designers are hired to create a custom tailored atmosphere for specific needs. While professional expertise will always be needed for creating complex ambiences, capturing the expert knowledge into an easy to use lighting tool is expected to be valuable for end users who do not have the time or budget to hire professional lighting designers. In order to provide people with such a solution we first have to understand how we can create certain atmospheric effects in a room. Various studies have investigated different approaches to create light configurations that elicit a certain atmosphere in a space.

When people experience a specific atmosphere, whether indoor or outdoor, they can often describe that with words like tense, relaxing or spacious. In the study of Vogels (2008) a list of atmosphere terms were obtained that people mentioned when they were asked to imagine different locations and the atmosphere of that environment. Also, Flynn and Spencer (1977b) related words such as relaxing, tense and spacious to spatial light distributions. The studies discussed in the previous chapters gave us insight in how lighting affected people's perception of the environment in different ways. The lighting design problem is to understand how we can combine different light characteristics, and translate that by means of luminaire arrangements and light distributions to create a certain atmosphere in a space.

In Moeck (2001) a method to describe and capture the essence of spatial lighting atmospheres and to synthesize the captured atmosphere for both indoor and outdoor illuminated settings was introduced. The described technique makes use of a 360 degrees spherical luminance map of an environment to capture the atmosphere of the space. The study shows that the captured lighting atmospheres can be analyzed and synthesized in a new context. According to the study of Moeck (2001), the benefit of this technique is that when people recognize a desired atmosphere, one can capture it by means of a luminance image map and recreate the atmosphere in any interior setting by analyzing the luminance map of the captured environment. Furthermore, using this technique a large amount of atmospheres can be captured, thus creating a large database of atmosphere luminance maps that can be studied to get more insight in how atmospheres can be synthesized in different contexts by means of indoor lighting. The technique described by Moeck (2001) however is rather complex and contains a large amount of calculations and tweaking to get the desired effect. In addition, since the synthesized atmosphere is described by the luminance map and some accompanying calculations, it is extremely difficult for end-users to adjust the light setting to their personal preference. Also, the study does not mention any evaluation with end-users to verify whether people actually perceive the atmosphere that is supposed to be elicited by a particular luminance map of an environment.

As mentioned previously, professional (lighting) designers are usually hired to create an atmosphere that fit specific needs. Therefore, a more direct approach to obtain more insight in creating an atmosphere is to gather expert knowledge from these professionals; for a detailed practical example of this approach refer to Harkin et al. (2005). The acquired knowledge can then be used to build different atmospheres for specific contextual settings. In a study conducted by Seuntiens and Vogels (2008) this approach was used. The goal of this study was to investigate what light characteristics lighting designers use to create certain atmosphere in the living room, and how these light characteristics are related to a certain atmosphere. By means of a questionnaire developed together with professional lighting designers and information from Reisinger et al. (2004), fifteen designers with different backgrounds were asked to create a lighting design for the atmospheres cosy, activating, relaxing and exciting in a living room. The choice for these four atmospheres was based on the fact that the study of Vogels (2008) showed that these atmospheres are near one of the ends of the two scales *cosiness* and *liveliness*. The results of the study showed that the designers were able to discriminate between the four atmospheres by means of different light characteristics. Furthermore, besides the commonly used light parameters such as brightness and color temperature, adding color, beam shaping and dynamics appeared to be important in achieving different attractive atmospheres. In a follow-up study by Seuntiens (internal report, 2008), the four atmospheres cosy, relaxing, activating and exciting were presented to end-users and assessed using the atmosphere questionnaire of Vogels (2008). The results of the follow-up experiment showed that people were able to clearly recognize the four.

The study of Seuntiens and Vogels (2008) showed that in order to create a cosy or relaxing atmosphere, a lower brightness and warmer color temperature for both the general and directional accent lighting was needed than when creating an activating or exciting atmosphere. Furthermore, the cosy and relaxing atmosphere shared the preference for a softer beam angle for the directional accent lighting as compared to the activating and exciting atmosphere. The use of large variations in light characteristics and fast dynamics was not surprisingly most important in creating an exciting atmosphere, while the other atmospheres were preferred to be static (cosy) or with slow dynamics and small variations in brightness and/or color temperature (relaxing and activating). The choice for colors to enhance the atmosphere consisted of medium saturated color pairs, except for the exciting atmosphere where random colors with high saturation were preferred (see Table 2).

Table 2: Color pairs for the atmospheres cosy, activating, relaxing and exciting

Atmospheres	Colors
Cosy	Orange, blue
Activating	Blue, cyan
Relaxing	Green, blue
Exciting	Random RGB

The findings in the study of Seuntiens and Vogels (2008) seems to support the results found by Flynn and Spencer (1977b), and Durak et al. (2007) with regard to the light characteristics of white light. Furthermore, the choice of the colors for the atmospheres cosy, activating and relaxing is supported in studies regarding color preference and color association as discussed previously. While professional designers were able to create discriminating atmospheres by means of light characteristics, the reasoning behind their choice of setting for each light characteristic is still unclear. Furthermore, it can be expected that there exists more combinations of light parameters that can result in the same or even more enhanced atmosphere. Nevertheless, the findings of this study can be used as a good starting point to further investigate the relation between the different light characteristics and perceived atmosphere to create even more appealing atmospheres.

3. Experimental setting and characterization of the luminaires

In order to answer the research question as stated in the introduction, three experiments were conducted. The experiments are described in Chapter 4, 5 and 6 respectively and were conducted in the same experimental room using the same luminaires. This chapter describes the apparatus and characteristics of the installed luminaires in the experimental room. The rest of this chapter is structured as follows. In the first paragraph, the physical properties of the experimental room are described. Next, the results of the characterization of the luminaires are presented. The characterization of the luminaires was necessary in order to create the design and stimuli for the experiments. Finally, the reader can find a summary of this chapter in the last paragraph.

3.1 Experimental setting

3.1.1 Experimental room

The experimental room is located at the Philips ExperienceLab where a “standard” living room has been furnished as shown in Figure 3. The dimensions of the living room were 6 meters by 4 meters and the height of the ceiling was 3 meters. The color of the walls was white, the ceiling had an off-white (i.e. cream white, ivory white) color and the floor consisted of dark grey carpet patches. In order to prevent possible influences of natural light during the experiments, the windows in the experimental room were covered by curtains. Furthermore, a black coffee table, white sofa and a white chair was set around the center of the room. Moreover, an off-white carpet was placed under the coffee table and the wall facing the sofa was decorated with two similar looking paintings. Finally, a black television cabinet was placed on the floor against the wall under the paintings, and a black dinner table was placed against the left wall of the room. The overall design of the room was western.

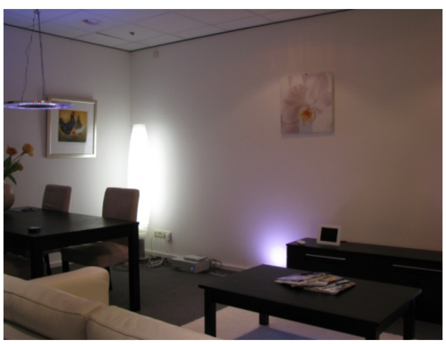
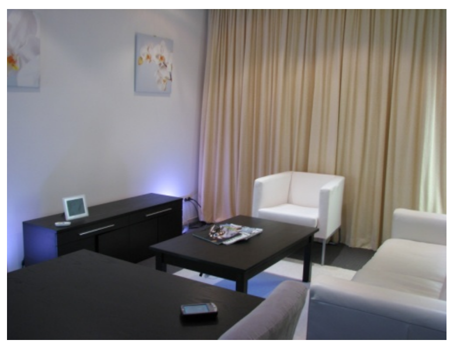



Figure 3: An impression of the experimental room.

3.1.2 Installed luminaires

The illumination in the experimental room was provided by a number of luminaires. Figure 4 provides an overview of the installed luminaires in the experimental room with their corresponding names which are used in the rest of this report. Two cylindrical floor lights were positioned in two corners of the room. Each of the floor lights consistsed of four fluorescent lamps; two lamps with a warm white (2700K) color temperature (Philips Master TL5 HE 28W/827), and two lamps with a cool white (6500K) color temperature (Philips Master TL5 HE 28W/865). The fluorescent floor lights accounted for the general lighting in the living room.

Accent lighting was provided by six pairs of spot lights that were installed in different sections of the ceiling. All the installed spot lights had a beam angle of 36 degrees. Furthermore, each pair of spot lights consistsed of two types of halogen lamps; one spot light with a lamp with a warm white (3000K) color temperature (Philips HR Dichroic 50W GU5.3 12V 36D) and one spot light with a lamp with a cool white (4700K) color temperature (Philips Diamondline 50W GU5.3 12V 36D 1CT). Two pairs of spot lights were directed to the paintings on the wall, the other spot lights were directed downwards to the coffee table and sofa.

Besides white light sources, decorative light was provided by three different types of colored luminaires. Philips Living Color lamps were placed on each side of the television cabinet and were directed to the wall to act as colored light. Each of the Living Color lamps consisted of an equal amount of red, green and blue LEDs. Furthermore, a custom made light source consisting of red, green and blue LED strips was mounted underneath the coffee table (Table light) in order to generate colored light on the carpet below. Finally, a colored light source (Gemini), which consistsed of red, green and blue LEDs, was mounted above the dinner table to generate colored light on the ceiling. In order to stabilize the luminance and chromaticity of the lamps, all the luminaires were turned on for 30 minutes before experiments were conducted.

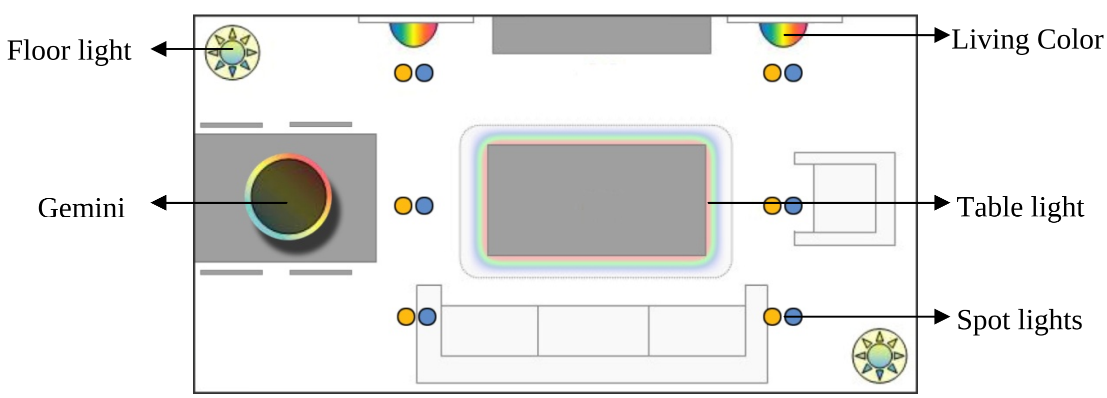


Figure 4: An overview of the installed luminaires in the experimental room.

3.1.3 Luminaire control system

Except for the Living Color lamps, all the luminaires were controlled by a DMX lighting control system that was pre-installed in the experimental room. Each lamp type in a luminaire was represented by a corresponding DMX node. The luminance and color temperature of the white luminaires were controlled by assigning an 8-bits value to the appropriate node representing the lamp type.

The Table light and Gemini light source could be controlled by assigning 8-bits values to the corresponding DMX node representing the red, green and blue channel of the luminaire. On the other hand, the Living Color lamps were connected separately to an internal network. They were controlled by sending triplets of 12-bits values (representing the red, green and blue color channels) to the corresponding network address representing the luminaire.

3.2 Characteristics of the luminaires

In this paragraph the characteristics of the installed luminaires are described. The output of the luminaires was measured in relation to the input values of the control software. In order to stabilize the luminance and chromaticity of the lamps, the luminaires were turned on for 30 minutes before measurements took place. All the measurements were done using a Topcon BM7 colorimeter from a distance of two meters. In the first section, we first describe the characteristics of the white luminaires, then the characteristics of the colored luminaires.

3.2.1 White light sources

For the purpose of the present research, the luminance in $[cd/m^2]$ and color temperature in $[K]$ for the white luminaires were measured in relation to the input values of the luminaire control system described previously. Since the floor lights consisted of two different types of fluorescent lamps, the lamps with a cool and warm color temperature were measured separately. Similarly, the halogen lamps with a cool and warm color temperature were measured separately in order to characterize the two types of spot lights that were installed.

Due to the diffuse property of the floor lights, the measurement of the luminance and color temperature was taken from a fixed spot on the luminaire. In a same manner, the measurements of the luminance and color temperature for the spot lights were taken from a fixed spot on the wall where the spot lights were directed to – the paintings were temporary removed during the measurements. For each lamp, 51 measurements were taken by increasing the input value of the luminaire control system from 0 to 255 with a step size of 5.

The results of the measurements for the luminance and color temperature for the white luminaires can be found in Appendix A. The results of the measurements for the floor lights showed that there is a non-linear relation between the luminance output and the input of the control software for both the fluorescent lamps with cool and warm color temperature. In addition, on average the color temperature for both lamps met their specifications and remained stable across the measured input values of the control software.

Similarly, a non-linear relation between luminance output and the input values for the control software was found for the halogen spot lights. However, in contrast to the floor lights, the color temperature of the halogen lamps started at a lower value than specified and increased gradually as the input value of the control software increased. As a result, on average, the color temperature of the spot lights appeared to be slightly lower than specified; the color temperature according to the specifications was only met at the maximum input of 255.

For the present research, it was necessary to adjust the luminance and color temperature of the white luminaires independently. One method to address this issue was to combine different output levels of the cool and warm color temperature lamps until the preferred combination of luminance and color temperature for the luminaire was found. This approach was taken to create the design and stimuli for the tuning experiment in the first study described in Chapter 4.

3.2.2 Colored light sources

In order to characterize the colored luminaires, the luminance in [cd/m^2] and the chromaticity coordinates (x, y) in the CIE 1931 XYZ color space were measured for each color channel (red, green and blue) in relation to the input values of the luminaire control system. Additionally, the chromaticity coordinates of the white point for each colored luminaire were measured. Where needed, the chromaticity coordinates of the D65 white point were used as the reference white point. Despite the difference in control system between the Living Color lamps and the other two colored luminaires, all the colored luminaires were controlled in the same way; by sending input values to the corresponding color channel in the luminaire control software.

The measurements for the characterization of the Living Color lamps were taken from a fixed spot on the wall where the light effect was projected on. On the other hand, because of the off-white surface where the light of the Table light and Gemini light source was projected on, the measurements for the Table light and Gemini light source were taken from a fixed spot on a reflectance plate.

The purpose of the luminance measurements of the colored light sources was to verify whether there was a linear relationship between the software control input and luminance output of the colored light sources. Therefore, in contrast to the white light sources, larger step sizes were chosen and less sample measurements were taken. More specifically, for each color channel (red, green and blue) of the Living Color lamps, 10 luminance measurements were taken for input values ranging from 0 to 2000 with a step size of 200. Similarly, for each color channel of the table light and Gemini light source, 25 measurements were taken for input values ranging from 0 to 250 with a step size of 10. Finally, in order to determine the color gamut of each colored luminaire, the chromaticity coordinates of each primary color and white point were measured. This was done by setting the value(s) of the corresponding color channel(s) in the control software to the maximum intensity value; 2047 for the Living Color lamps and 255 for the Table light and Gemini light source.

The results of the measurements for the luminance and chromaticity coordinates of the colored luminaires can be found in Appendix A. In contrast to the luminance measurements for the white light sources, a consistent linear relation between the luminance and the input of the control software was found for all colored light sources. Furthermore, as expected, the green primary color provided the highest amount of luminance, followed by the red and blue color primaries. This can be explained by the fact that the luminous efficiency function peaks in the green region of the spectrum. Finally, it is important to notice that the measured chromaticity coordinates for the white points were all different from the reference white point (D65) for all of the colored light sources in the experimental room.

The obtained results from the characterization of the colored light sources gave us insight in the way these luminaires behave. Since we wanted to adjust the hue and chroma of the colored light sources independently, it was important to choose an appropriate color appearance model to work with. While many color appearance models exist (e.g. CIE 1976 LUV and Hunt model), each with their own strengths and weaknesses, the CIE 1976 LAB color appearance model is generally recommended by the CIE. Therefore, in the current research, the CIE 1976 LAB color appearance model was adopted for creating the stimuli of the tuning experiment that is described in the following chapter. Finally, we have to emphasize that since the measured white points for all the colored light sources were different from the reference white point, a white point correction using the D65 white point as reference was applied to all calculations with regard to the colored luminaires.

3.3 Summary

In this chapter, the experimental set-up for the present research is described. Furthermore, the results of the characterization of the white and colored light sources are discussed separately.

The luminance of the floor and spot lights was found to have a non-linear relationship with the input values of the DMX lighting control system. Furthermore, except for the halogen spot lights, the color temperature of the fluorescent lamps in the floor lights was found to meet the specifications, and remained stable on average across the measured values. Also, it was suggested to combine the different outputs of lamps with a cool and warm color temperature; this in order to adjust the luminance and color temperature of the white light sources independently.

With regard to the colored light sources, a linear relationship was found between the input values of the control software and the measured luminance. In addition, the chromaticity coordinates of the measured white point for all colored luminaires were found to be different from the reference white point. Finally, a color appearance model (CIE 1976 LAB) was suggested in order to adjust the hue and chroma of the colored light sources in a controlled manner.

4. Study 1: the allowed variation in light characteristics on the initially perceived atmosphere cosy and activating

In this chapter the experimental details of the first study are described. In an approach to answer the research question as stated in the introduction, a tuning experiment was conducted to investigate the following sub-research question:

> *"What is the allowed variation in light characteristics on an initially perceived atmosphere?"*

For the purpose of this study, the light settings of the original "cosy" and "activating" atmosphere as described in Seuntiens and Vogels (2008) were used as initial atmospheres from, which variations in light characteristics were applied. The "cosy" atmosphere was mainly characterized by a low overall brightness and a low color temperature. Furthermore, the color pair blue and orange was chosen for the colored light sources. On the other hand, the "activating" atmosphere was mainly characterized by a high overall brightness and a high color temperature. Moreover, the color pair cyan and blue was chosen for the colored light sources. An impression of the "cosy" and "activating" atmosphere as found in Seuntiens and Vogels (2008) is shown in Figure 5.

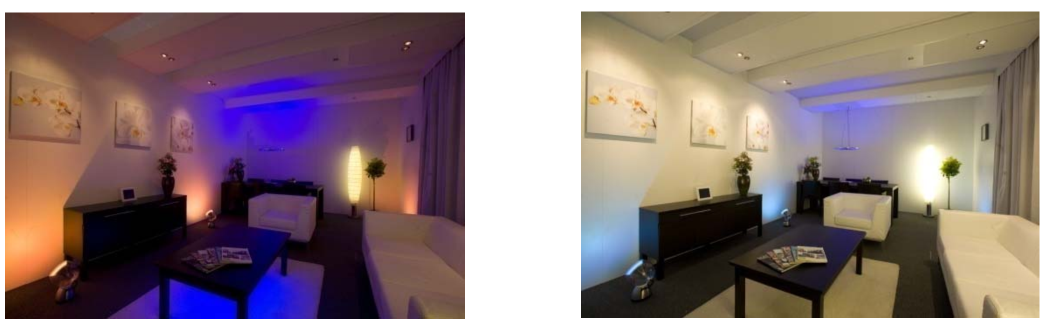


Figure 5: An impression of the light settings for the "cosy" (left) and "activating" (right) atmospheres as described in Seuntiens and Vogels (2008).

This chapter is structured as follows: first the methodology of the experiment is described in detail including a description of the participants, the experimental design and the procedure. Next, the results of the experiment are presented and a conclusion can be found in the last paragraph.

4.1 Methodology

4.1.1 Participants

In this study, 10 males and 10 females aged between 22 and 38 participated in the experiment. Furthermore, all participants were native Dutch employees or students at Philips Research Eindhoven in the Netherlands. Additionally, they had little to no knowledge with regard to lighting design and atmosphere creation; this in order to avoid possible biases and the influence of personal experiences.

People with a Dutch nationality were chosen because the atmosphere questionnaire of Vogels (2008), which consists of Dutch terms, was used for follow-up experiments in the second and third study. Furthermore, the light settings of the initial “cosy” and “activating” atmosphere in Seuntiens and Vogels (2008) were designed by professional lighting designers for a typical “Dutch” living room.

4.1.2 Design and stimuli

A tuning experiment was designed allowing participants to adjust different light characteristics of an initially presented atmosphere in the room independently. In order to let the participants apply the adjustments, an application was implemented for a PDA device. In total, 24 tunings were designed; 14 tunings for the “cosy” atmosphere and 10 for the “activating” atmosphere. In this section the tunings for the white and colored light sources are described sequentially.

4.1.2.1 Tunings for the white light sources

The variation in light characteristics for the white luminaires consisted of tuning the initial luminance and color temperature separately. In order to achieve this, different output values for the lamps with cool and warm color temperature were combined in a way that the initial color temperature remained stable while the luminance was adjusted and vice versa.

For the present study, it was decided to let the participants apply adjustments to the luminance of the floor and spot lights separately. Differently, in tunings for the variation in color temperature, the floor and spot lights were adjusted together. The reason for the coupling of the floor and spot lights for the variation in color temperature was because it was expected that a mixture of two (or more) luminaire outputs, with different color temperatures, would be perceived as unnatural. Since two initial atmospheres (“cosy” and “activating”) were investigated in the present study, separate tunings were performed for each of the atmospheres.

Preferably, we liked to have designed tunings in which the initial luminance and color temperature could be adjusted in two directions: increase and decrease. However, results of the physical characterization of the light sources showed that not all the preferred adjustments in light characteristics were possible. For example, due to the properties of the lamps used and the initial high luminance of the spot lights in the “activating” atmosphere, the luminance of the spot lights could only be decreased. In the same manner, the color temperature in the “cosy” atmosphere could only be increased and in the “activating” atmosphere the color temperature could only be decreased – while keeping the initial luminance level of the luminaire stable. An overview of the tunings for the white light sources can be found in Table 3 below. It shows that each participants had to do 9 tunings.

Table 3: Tunings for the white light sources in the "cosy" and "activating" atmosphere

	Cosy atmosphere	Activating atmosphere
1. Luminance floor lights	Increase & decrease	Increase & decrease
2. Luminance spot lights	Increase & decrease	Decrease
3. Color temperature	Increase	Decrease

Each of the tuning consisted of a number of input values for the luminaire control system. The tunings for the increase and decrease in luminance of the white luminaires consisted of 20 tuning steps. Where each tuning step represents a change in luminance of around 40 to 80 $cd/m^2$for the floor lights and 5 to 10 cd/m^2 for the spot lights. The tuning for the increase in color temperature in the "cosy" atmosphere consisted of 8 tuning steps, whereas the tuning for the decrease in color temperature in the "activating" atmosphere consisted of 20 tuning steps. Each tuning step represent a change in color temperature of around 50K. The small amount of available tuning steps in the "cosy" atmosphere was due to technical limitations of the light sources used. The results of the measurements for the tunings of the white light sources for the "cosy" and "activating" atmosphere can be found in Appendix B.

4.1.2.2 Tunings for the colored light sources

For the present study we investigated the allowed variation in the hue and chroma of the colored light sources in the "cosy" and "activating" atmosphere. So, participants were asked adjust the hue and chroma of each colored luminaire in the initial presented atmosphere separately while keeping the initial lightness level of the luminaire stable. For an overview of the initial color for each colored luminaire in the "cosy" and "activating" atmosphere see Table 4.

Table 4: Initial color of each colored light source in the "cosy" and "activating" atmosphere.

	Cosy	Activating
Living Colors	Orange	Cyan
Gemini	Blue	Blue
Table light	Blue	Not used

For the variation in hue of the colored light sources, separate tunings were performed for the clockwise (CW) and counter-clockwise (CCW) directions. For the variation in chroma we liked to have created tunings for both the increase and decrease in chroma of the light sources. However, due to the highly saturated colors used in the "cosy" and "activating" atmosphere, the chroma of the initial color of the colored light sources could only be increased by a small amount. Consequently, only tunings towards a decrease in chroma were included. An overview of the tunings for the variation in hue and chroma of the colored light sources is presented in Table 5. It shows that participants in total had to do 15 tunings.

Table 5: Tunings for the colored light sources in the "cosy" and "activating" atmosphere.

	Cosy atmosphere	Activating atmosphere
1. Living Colors hue	CW & CCW	CW & CCW
2. Living Colors chroma	Decrease	Decrease
3. Gemini hue	CW & CCW	CW & CCW
4. Gemini chroma	Decrease	Decrease
5. Table light hue	CW & CCW	Not used
6. Table light chroma	Decrease	Not used

The following approach was taken to compute the input values of the control software of the colored light sources for each step in the tuning. First, the initial RGB values of the colored light source were normalized and transformed to chromaticity coordinates in the CIE 1931 XYZ color space using the previously measured chromaticity coordinates of the color primaries (RGB) and white point of the colored light source. Next, the chromaticity coordinates in XYZ were transformed to chromaticity coordinates in the CIE 1976 LAB color appearance model. This was done by using the measured chromaticity coordinates of the color primaries (RGB) of the colored light source and the chromaticity coordinate of the D65 reference white point. Then, the corresponding LCh values were derived from the CIE 1976 LAB coordinates. Finally, starting from the LCh values, variations in hue and chroma were applied by separately increasing or decreasing the h and C values respectively. The adjusted LCh values were converted back to the corresponding input values of the software control system and saved in text files. It should, however, be noted that some of the calculated hue angles were outside the gamut of the luminaire and clipped to fit within the boundaries of the gamut of the luminaire.

4.1.3 Procedure

In this experiment the participants were divided into two groups of ten people, each group containing five males and five females. For both groups, the procedure of the experiment remained the same with the exception that a different task description was provided for each group. The following task descriptions were presented to the participants in the first and second group:

1. Apply changes to the initially presented light setting until the experience of the initially perceived atmosphere in the whole room *changes.*
2. Apply changes to the initially presented light setting until the experience of the initially perceived atmosphere in the whole room *disappears.*

Two task descriptions were presented because it was not clear whether the difference in task description would influence the way participants apply changes to the initial presented atmosphere.

The procedure of the experiment for both groups was as follows. First, participants were welcomed in the experimental room with a neutral light setting presented. Furthermore, they were asked to take a seat at the right corner of the sofa. This position was chosen to make sure that participants had a good overview of the illumination in the whole room. Next, they were asked to perform the Isihara Color Blindness Test to ensure they had normal color vision; none of the participants were found to suffer from color blindness. Finally, the instructions for the experiment were presented and the procedure of the experiment was explained.

By means of a graphical user interface on the PDA, participants adjusted the light characteristics of the initial atmosphere for a certain tuning. It is important to emphasize that the rest of the light sources that were not part of the active tuning remained stable during the tuning process. The name of the luminaire being adjusted was indicated on the screen of the device. The different steps for each of the 24 tunings (14 cosy, 10 activating) described in the previous section were stored in the PDA device in advance. The tunings were presented in random order to the participant; this in order to minimize order effects. Finally, a reset button was provided in the user interface allowing participants to undo the changes made on the initial presented atmosphere for the active tuning.

4.2 Results & Discussion

In this paragraph the results of the first study are presented. As mentioned in section 4.1.3, participants were divided into two separate groups and were presented with different task descriptions. Therefore, preliminary analyses were performed for each tuning separately in order to test whether there was an effect of task description on the allowed variation in light characteristics. The results of the analyses showed no significant effect of task description on the tuning results ($p > .05$). Furthermore, additional analyses indicated that there was no significant effect of gender on the tuning results ($p > .05$) for all tunings. Consequently, data from both groups and gender were combined in all further analyses.

In the first two sections, the results for the variation in luminance and color temperature of the white light sources are described. Finally, the results for the variation in hue and chroma of the colored light sources can be found in the last section.

4.2.1 Variation in luminance for white light sources

In Figure 6 the average tuned luminance level of the floor lights is presented in relation to the initial luminance level of the floor lights in the “cosy” and “activating” atmosphere. Overall, the results show that in both atmospheres a large amount of variation in luminance of the floor lights is allowed before the initial atmosphere disappears. According to our results, participants allowed an increase in luminance of the floor lights of almost 300% (from 85 to 252 cd/m^2) in the “cosy” atmosphere. Moreover, participants allowed a decrease in luminance of the floor lights of around 50% (85 to 40 cd/m^2). With regard to the “activating” atmosphere, participants allowed an increase in luminance of the floor lights of slightly more than 200% (from 533 to 1117 cd/m^2) and a decrease of around 62% (from 533 to 204 cd/m^2).

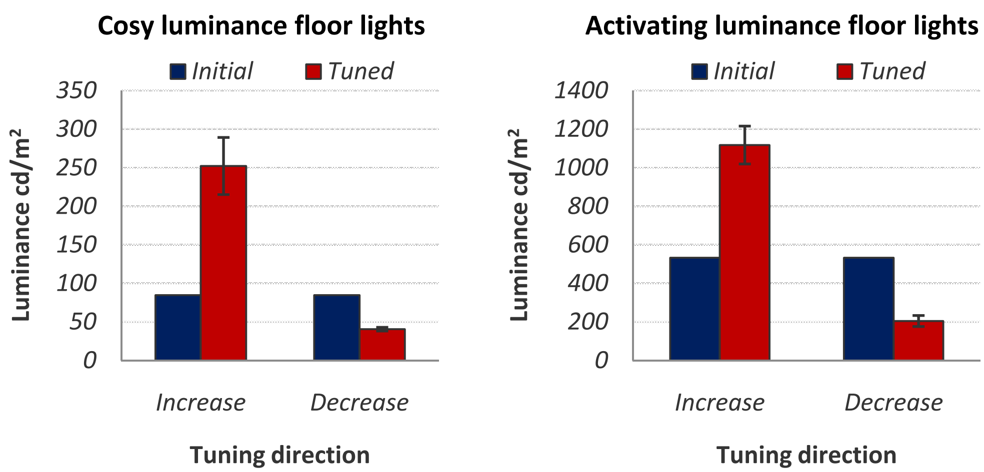


Figure 6: The results for the variation in luminance of the floor lights in the "cosy" (left) and "activating" (right) atmospheres are depicted above. The blue bar represents the initial luminance level of the floor lights and the red bar the average tuned luminance level of the floor lights before the initial atmosphere disappears. The error bars correspond to one standard error.

The results with regard to the variation in luminance of the spot lights in the "cosy" and "activating" atmosphere are shown in Figure 7. Similar to the floor lights, first impression of the results suggested that participants allowed a large variation in luminance level in both the "cosy" and "activating" atmosphere before the initial atmosphere disappears. On average, participants allowed for the "cosy" atmosphere an increase in luminance of the spot lights of almost 400% (from 7.5 to $36\ cd/m^2$) and a decrease of 78% (from 7.5 to $1.6\ cd/m^2$). In contrast to the "cosy" atmosphere, the variation in luminance of the spot lights in the "activating" atmosphere was limited to a decrease only. The results showed that, on average, a decrease of around 76% (from 72 to $17.97\ cd/m^2$) was allowed.

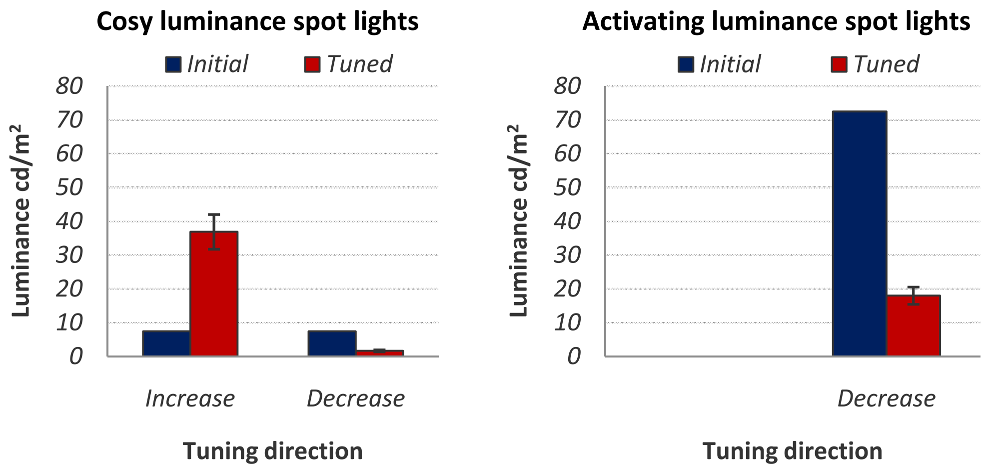


Figure 7: The results for the variation in luminance of the spot lights in the "cosy" (left) and "activating" (right) atmospheres are depicted above. The blue bar represents the initial luminance level of the spot lights and the red bar the average tuned luminance level of the spot lights before the initial atmosphere disappears. The error bars correspond to one standard error.

The results for the variation in luminance of the white luminaires showed that in both the "cosy" and "activating" atmosphere participants allowed a large amount of variation in luminance level before the initial atmosphere disappeared. Specifically, the results indicated an allowed increase in luminance of around 200 to 400% and a decrease of around 50 to 80%.

First impression of the error bars suggested a difference in tuning accuracy between the luminance increase and decrease conditions for both the floor and spot lights. However, in relative terms, no consistent difference in error bar size was found between the two directions. Thus, there was no difference in tuning accuracy between the luminance increase and decrease conditions.

4.2.2 Variation in color temperature for white light sources

The initial and average tuned color temperature for the white luminaires (floor and spot lights) in the "cosy" and "activating" atmosphere are shown in Figure 8. As can be observed, the color temperature of the floor lights in the "cosy" atmosphere increased from 2700K to approximately 3500K and the spot lights from 2200K to approximately 3040K. With regard to the "activating" atmosphere, a decrease in color temperature from 4040K to approximately 3240K was found for both the floor and spot lights.

Interestingly, the results showed that the amount of variation in color temperature was nearly the same in both the "cosy" and "activating" atmosphere (approximately 800K). In addition, the error bars indicated that there was a small variation between participants with regard to the allowed variation in color temperature for the "cosy" and "activating" atmosphere. While the color temperature in both atmospheres was only adjusted in one direction, these findings suggest that, on average, participants were accurate with regard to the allowed variation in color temperature.

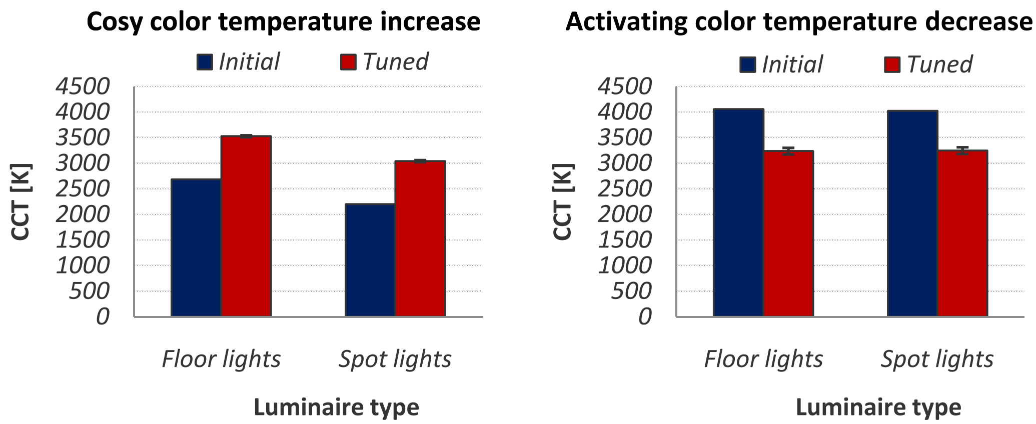


Figure 8: The results for the variation in color temperature in the "cosy" (left) and "activating" (right) atmospheres are depicted above. The blue bar represents the initial color temperature level of the luminaire and the red bar the average tuned color temperature level of the luminaire before the initial atmosphere disappears. The error bars correspond to one standard error.

4.2.3 Variation in hue and chroma for colored light sources

In this section, the results for the variation in hue angle and chroma level for the colored light sources are presented. For each of the colored light sources in the experimental room, the average variation in hue and chroma was calculated. The CIE 1976 LAB color appearance model was used to visualize the results. Finally, in order to quantify the allowed variation in hue and chroma level, the color difference (ΔE_{00} ,CIEDE2000) was calculated between the initial and average tuned color point for each tuning.

4.2.3.1 Living Color lamps

The results for the variation in hue angle and chroma level of the Living Color lamps in the "cosy" and "activating" atmosphere are illustrated in Figure 9. On average, participants adjusted the initial orange color of the Living Color lamps in the "cosy" atmosphere to a reddish and yellowish color for the clockwise and counter-clockwise hue directions respectively. The calculation of the color differences in the "cosy" atmosphere between the initial and tuned hue angles revealed that the amount of variation in hue in the clockwise direction ($\Delta E_{00} = 16.90$) was slightly smaller than in the counter-clockwise direction ($\Delta E_{00} = 20.40$). In addition, the initial chroma of the Living Color lamps was decreased by approximately 50% with a color difference of $\Delta E_{00} = 10.91$ compared to the initial color point.

On the other hand, results for the "activating" atmosphere show that on average participants adjusted the initial cyan color of the Living Color lamps to a greenish and purplish color for the counter-clockwise and clockwise hue directions respectively. The color differences between the initial and tuned hue angles in the "activating" atmosphere showed that the amount of variation in hue in the clockwise direction ($\Delta E_{00} = 32.40$) was slightly smaller than in the counter-clockwise direction ($\Delta E_{00} = 37.75$). Moreover, the initial chroma of the Living Color lamps in the "activating" atmosphere was decreased by approximately 80% with a color difference of $\Delta E_{00} = 13.42$ compared to the initial color point.

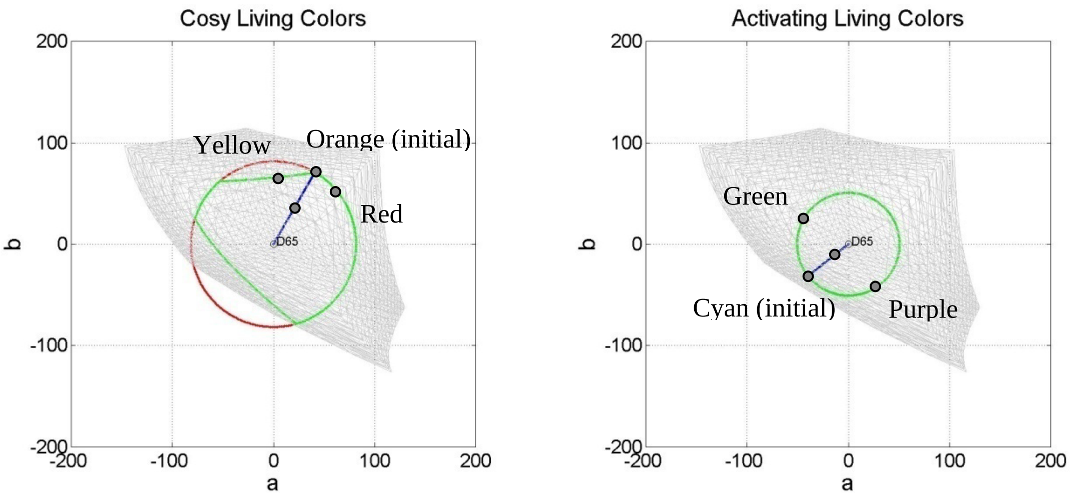


Figure 9: The results of the average tuned hue angle and chroma level for the Living Color lamps in the "cosy" (left) and "activating" (right) atmosphere are depicted above in the CIE 1976 LAB color appearance model. The green line represents the values use for tuning the hue and the red line shows the clipped hue angles. The blue line represents the values used for tuning the decrease in chroma.

4.2.3.2 Gemini

Figure 10 shows the results for the variation in hue angle and chroma level of the Gemini light source in the "cosy" and "activating" atmosphere. As can be seen, the luminaire in both atmospheres shared the same initial bluish color. With regard to the variation in hue, participants adjusted the initial bluish color of the luminaire in both atmospheres to a cyan and purplish color for the clockwise and counter-clockwise hue directions, respectively. The color difference between the initial and tuned color point for the variation in hue in the "cosy" atmosphere was $\Delta E_{00} = 22.45$ and $\Delta E_{00} = 24.85$ for the clockwise and counter-clockwise hue directions. Additionally, the initial chroma of the luminaire was decreased by approximately 55% with a color difference of $\Delta E_{00} = 12.12$ compared to the initial color point. On the other hand, the amount of color difference between the initial and tuned hue angles in the "activating" atmosphere was $\Delta E_{00} = 26.45$ and $\Delta E_{00} = 28.26$ for the clockwise and counter-clockwise hue directions respectively. The initial chroma of the Gemini light in the "activating" atmosphere was decreased by around 72% with a color difference of $\Delta E_{00} = 18.23$ with the initial color point.

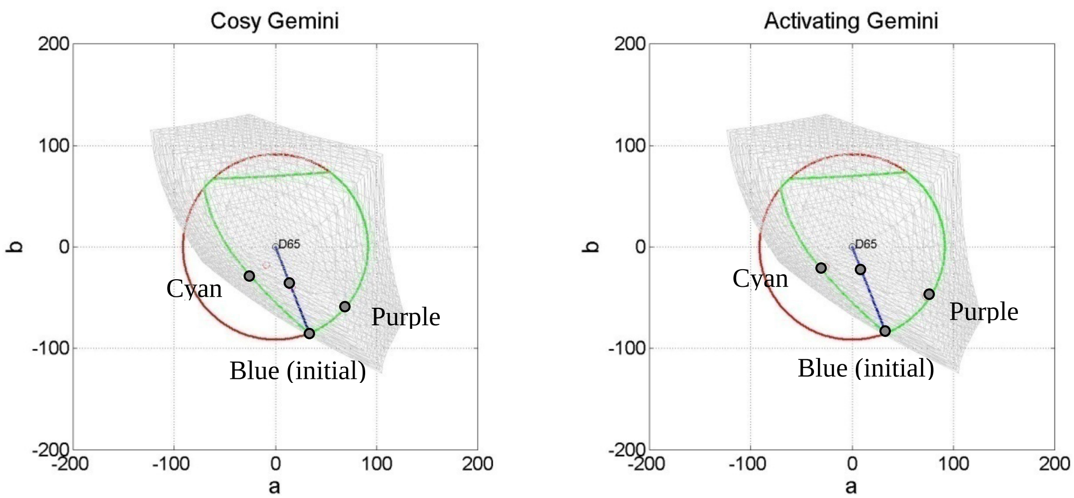


Figure 10: The results of the average tuned hue angle and chroma level for the Gemini light source in the "cosy" (left) and "activating" (right) atmosphere are depicted above in the CIE 1976 LAB color appearance model. The green line represents the values used for tuning the hue and the red line shows the clipped hue angles. The blue line represents the values used for tuning the decrease in chroma.

4.2.3.3 Table light

The results for the variation in hue angle and chroma level of the Table light in the "cosy" atmosphere are shown in Figure 11. Similar to the Gemini light source, the initial color of the Table light was bluish. The results showed that on average participants adjusted the hue of the initial color to a cyan and purplish color for both clockwise and counter-clockwise hue directions, respectively. Furthermore, the color difference between the initial and tuned color points for the variation in hue was $\Delta E_{00} = 27.32$ and $\Delta E_{00} = 32.07$ for the clockwise and counter-clockwise hue directions. Finally, on average a decrease of 80% on the initial chroma of the luminaire was allowed by participants and a color difference of $\Delta E_{00} = 20.33$ compared to the initial color point was found. It is interesting to observe that compared to the other colored light sources in the "cosy" atmosphere, the allowed decrease in chroma of the Table light was found to be much larger.

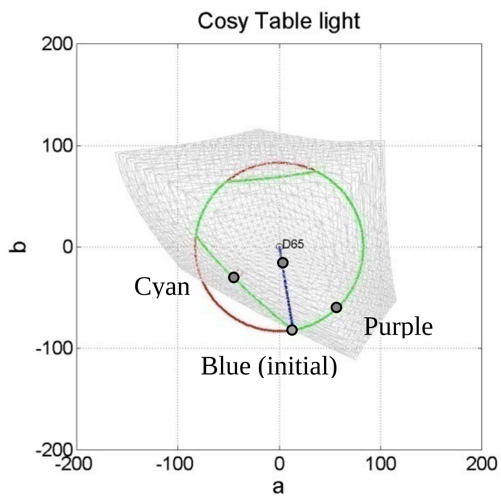


Figure 11: The results of the average tuned hue angle and chroma level for Table light in the "cosy" atmosphere is depicted above in the CIE 1976 LAB color appearance model. The green line represents the values used for tuning the hue and the red line shows the clipped hue angles. The blue line represents the values used for tuning the variation in chroma.

4.2.3.4 Discussion colored light sources

The results of the colored light sources indicated that a variation in hue between 20 and 30 ΔE_{00} was allowed independent of the initial color and atmosphere. With regard to chroma, it was found that a decrease of at least 50% was allowed with a color difference between 10 and 20 ΔE_{00}. Furthermore, it was observed that the allowed decrease in chroma for the Table light in the "cosy" atmosphere was considerably larger compared to the other colored luminaires. This suggests that the participants were less sensitive to variation in chroma for colored light directed to the floor.

Overall, the allowed variation in hue and chroma was found to be larger for all colored light sources in the "activating" atmosphere compared to the "cosy" atmosphere. This could be explained by the fact that the "activating" atmosphere is mainly characterized by high brightness and high color temperature (Seuntiens and Vogels, 2008). As a result, it is possible that the effect of colored light sources in the "activating" atmosphere is less prominent, and therefore, larger variation in hue and chroma is allowed compared to the "cosy" atmosphere.

4.3 Conclusion

The results of the tuning experiment showed that participants allowed a large variation in luminance for both the floor and spot lights in the "cosy" and "activating" atmosphere. With regard to the variation in color temperature, a consistent amount of variation around $800K$ was allowed for the increase in color temperature in the "cosy" atmosphere and for the decrease in color temperature in the "activating" atmosphere.

The variation in hue of the Living Color lamps in the "cosy" atmosphere resulted in a yellowish and reddish color for the clockwise and counter-clockwise directions, respectively. On the other hand, the initial cyan color of the Living Color lamps in the "activating" atmosphere was tuned by participants to a greenish and purplish color. Also, the initial bluish color of the Gemini light source and the Table light were both tuned by participants to a cyan and purplish color. In general, the allowed variation in hue and chroma in the activating atmosphere was found to be larger than the cosy atmosphere.

In this study, boundaries for the allowed variation in light characteristics in the “cosy” and “activating” atmosphere were obtained. In order to investigate how the average tuned light settings obtained from this study affected the perceived atmosphere, a second experiment was conducted which is described in the following chapter.

5. Study 2: the effect of the tuned change in light characteristics on the initially perceived reference atmosphere cosy and activating

A second experiment was conducted in which the average tuned light settings from the previous study were compared to the corresponding reference atmosphere ("cosy" or "activating"); this in order to answer the following sub-research question as described in the introduction:

> *"What is the effect of a change in light characteristics on an initially perceived atmosphere?"*

In this chapter, the experimental details for the second study are presented. First, the methodology is described including a description of the participants, the experimental design and the procedure. Finally, the results of the experiment can be found in the last paragraph.

5.1 Methodology

5.1.1 Participants

In this study, 10 males and 10 females aged between 23 and 31 participated in the experiment. Sixteen participants of the current study also participated in the first study. Furthermore, similar to the previous study, they were all native Dutch employees or students at Philips Research Eindhoven in the Netherlands. In addition, they had little to no knowledge with regard to lighting design and atmosphere creation.

5.1.2 Design and stimuli

A difference scaling experiment was designed in which the average tuned light settings from the previous study were compared to the initial lights setting of one of the two atmospheres. For example, the atmosphere corresponding to the average result for the increase in luminance of the floor lights in the "cosy" atmosphere was compared to the initial "cosy" atmosphere. As a result, 24 paired stimuli were presented to participants in the current experiment. Each pair of stimuli consisted of an average tuned light setting from the previous study and the light settings of the corresponding initial atmosphere ("cosy" or "activating").

Obviously, since only one light setting could be presented at a time, the light settings in each pair of stimuli were presented sequentially to the participants. They were asked to rate the light setting shown last in the pair of stimuli in relation to the first one; the order in which the two light settings were presented was randomized. In order to measure the perceived atmosphere, a shorter version of the atmosphere questionnaire of Vogels (2008) which is described in the next section was used.

5.1.3 Dependent measures

For the current study a shorter version of the atmosphere questionnaire of Vogels (2008) was used (see Appendix C). The original atmosphere questionnaire of Vogels consistsed of 38 Dutch terms, which were shortened to 12 terms in a follow-up study. Furthermore, it was found that the atmosphere terms can be combined into the following four atmosphere factors: *cosiness*, *liveliness*, *tenseness* and *detachment*.

For the purpose of this study, the use of the 12-terms atmosphere questionnaire would have resulted in a fairly time consuming experiment. In an effort to reduce the duration of the experiment and the cognitive workload of the participants, the atmosphere questionnaire was further shortened to four terms. Consequently, the following four Dutch terms: (1) Intiem (intimate), (2) Levendig (lively), (3) Beangstigend (frightening) and (4) Formeel (formal) were chosen to represent the four atmosphere factors described above. These terms were found to have the highest correlation with the *cosiness*$(\rho_{intiem,cosiness} = 0.81)$, *liveliness*$(\rho_{levendig,liveliness} = 0.82)$, *tenseness*$(\rho_{beangstigend,tenseness} = 0.84)$ and *detachment*$(\rho_{formeel,detachment} = 0.69)$ factors respectively. Finally, for each term a seven-point bipolar Likert scale (-3 to +3) was used.

5.1.4 Procedure

The procedure of the experiment was as follows. Participants were welcomed to the experimental room where a neutral light setting was presented. They were given time to walk around and observe the room. Next, similar to the previous study, participants were asked to take a seat in the right corner of the sofa. Subsequently, instructions of the experiment were presented and the procedure of the experiment was explained. Moreover, participants that did not participate in the tuning experiment were asked to perform an Ishihara Color Blindness Test; none of the participants were found to suffer from color blindness.

The participants evaluated the presented stimuli for each questionnaire term separately. Consequently, the 24 paired stimuli were presented four times to each participant. Between each pair of stimuli the neutral light settings was presented for five seconds. It should be noted that a neutral light setting was not presented *between* the two light settings of a stimulus pair. Furthermore, the order in which the questionnaire terms and stimuli pairs were presented to participants was randomized; this in order to minimize possible order effects. Since only one light setting could be shown at a time, participants were allowed to switch back and forth between the two light settings of a stimuli pair.

5.2 Results

The results of the atmosphere questionnaire are presented in this paragraph. Preliminary analyses suggested that the distribution of the questionnaire scores for each tuning was not normally distributed. This could be due to possible different interpretations of the four atmosphere terms by participants. In order to verify the normality of the data in an objective way, Kolmogorov-Smirnov and Shapiro-Wilk tests of normality were performed in SPSS on the questionnaire scores for each tuning separately. Indeed, the results of the normality tests revealed that the questionnaire scores were all significantly non-normal $(P < .05)$. As a consequence, the Wilcoxon signed-rank test was adopted to analyze the results of this study. The Wilcoxon signed-rank test does not require assumptions about the form of the distribution. Therefore, it can be used as an alternative to the paired Student's t-test to compare differences between measurements of data measured at an interval state. The results of the Wilcoxon signed-rank tests are expressed by the test statistics z, the significance value p and the effect size r. The effect size is a number between zero and one where a value around 0.3 means a small effect, around 0.5 a medium effect and around 0.7 a large effect.

In the next section, the results of the questionnaire for variation in luminance of the floor and spot lights are presented. Next, the questionnaire results for the variation in color temperature are described. Finally, the results of the questionnaire for the colored light sources can be found in the last section.

5.2.1 Luminance white light sources

5.2.1.1 Floor lights

Figure 12 shows the average scores for each of the questionnaire terms in the "cosy" and "activating" atmosphere for the tuned increased and decreased luminance of the floor lights. The figure shows that in general an increase in luminance of the floor lights in both atmospheres was perceived as less cosy, more lively, less tense and more detached compared to the initial atmosphere. On the contrary, as expected, the results for the decrease in luminance of the floor lights showed a reverse effect in both atmospheres.

A Wilcoxon signed-rank test on the questionnaire scores for the increase in luminance of the floor lights in the "cosy" atmosphere revealed a significant and large effect on *liveliness* $(z = -3.69,\ p < .05, r = -.82)$, *tenseness* $(z = -3.93, p < .05, r = -.87)$, and *detachment* $(z = -3.69, p < .05, r = -.82)$. Interestingly, the decrease in *cosiness* was found to be non-significant $(p > .05)$.

On the other hand, with regard to the decrease in luminance of the floor lights in the "cosy" atmosphere a significant and medium effect was found on *cosiness* $(z = -2.29, p < .05, r = -.51)$. In addition a significant and large effect was found on *liveliness* $(z = -3.25, p < .05, r = -.72)$, *tenseness* $(z = -3.27,\ p < .05, r = -.73)$ and *detachment* $(z = -3.83, p < .05, r = -.85)$.

As can be observed in Figure 12, the results of the questionnaire for the floor lights in the "activating" atmosphere showed a similar trend as in the "cosy atmosphere". In contrast to the "cosy" atmosphere, the effect of the increase in luminance on *cosiness* was found to be significant and large $(z = -3.68, p < .05, r = -.82)$ in the "activating" atmosphere. Furthermore, similar to the results found in the "cosy" atmosphere, the effects on *liveliness* $(z = -3.69, p < .05, r = -.82)$, *tenseness* $(z = -3.48, p < .05, r = -.77)$ and *detachment*$(z = -3.93, p < .05, r = -.87)$ were found to be large and significant.

Finally, results of the Wilcoxon signed-rank test for the decrease in luminance of the floor lights revealed a significant and large effect on *cosiness*$(z = -4.00, p < .05, r = -.89)$, *liveliness*$(z = -3.73, p < .05, r = -.83)$, *tenseness*$(z = -3.49, p < .05, r = -.78)$ and *detachment*$(z = -4.05, p < .05, r = -.90)$.

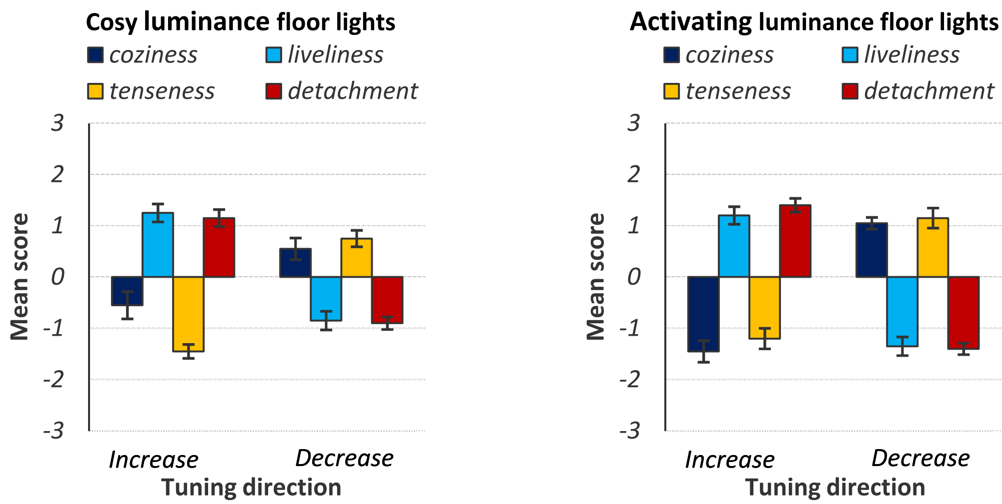


Figure 12: The average scores of the atmosphere questionnaire for the tuned increase and decrease in luminance of the floor lights in the "cosy" (left) and "activating" (right) atmosphere are depicted above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error .

5.2.1.2 Spot lights

The results of the questionnaire for the tuned increase and decrease in luminance of the spot lights in the "cosy" and "activating" atmosphere are presented in Figure 13. As can be observed, the results for the spot lights showed similar trends as the results found previously for the floor lights. The only difference was that for the spot lights, a Wilcoxon signed-rank test revealed that an increase in luminance of the spot lights in the "cosy" atmosphere was found to have a significant and medium effect on *cosiness* $(z = -2.25, p < .05, r = -.50)$. This suggests that, compared to the floor lights, the spot lights have a larger effect on the *cosiness* of the initial "cosy" atmosphere. Similar to the floor lights the effect on *liveliness* $(z = -3.87, p < .05, r = -.86)$, *tenseness*$(z = -3.82, p < .05, r = -.85)$, and *detachment* $(z = -3.81, p < .05, r = -.85)$ were found to be significant and large for the increase in luminance. On the other hand, a decrease in luminance was found to have a significant and medium effect on *cosiness* $(z = -2.87, p < .05, r = -.64)$, a significant and large effect on *liveliness* $(z = -4.09, p < .05, r = -.91)$, *tenseness* $(z = -3.38, p < .05, r = -.75)$, and *detachment* $(z = -3.39, p < .05, r = -.75)$.

Finally, results of the Wilcoxon signed-rank test for the tuned decrease in luminance in the "activating" atmosphere revealed a significant and medium effect on *cosiness* $(z = -3.92, p < .05, r = -.87)$, a significant and large effect on *liveliness* $(z = -3.58, p < .05, r = -.80)$, *tenseness* $(z = -3.95, p < .05, r = -.88)$, and *detachment* $(z = -3.96, p < .05, r = -.88)$.

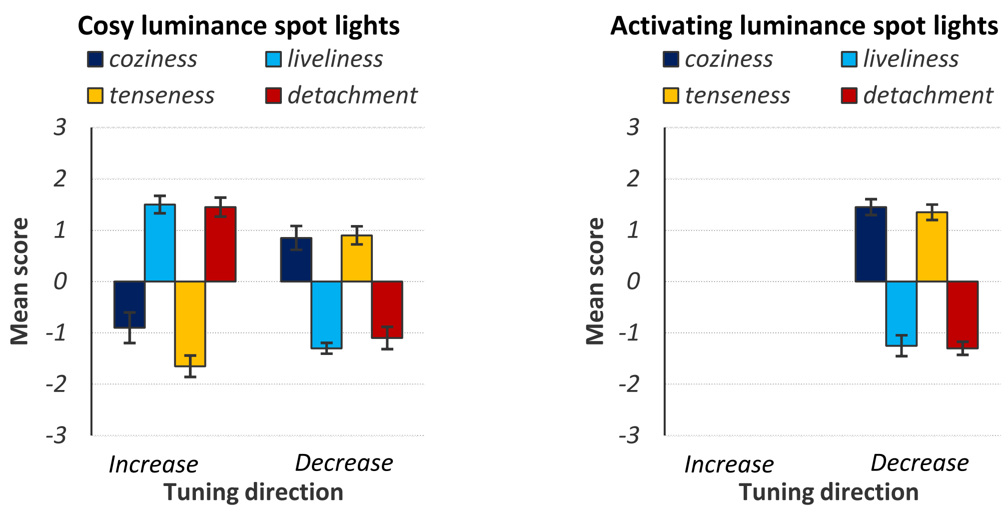


Figure 13: The average scores of the atmosphere questionnaire for the tuned increase and decrease in luminance of the spot in the "cosy" (left) and "activating" (right) atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error .

5.2.2 Color temperature white light sources

The results of the questionnaire for the combined tuned change in color temperature of the floor and spot lights in the "cosy" and "activating" atmosphere are shown in Figure 14. The results for the "cosy" atmosphere show that an *increase* in color temperature of the white luminaires from 2700K to about 3500K was on average perceived by participants as less cosy, more lively, slightly more tense and more detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed that there was a significant and large effect on *cosiness* $(z = -3.93, p < .05, r = -.88)$, a significant and medium effect on *liveliness* $(z = -3.04, p < .05, r = -.67)$ and a significant and large effect on *detachment* $(z = -4.04, p < .05, r = -.90)$. The effect on *tenseness* was found to be non-significant $(p > .05)$.

On the other hand, the results for the "activating" atmosphere showed that a *decrease* in color temperature from 4040K to about 3240K was on average perceived by participants as more cosy, less lively, less tense and less detached compared to the initial atmosphere. In general, the results for the "activating" atmosphere showed a reverse effect on the questionnaire terms than the results for the "cosy" atmosphere. These findings suggest that the effect of color temperature is atmosphere independent. The results of the statistics revealed that for the "activating atmosphere" there was only a significant and large effect on *cosiness* $(z = -4.04, p < .05, r = -.90)$ and *detachment* $(z = -3.96, p < .05, r = -.88)$. The effect on *liveliness* and *tenseness* were found to be non-significant $(p > .05)$.

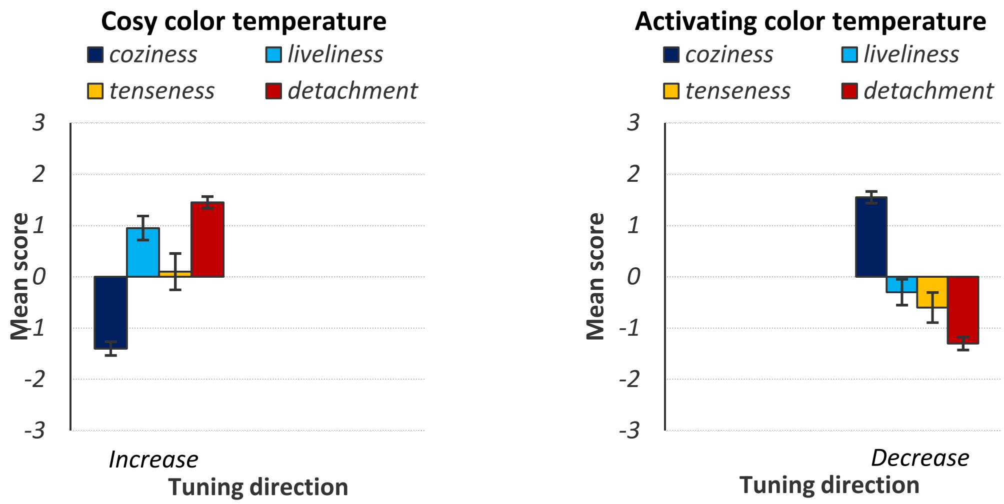


Figure 14: The average scores of the atmosphere questionnaire for the tuned change in color temperature in the "cosy" (left) and "activating" (right) atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.2.3 Colored light sources

5.2.3.1 Living Color lamps in the cosy atmosphere

Figure 15 shows the results of the questionnaire for the tuned change in hue angle and chroma level of the Living Color lamps in the "cosy" atmosphere. The results show that a yellowish color was on average perceived by the participants as less cosy, slightly less lively, slightly less tense and more detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed that there was only a significant and large effect on *cosiness* $(z = -3.94, p < .05, r = -.088)$ and a medium effect on *detachment* $(z = -2.97, p < .05, r = -.66)$. The effect on *liveliness* and *tenseness* were found to be non-significant $(p > .05)$.

On the other hand, a reddish color of the Living Color lamps in the "cosy" atmosphere was on average perceived by the participants as slightly less cosy, slightly more lively, more tense and less detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed that the effect on *liveliness* was significant and small $(z = -2.00, p < .05, r = -.44)$. Furthermore, a significant and large effect was found on *tenseness* $(z = -3.71, p < .05, r = -.82)$ and *detachment* $(z = -3.50, p < .05, r = -.78)$. The effect on *cosiness* was found to be non-significant $(p > .05)$.

A decrease in chroma of the initial orange color was on average perceived by the participants as less cosy, less lively, slightly less tense and more detached compared to the initial atmosphere. Results of the Wilcoxon signed-rank test revealed a significant and large effect on *cosiness* $(z = -3.62, p < .05, r = -.81)$, *liveliness* $(z = -3.57, p < .05, r = -.80)$ and *detachment* $(z = -3.49, p < .05, r = -.78)$. The effect on *tenseness* was found to be non-significant $(p > .05)$.

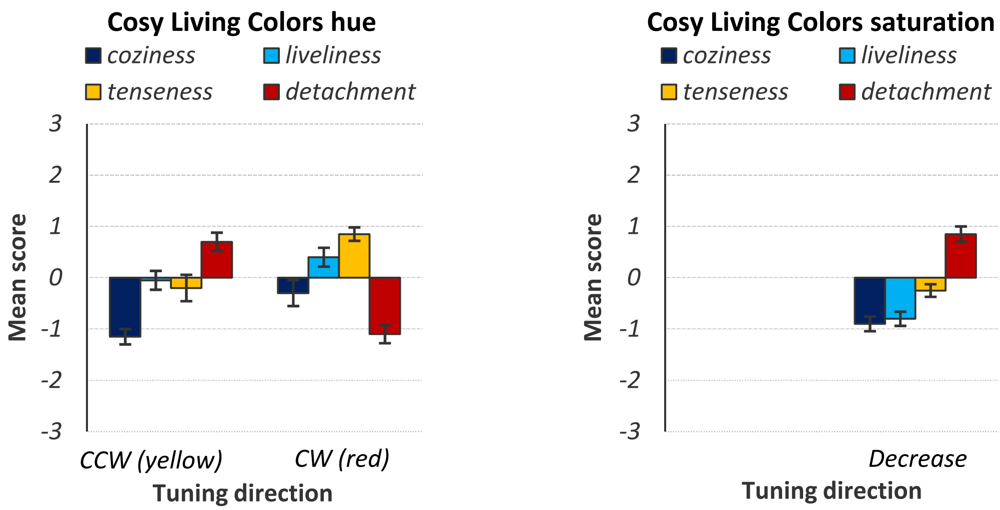


Figure 15: The average scores of the atmosphere questionnaire for the tuned change in hue (left) and chroma (right) of the Living Color lamps in the "cosy" atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.2.3.2 Living Color lamps in the activating atmosphere

The results of the questionnaire for the tuned change in hue angle and chroma level of the Living Color lamps in the "activating" atmosphere are shown in Figure 16. A first impression of the results of the questionnaire scores for the greenish color suggested that there was only a small effect on the initial "activating" atmosphere. Indeed, results of the Wilcoxon signed-rank test revealed that a greenish color of the Living Color lamps only had a significant and medium effect on increase in *cosiness* $(z = -2.33, p < .05, r = -.52)$. All the other effects were found to be non-significant $(p > .05)$.

On the other hand, the results showed that compared to the initial cyan color, a purplish color was on average perceived by the participants as more cosy, slightly more lively, slightly more tense and less detached. However, the results of the Wilcoxon signed-rank test revealed that there was only a significant and large effect on *cosiness* $(z = -3.50, p < .05, r = -.78)$ and *detachment* $(z = -3.35, p < .05, r = -.75)$. The effects on *liveliness* and *tenseness* were not significant $(p > .05)$.

Finally, a decrease in chroma of the initial cyan color was on average perceived by the participants as slightly more cosy, slightly less lively, slightly less tense and more detached compared to the initial atmosphere. Results of the Wilcoxon signed-rank revealed only a significant and small effect on *liveliness* $(z = -1.34, p < .05, r = -.30)$ and a significant and medium effect on *detachment* $(z = -2.98, p < .05, r = -.066)$. The effect on *cosiness* and *tenseness* were found to be non-significant $(p > .05)$.

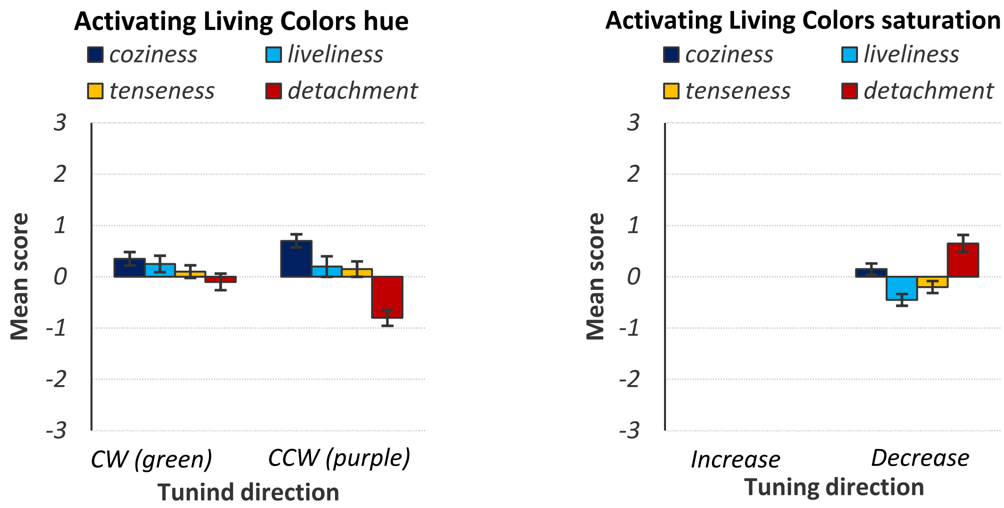


Figure 16: The average scores of the atmosphere questionnaire for the tuned change in hue (left) and chroma (right) of the Living Color lamps in the "activating" atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.2.3.3 Gemini in the cosy atmosphere

The results of the questionnaire for the tuned change in hue angle and chroma level of the Gemini light source in the "cosy" atmosphere are illustrated in Figure 17. The results for the variation in hue suggested a small to medium effect on *cosiness*, *liveliness*, *tenseness* and *detachment* for a cyan color of the Gemini light source. On average, a cyan color was perceived as more cosy, less lively, slightly less tense and slightly less detached. Results of the Wilcoxon signed-rank test revealed only a significant and medium effect on *cosiness* $(z = -2.56, p < .05, r = -.57)$ and *liveliness* $(z = -2.18, p < .05, r = -.48)$. The effect on *tenseness* and *detachment* were found to be non-significant $(p > .05)$

Interestingly, the results of the questionnaire with the Gemini light source set to a purplish color showed a similar trend as the results with a cyan color. A purplish color was on average perceived by the participants as more cosy, slightly less lively, slightly less tense and less detached. The results suggested a larger effect on *cosiness* and *detachment* compared to the cyan color. Indeed, results of the Wilcoxon signed-rank test revealed a significant and large effect on *cosiness* $(z = -3.96, p < .05, r = -.88)$ and *detachment* $(z = -3.96, p < .05, r = -.88)$. However, in contrast to the cyan color, the effect on *liveliness* was found to be non-significant $(p > .05)$

Finally, the results of the questionnaire showed that a decrease in chroma of the Gemini light source was on average perceived by the participants as more cosy, less lively, less tense and slightly less detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed that the effect on *cosiness* was significant and large $(z = -3.41, p < .05, r = -.76)$. In addition, a significant and medium effect was found on *liveliness* $(z = -2.35, p < .05, r = -.52)$ and *tenseness* $(z = -2.42, p < .05, r = -.54)$. The effect on *detachment* was not significant $(p > .05)$.

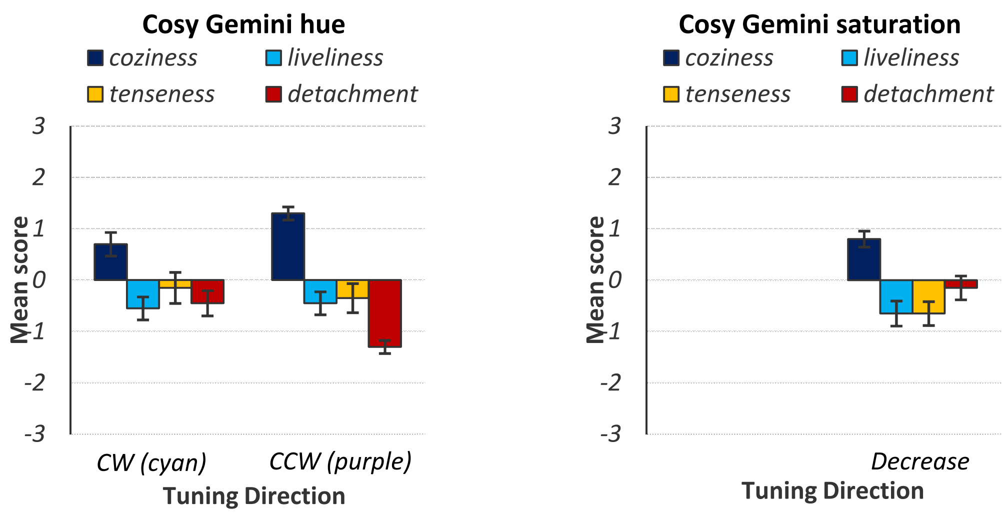


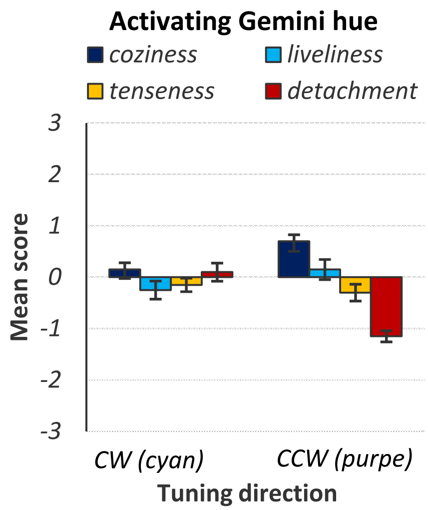
Figure 17: The average scores of the atmosphere questionnaire for the tuned changed in hue (left) and chroma (right) of the Gemini light source in the "cosy" atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.2.3.4 Gemini in the activating atmosphere

Figure 18 shows the results of the questionnaire for the tuned change in hue angle and chroma level of the Gemini light source in the "activating" atmosphere. On average, a cyan color was perceived by the participants as slightly more cosy, slightly less lively, slightly less tense and slightly more detached. First impression of the results suggested that there was only a small effect of the cyan color on the initial "activating" atmosphere. Results of the Wilcoxon signed-rank tests confirmed this and revealed that the effect on all atmosphere factors was non-significant $p > .05$).

Similar to the results of the Gemini light source in the "cosy" atmosphere, a purplish color of the Gemini light source in the "activating" atmosphere was on average perceived by participants as more cosy, slightly more lively, slightly less tense and less detached. A Wilcoxon signed-rank test revealed a significant and large effect on *cosiness* ($z = -3.50, p < .05, r = -.78$) and *detachment* ($z = -4.06, p < .05, r = -.90$). The effect on the *liveliness* and *tenseness* factors were found to be non-significant ($p > .05$).

With regard to the variation in chroma of the Gemini light source in the "activating" atmosphere, a decrease in chroma was on average perceived by the participants as slightly more cosy, less lively, equally tense and slightly more detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed only a significant and large effect on *liveliness* ($z = -3.44, p < .04, r = -.76$). All the other effects were found to be non-significant ($p > .05$).



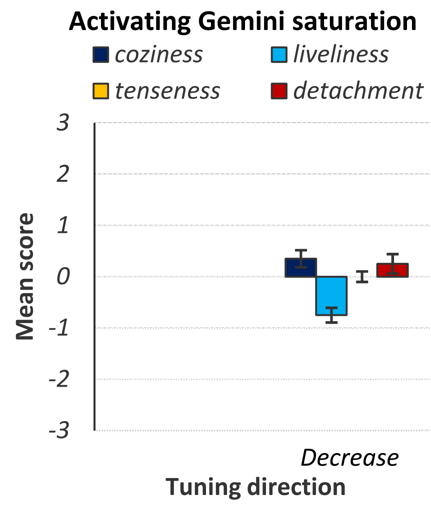


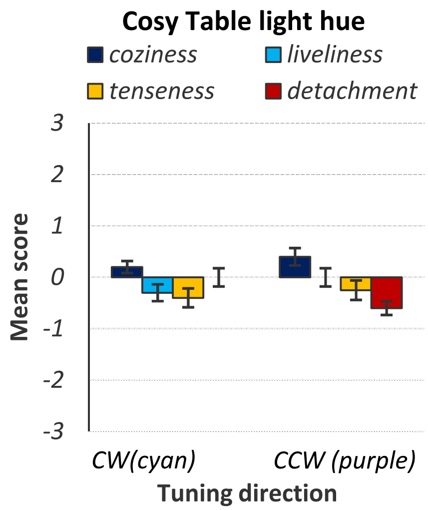
Figure 18: The average scores of the atmosphere questionnaire for the tuned change in hue (left) and chroma (right) of the Gemini light source in the "activating" atmosphere are depicted above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.2.3.5 Table light in the cosy atmosphere

The results of the questionnaire for the tuned change in hue angle and chroma level of the Table light are shown in Figure 19. As can be observed, in general only a small effect of the tuned change in hue and chroma on the initial "cosy" atmosphere in terms of *cosiness*, *liveliness*, *tenseness* and *detachment* was found. According to our results, a cyan color was on average perceived by the participants as slightly more cosy, slightly less lively, slightly less tense and equally detached compared to the initial atmosphere. A Wilcoxon signed-rank test revealed only a significant and small effect on tenseness $(z = -1.63, p < .05, r = -.44)$. The effects on the other atmosphere factors were non-significant $(p > .05)$.

The purplish color was on average perceived as more cosy, equally lively, slightly less tense and less detached compared to the initial atmosphere. Results of the Wilcoxon signed-rant test revealed a significant and small effect on *cosiness* $(z = -2.13, p < .05, r = -.47)$ and a significant and medium effect on *detachment* $(z = -3.20, p < .05, r = -.61)$. The effect on *liveliness* and *tenseness* were not significant $(p > .05)$.

Finally, a decrease in chroma was on average perceived by the participants as slightly more cosy, slightly less lively, less tense and more detached compared to the initial atmosphere. Results of the Wilcoxon signed-rank test revealed a significant and medium effect on *tenseness* $(z = -2.51, p < .05, r = -.56)$ and *detachment* $(z = -2.67, p < .05, r = -.59)$. The effect on *cosiness* and *liveliness* were found to be non-significant $(p > .05)$.



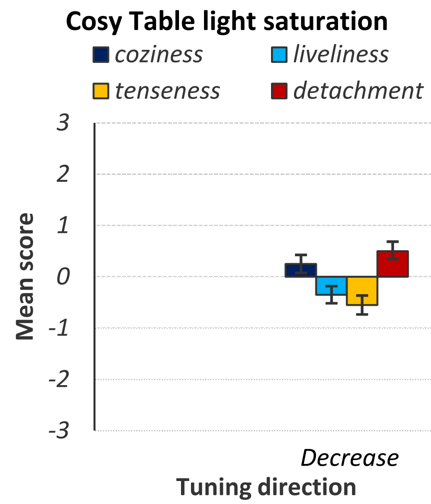


Figure 19: The average scores of the atmosphere questionnaire for the tuned change in hue (left) and chroma (right) of the Table light in the "cosy" atmosphere are illustrated above. The four bars represent the cosiness, liveliness, tenseness and detachment atmosphere factors. The error bars correspond to one standard error.

5.3 Conclusion

With regard to the white luminaires, the results of the atmosphere questionnaire indicated that an increase in luminance level of the floor and spot lights was perceived as less cosy, more lively, less tense and more detached in both atmospheres. Contrary, a reverse effect was found for the decrease in luminance. Furthermore, a cooler color temperature in the "cosy" atmosphere was perceived by participants as less cosy, more lively and more detached compared to the initial atmosphere. On the contrary, a warmer color temperature in the "activating" atmosphere was found to be significantly more cosy and less detached.

The questionnaire results for the colored luminaires showed that the variation in hue mainly affected the *cosiness* and *detachment* of the initially perceived atmosphere. With regard to the variation in chroma, a decrease in chroma was found to affect all atmosphere factors across the colored light sources. In general, the effect of variation in hue and chroma on the initial atmosphere seems be larger in the "cosy" atmosphere compared to the "activating" atmosphere. As mentioned in the previous study, this could be due to the rather high brightness level in the initial "activating" atmosphere.

In this study, the effect of the average tuned light settings from the first study on initially perceived atmosphere was investigated. It should be noted that in the current study the new light settings were compared to the original ones, i.e. with the corresponding initial atmosphere ("cosy" or "activating") as a reference. It would be interesting to investigate whether similar effects were found when the reference was absent. Consequently, a third experiment was conducted in order to verify this. The experimental design and results of the third experiment are described in the next chapter.

6. Study 3: the effect of the tuned change in light characteristics on the initial cosy and activating atmosphere without reference

The results of the second study indicated significant effects of the change in light characteristics on the initial atmosphere. However, it can be hypothesized that the effects of variation in light characteristics on the initial “cosy” and “activating” atmosphere would smaller when participants would be asked to evaluate each light setting separately *without* a reference.

In order to verify this hypothesis, a third experiment was conducted. In this chapter, the experimental details of the third study are presented. First, the methodology is described including a description of the participants, the experimental design and the procedure of the experiment. Finally, the results of the experiment can be found in the last paragraph.

6.1 Methodology

6.1.1 Participants

In this study, 18 participants consisting of 9 males and 9 females aged between 23 and 38 participated in the experiment. Sixteen participants of the current study also participated in the first and second studies. The rest of the participants only participated in the second study.

6.1.2 Design and stimuli.

In this study, all the average tuned light settings obtained in the first study were presented to the participants as a single stimulus. In addition, the initial light settings for the “cosy” and “activating” atmosphere were also included as stimuli. This resulted in a total of 26 stimuli that were presented to the participants in random order.

6.1.3 Dependent measures

In order to let participants evaluate the presented light settings, the shorter four-terms atmosphere questionnaire of the previous study was used. For more information with regard to the shortened atmosphere questionnaire of Vogels (2008) please refer to sub-section 5.1.3

6.1.4 Procedure

The procedure of the experiment was as follows. Participants entered the experimental room with the neutral light setting switched on and were asked to take a seat in the right corner of the sofa. Since the participants already participated in at least one of the previous experiments, no additional tests for color blindness were performed. Next, instructions of the experiment were presented and the procedure of the experiment was explained to the participants.

Similar to the previous study all light settings were evaluated by participants in random order for one questionnaire term at a time; thus, in total all stimuli were presented four times. The order in which the questionnaire terms were presented to the participants was randomized. Furthermore, between each stimuli a neutral light setting was presented to the participants for five seconds to minimize the effects of chromatic and light adaptation between the presented light settings.

6.2 Results

The results of the atmosphere questionnaire are presented in this paragraph. Similar to the previous study, Wilcoxon signed-rank tests were performed in order to investigate whether there was a significant difference in perceived atmosphere between the average tuned light settings and the initial light setting corresponding to the “cosy” and “activating” atmosphere.

This paragraph is structured as follows. First, the results for the variation in luminance and color temperature of the white light sources are presented. Next, the results for the variation in hue and chroma of the colored light sources can be found in the last section. Only these lighting conditions where significant results were found are presented in this paragraph. For an overview of the results of the conditions that were found not significant ($p > .05$) please refer to Appendix D

6.2.1 Luminance white light sources

In general, the results for the tuned change in luminance of the white light sources in the current study showed similar trends as found in the previous study. An increase in luminance of the floor and spot lights was on average perceived by the participants as less cosy, more lively, less tense and more detached with respect to both initial atmospheres. On the other hand, a reverse trend was found for the decrease in luminance of the floor and spot lights. While similar trends as in the previous study were found, only significant effects were found for the luminance increase of the floor and spot lights in the “cosy” atmosphere. With regard to the “activating” atmosphere, only significant effects were found for the luminance decrease of the spot lights. The remaining light conditions were found to be non-significant ($p > .05$).

Figure 20 shows the average scores of each questionnaire term for the luminance increase of the floor and spot lights in the “cosy” atmosphere in relation to the average questionnaire scores for the initial “cosy” atmosphere. As can be observed, the results of an increase in luminance of the floor and spot lights in the “cosy” atmosphere was on average perceived by the participants as less cosy, more lively, less tense and slightly less detached compared to the initial “cosy” atmosphere. A Wilcoxon signed-rank test on the results of the floor lights revealed that there was only a significant and medium effect on *tenseness* $(z = -1.97, P < .05, r = -.46)$. The effect on *cosiness*, *liveliness* and *detachment* were found to be non-significant ($p > .05$).

Similarly, the results of the statistics for the spot lights showed a significant and medium effect on *tenseness* $(z = -2.38, p < .05, r = -.56)$. In addition, a significant and medium effect was also found *cosiness* $(z = -1.98, p < .05, r = -.47)$. The effect on *liveliness* and *detachment* were found to be non-significant ($p > .05$).

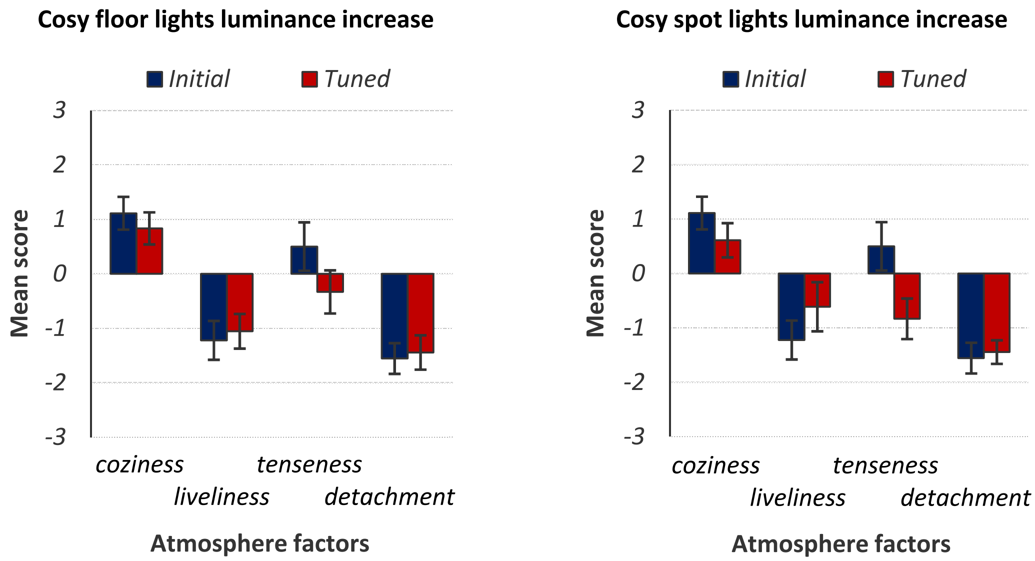


Figure 20: The average questionnaire scores for the increase in luminance of the floor (left) and spot (right) lights in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores for the light setting of the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores for the tuned light setting. The error bars correspond to one standard error.

Finally, the questionnaire results for the decrease in luminance of the spot lights in the "activating" atmosphere are shown in Figure 21. As can be observed, the decreased luminance of the spot lights was on average perceived by the participants as more cosy, less lively, more tense and less detached compared to the initial "activating" atmosphere. A Wilcoxon signed-rank test revealed only a significant and medium effect on *tenseness* ($z = -2.17, P < .05, r = -.51$) and *detachment* ($z = -2.11, p < .05, r = -.49$). The effect on *cosiness* and *liveliness* were found to be non-significant ($p > .05$).

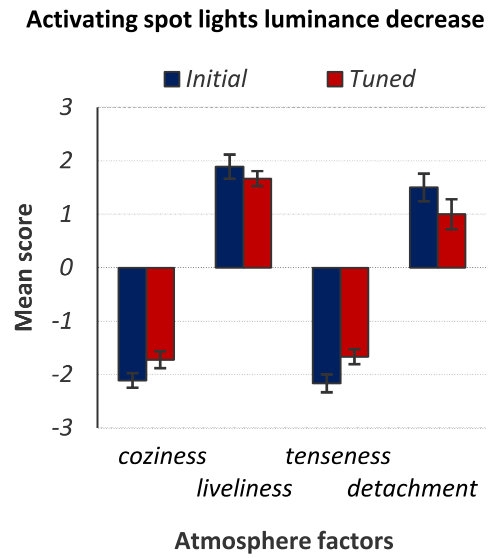
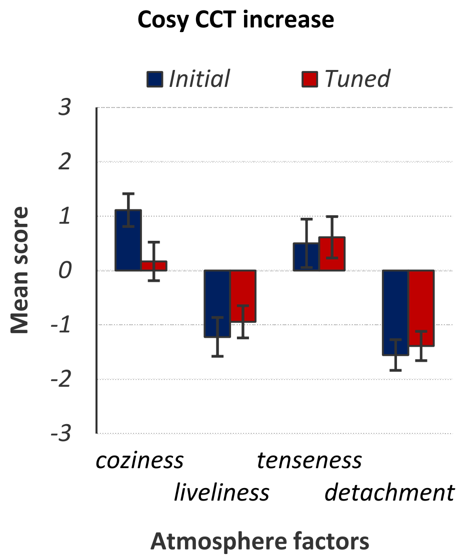


Figure 21: The average questionnaire scores for the decrease in luminance of the spot lights in the "activating" atmosphere is depicted above. The blue bars indicate the average questionnaire scores for the initial light setting of the "activating" atmosphere. The red bars indicate the average questionnaire scores for the tuned light setting. The error bars correspond to one standard error.

6.2.2 Color temperature white light sources

The results of the questionnaire for the change in color temperature are presented in relation to the average questionnaire scores of the initial "cosy" and "activating" atmosphere in Figure 22. As expected, the results in both the "cosy" and "activating" atmosphere showed similar trends as found in the previous study. The increase in color temperature in the initial "cosy" atmosphere was on average perceived by the participants as less cosy, more lively, more tense and more detached compared to the initial "cosy" atmosphere. The results of the Wilcoxon signed-rank tests revealed only a significant and medium effect on *cosiness* $(z = -2.013, p < .05, r = -.47)$. The effect on *liveliness*, *tenseness* and *detachment* were found to be non-significant $(p > .05)$.

On the other hand, a reverse trend was found for the decrease in color temperature for the initial "activating" atmosphere. As can be observed, a lower color temperature was on average perceived by the participants as more cosy, less lively, less tense and less detached. Similar to the results in the "cosy" atmosphere, a Wilcoxon signed-rank test revealed a significant and medium effect on *cosiness* $(z = -2.072, p < .05, r = -.48)$. Additionally, a significant and medium effect was also found on *detachment* $(z = -2.10, p < .05, r = -.50)$. The effects on *tenseness* and *liveliness* were found to be non-significant $(p > .05)$.



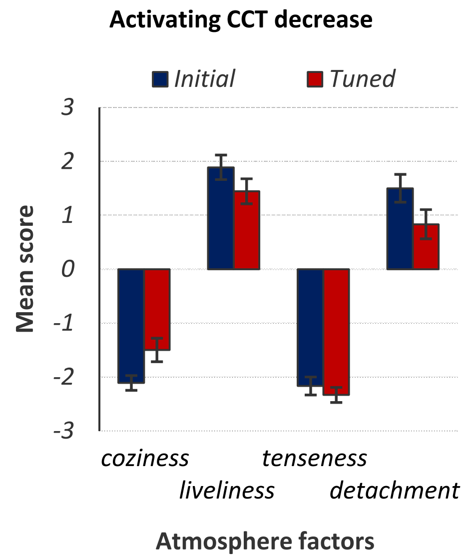


Figure 22: The average questionnaire scores for the increase and decrease in color temperature in the "cosy" (left) and "activating" (right) atmosphere, respectively, is depicted above. The blue bars indicate the average questionnaire scores for the light settings corresponding to the initial atmospheres. The red bars indicate the average questionnaire scores for the tuned light setting. The error bars correspond to one standard error.

6.2.3 Colored light sources

Interestingly, while the results of the questionnaire for the colored light sources in the current study showed similar trends as found in the previous study, only the change in hue in the counter-clockwise direction for the Gemini light source in the "activating" atmosphere was found to be significant. All other results of the questionnaire were found to be non-significant ($p > .05$). As shown in Figure 23, the purplish color for the Gemini light source atmosphere was on average perceived by the participants on average as more cosy, slightly more lively, more tense and less detached. Results of a Wilcoxon signed-rank test revealed only a significant and medium effect on *detachment* ($z = -1.98, p < .05, r = -.46$). The effect on *cosiness*, *liveliness* and *tenseness* were all found to be non-significant ($p > .05$).

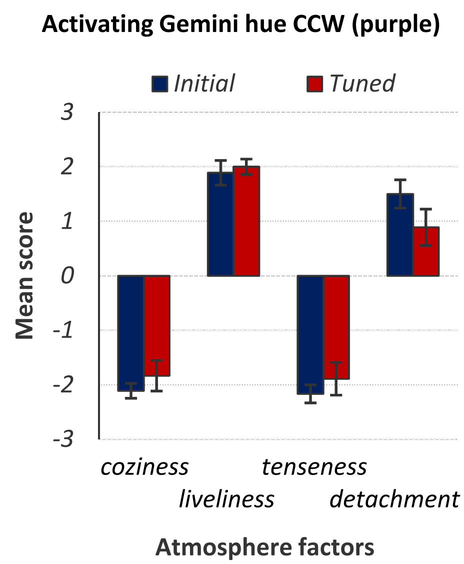


Figure 23: The average questionnaire scores for the tuned change in hue in counter-clockwise direction of the Gemini light source in the "activating" atmosphere is depicted above. The blue bars indicate the average questionnaire scores for the initial light setting corresponding to the "activating" atmosphere. The red bars indicate the average questionnaire scores for the tuned light setting. The error bars correspond to one standard error.

6.3 Conclusion

A follow-up experiment was conducted in order to investigate whether similar effects as in the previous study were found when the average tuned light settings were presented to the participants as a single stimulus without reference. As expected, the overall trend of the results in the current study were in line with the findings of the previous study. But compared to the previous study, the results of the current study indicated considerably smaller effects on the initial "cosy" and "activating" atmosphere. Only for a few lighting conditions a significant difference compared to the initial "cosy" and "activating" atmosphere were found.

With regard to the change in luminance of the white light sources, an increase in luminance of the floor and spot lights in the "cosy" atmosphere was found to mainly affect the *tenseness* and to some extent the *cosiness* of the initial "cosy" atmosphere. On the other hand, a decrease in luminance of the spot lights in the "activating" atmosphere was found to affect the *tenseness* and *detachment* of the initial "activating" atmosphere. The results for the change in color temperature in both the "cosy" and "activating" atmosphere were found to mainly affect the *cosiness* and to some extent the *detachment* of the initial atmosphere. Furthermore, with regard to the colored light sources, only a significant effect on *detachment* was found for the change in hue in the counter-clockwise direction of the Gemini light source in the "activating" atmosphere. The results for all the other light conditions were found to be non-significant.

7. Discussion

The goal of the present research was to investigate the effect of the allowed variation in light characteristics on the initially perceived atmosphere in the living room. In this research the effect of the variation in (1) luminance, (2) color temperature, (3) hue and (4) chroma on the initially perceived “cosy” and “activating” atmosphere was investigated. Three experiments were conducted in order to answer the research question stated in the introduction. In this chapter the findings in the present study are discussed and compared to existing literature. Finally, recommendations and suggestions for future work are provided in the last paragraph.

7.1 Atmosphere questionnaire

The evaluation of the perceived atmosphere in the room was based on a shortened version of the atmosphere questionnaire of Vogels (2008) where each atmosphere factor (*coziness*, *liveliness*, *tenseness* and *detachment*) was represented by only one term with the highest correlation. In the previous study (Seuntiens, internal report 2008), a more extended version of the atmosphere questionnaire (12 atmosphere terms) was used to measure the perceived atmosphere in room. It could be argued whether the shortened atmosphere questionnaire is still accurate enough to measure the perceived atmosphere in the room. In order to verify this, analyses were performed on the questionnaire results from Seuntiens (internal report, 2008). The result of the statistics revealed that there was no significant difference ($p > .05$) in perceived atmosphere when twelve or four atmosphere terms was used. Thus, it can be expected that the shortened atmosphere questionnaire used in the present study was accurate enough to measure the perceived atmosphere in the room.

7.2 Luminance

In general, participants allowed a large change in luminance of the white light sources in both the “cosy” and “activating” atmosphere. The results indicated that on average participants allowed an increase in luminance of at least a factor two to four and a decrease in luminance of at least a factor two with respect to the initial luminance level of the luminaire. In addition, the range of luminance within which the “cosy” and “activating” atmosphere were still perceived, were found to be different. The luminance of the floor lights ranged from 40 to 252 cd/m^2 in the “cosy” atmosphere and from 204 to 1117 cd/m^2 in the “activating” atmosphere. As for the spot lights, the luminance ranged from 1.6 to 36 cd/m^2 in the “cosy” atmosphere and from 27 to at least 72 cd/m^2 in the “activating atmosphere”. Furthermore, it should be noted that the initially chosen luminance levels for the “cosy” and “activating” atmosphere were found to be approximately half way the low and high range of luminance levels respectively. These findings indicate that professional lighting designers in Seuntiens and Vogels (2008) were able to make good estimates of the required luminance levels for the white luminaires in the given atmospheres.

Results with respect to the effect of a change in luminance on the perceived atmosphere indicated similar trends for the floor and spot lights in both the “cosy” and “activating” atmosphere. In general, an increase in luminance was perceived as less cosy, more lively, less tense and more detached in both atmospheres. As expected, a reverse trend was found for the decrease in luminance for both the floor and spot lights. These findings can be intuitively understood and are in line with earlier studies related to atmosphere perception (van Erp, 2008; Vogels & Bronckers, 2009). The consistent relation between luminance and perceived atmosphere found in the present and previous research provides strong evidence that similar effects can be expected in other atmospheres, for example the “relaxing” and “exciting” atmosphere.

7.3 Color Temperature

Despite the significant difference in light setting between the “cosy” and “activating” atmosphere, a consistent and large amount of variation in color temperature was allowed in both atmospheres. The results indicated that *low* color temperature levels ranging from 2700K to approximately 3250K were allowed by participants in the “cosy” atmosphere. On the other hand, *high* color temperature levels ranging from 4040K to 3240K were allowed by participants in the “activating” atmosphere. These findings suggest that the allowed change in color temperature consistently is about 800K in both the increase and decrease direction independent of the atmosphere. It should be, however, noted that due to technical constraints, the variation in color temperature in the “cosy” and “activating” atmosphere was only investigated in one direction: increase in the “cosy” atmosphere and decrease in the “activating” atmosphere. Therefore, follow-up research is needed in order to determine the complete range of allowed change in color temperature in the “cosy” and “activating” atmosphere. Nevertheless, the findings in this research suggested that the allowed change in color temperature for other atmospheres (e.g. “relaxing” and “exciting”) is expected to be around 800K before a difference in atmosphere is perceived.

The results with respect to perceived atmosphere suggest that in general a low color temperature level is perceived as more cosy, less lively, less detached and slightly less tense. On contrary, a reverse effect was found for a high color temperature level. These findings are partially in line with earlier studies (van Erp, 2008; Vogels and Bronckers, 2009). In contrast to the current study, these studies found a reverse effect on *liveliness*. The contradicting results found on *liveliness* and the lack of significant results on *tenseness* in the current research could be due to many factors. For example, the previous studies investigated only the effect of color temperature on perceived atmosphere for white light sources with a uniform spatial distribution , whereas the current study used a mixture of spatial distributions. It is possible that the effect of color temperature on perceived atmosphere is dependent on the spatial distribution of light. Furthermore, the addition of colored light sources in the present research might have influenced the effect of color temperature on the perceived atmosphere.

7.4 Hue

The results of the current research showed that participants adjusted the Gemini light source with an initial bluish color in both atmospheres to a cyan and purplish color for the variation in hue angle in the CCW and CW direction. Similar results were found for the allowed change in hue of the Table light in the “cosy” atmosphere. With respect to the allowed change in hue of the Living Color lamps, the initial orange color in the “cosy” atmosphere was adjusted by participants to a yellowish and reddish color. On the other hand, participants adjusted the initial cyan color of the Living Color lamps in the “activating” atmosphere to a greenish and purplish color.

With the exception of the Living Color lamps in the “cosy” atmosphere, results of the current study indicated that the change in hue mainly affected the *cosiness* and *detachment* of the perceived atmosphere. Overall, a cyan and purplish color of the Gemini light source in the “cosy” and “activating” atmosphere was perceived as more cosy and less detached compared the initial deep blue color. Moreover, participants reported that the initial deep blue color in the “cosy” atmosphere was cold, harsh and unpleasant, which support the findings of Mahnke (1996) who found that a blue color was associated with unpleasant feelings such as depression. Our results indicated that, compared to the initial deep blue color used for the Gemini light source and the Table light, a cyan or purplish color might be more appropriate to elicit a cosy and pleasant atmosphere in the living room. The use of a cyan color in a living room seems to be in line with the findings of Manav (2007). In that study participants indicated that a light blue color was preferred for the living room area which they related to emotions like calm, peaceful, modern and relaxing.

The results of the questionnaire for a change in hue of the Living Color lamps supported the use of an orange color in the “cosy” atmosphere. The tuned yellowish and reddish color of the Living Color lamps in the “cosy” atmosphere were both perceived as less cosy compared to the initial orange color. In addition, participants rated the reddish color as more tense and reported it as unpleasant. The unpleasant feeling for the reddish color could be due to negative associations with the color. For example, in Kaya and Eps (2004) it was found that a red color was not only associated with positive emotional responses like love and romance, but also negative emotional responses such as evil and blood.

It should be noted that the findings of all the studies previously mentioned with regard to color emotion and preference were all based on color patches instead of colored light sources. Thus, the findings of these studies cannot be generalized for colored light sources. Further research is needed in order to gain more insight in the relation between color and atmosphere perception for colored light sources.

7.5 Chroma

Results with respect to the allowed change in chroma of the colored light sources showed that in general a larger amount of decrease in chroma was allowed in the “activating” atmosphere than in the “cosy” atmosphere. The decrease in chroma in the “cosy” atmosphere was found to be around 50% and in the “activating” atmosphere around 75%. Also in terms of color differences ΔE_{00} the decrease in chroma was larger for all colored light sources in the “activating” atmosphere. It should be noted that in terms of ΔE_{00}, the allowed change in chroma was smaller than hue. This indicates that in terms of perceived atmosphere, people were more sensitive for changes in chroma compared to hue.

Overall, the results of the atmosphere questionnaire showed that the decrease in chroma mainly had an effect on the *liveliness* and *detachment* of the perceived atmosphere. In general, a decrease in chroma was perceived as less lively and more detached independent of the initial atmosphere. These findings suggest that the colorfulness of the colored lights sources in a room mainly contribute to the *liveliness* and *detachment* of a perceived atmosphere. In addition, a decrease in chroma of the initial deep blue color of the Gemini light source and the Table light was found to be more cosy. This further supports the findings of Manav (2007) and our hypothesis that a less saturated blue color might be more appropriate to use in the “cosy” atmosphere.

We should emphasize that, due to the limitations in the current research, only a decrease in chroma for all colored light sources was investigated. Therefore, we cannot be sure whether the same relation between chroma and the atmosphere factors holds when the chroma of the colored light sources is increased. Further research is needed in order to verify the relation between chroma and atmosphere factors found in the present research.

7.6 Double Stimulus versus Single Stimulus

In this research, the allowed change in settings obtained from the first study were presented to the participants with the original light settings as a reference in the second study, and as single stimulus (i.e. without the original light settings as reference) in the third study. Overall, the results of the second study showed that participants were clearly able to indicate the change in perceived atmosphere when the new settings were compared to the original ones. However, there was a possibility that participants just assessed the change in light characteristics instead of the perceived atmosphere in the room.

Therefore, a follow-up experiment without reference was conducted in the third study to verify whether similar results as in the second study were found. In general, the results of the third study showed similar trends as found in the second study for all the light settings. This further supported the relation between light characteristics and the perceived atmosphere. It should be noted, however, that the effects found were considerably smaller in the absence of a reference. In general, a larger amount of significant results were found for light settings of the white luminaires compared to the colored luminaires. This suggests that the participants were more sensitive to changes in luminance and color temperature compared to changes in hue and chroma. Overall, the findings in this study indicated that participants found it more difficult to distinguish the atmosphere between the initial light settings and the new light settings when the initial ones were not explicitly shown. On the other hand, this also indicates that it is possible to create the same atmosphere with a large range of different light settings.

7.7 Recommendations and Future Works

The findings in the present study gave further insight into the relation between different light characteristics and the perceived atmosphere in a room. At this point, it should be noted that the present findings were obtained under specific experimental conditions in experiments of relatively short duration. Thus, the extent to which they are generalizable to actual home settings and the long-term effects of the presented light settings on perceived atmosphere remains to be investigated in the future. In addition, this research only investigated the effect of a change in light characteristics for the initially “cosy” and “activating” atmosphere in the living room. It would be interesting to investigate whether similar trends can be found for different atmospheres (e.g. “relaxing” and “exciting” atmosphere).

In this study participants evaluated the light settings from a fixed location on the sofa for one specific luminaire arrangement. Research has shown that the judgment of light is affected by the visual direction (Loe et al. 1994) and luminaire arrangement in a space (Durak et al., 2007). It would be interesting to investigate how the location of people in the room and how different arrangements of the light sources would affect the perceived atmosphere in a room. In addition, it should be noted that in general the sample group used in this study was homogeneous in age, professional background and nationality. As mentioned by Vogels (2008), it is possible that people have different opinions about atmosphere in an environment depending on culture, age, and professional background. Further research is needed in order to investigate how these variables influence the way an atmosphere is perceived.

The present study investigated the effect of variation in luminance, color temperature, hue and chroma on the perceived atmosphere and gave insight in how these light characteristics affect the perceived atmosphere in a room. It should be noted, however, that the adjustment of the light characteristics also changed the spatial distribution of the light in the room and it is known that also the spatial distribution of the light has an effect on perceived atmosphere. In our studies, the spatial distribution of the light sources was changed in an uncontrolled way. In order to investigate the effect of spatial distribution on atmosphere, light settings with a different spatial distribution, but equal perceived brightness and color temperature have to be created. However, this requirement meets some practical issues. First, there is no physical measure known that is a good predictor for the brightness impression of a room (van Erp, 2008). Second, due to the amount of different light sources used in the present study and the complexity of the light settings it was impossible to investigate the effect of spatial distribution in a unique way. Therefore, we would like to point out that the findings in the present study with regard to the effect of variation in light characteristics on the perceived atmosphere might be partly affected due to changes in the spatial distribution of light in the room. Nevertheless, overall the results in the present study were found to be in line with previous studies.

Finally, it should be mentioned that, besides the light characteristics investigated in the present study, more light characteristics exist which affect atmosphere perception (e.g. modeling, texture and density) as described in Reisinger et al. (2004). Further research is needed in order to gain insight in the relation between these light characteristics and atmosphere perception.

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Appendices

Appendix A: measurements luminaires characterization

Measurement results for the characterization of the white luminaires in the experiment room.

A.1 White light sources

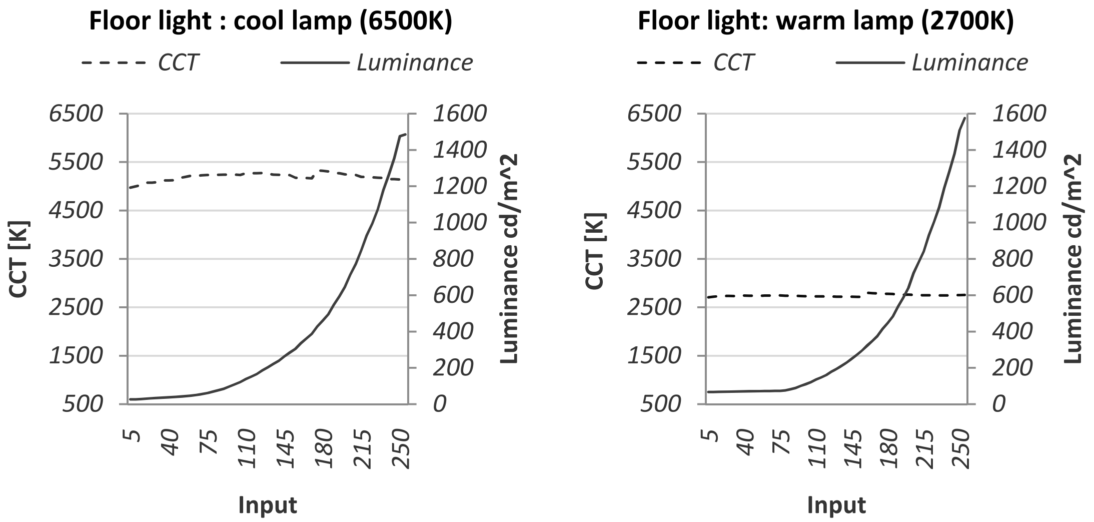


Figure A-1: Measurement results for the cool (left) and warm (right) lamp in the floor lights are depicted above. The solid line represents the measurements of the luminance (right y-axis) and the dashed line represents the measurements of the color temperature (left y-axis) in relation to the input values of the control software (x-axis).

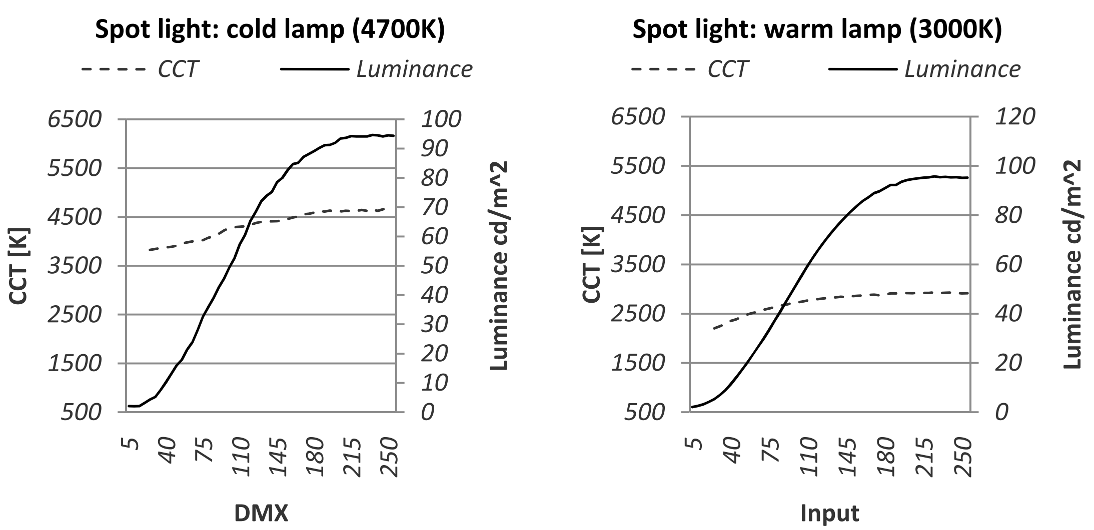
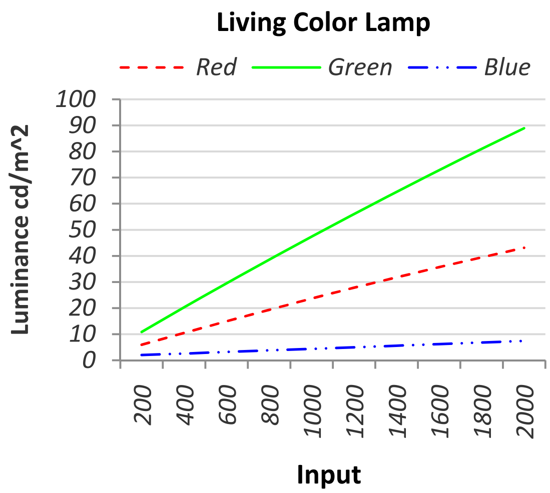


Figure A-2: Measurement results for the spot lights with cool (left) and warm (right) lamp are depicted above. The solid line represents the measurements of the luminance (right y-axis) and the dashed line represents the measurements of the color temperature (left y-axis) in relation to the input values of the control software (x-axis).

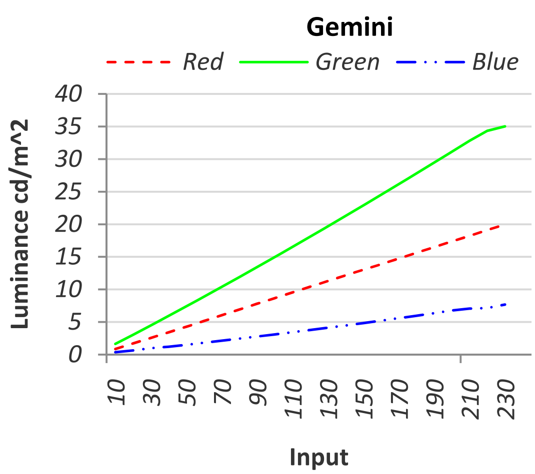
A.2. Colored light sources



Chromaticity Coordinates Living Color lamp

	X	Y	Z
R	91.88	40.93	0.6053
G	25.75	90.52	9.31
B	33.63	7.35	183.9
RGB	144.4	132.8	188.6

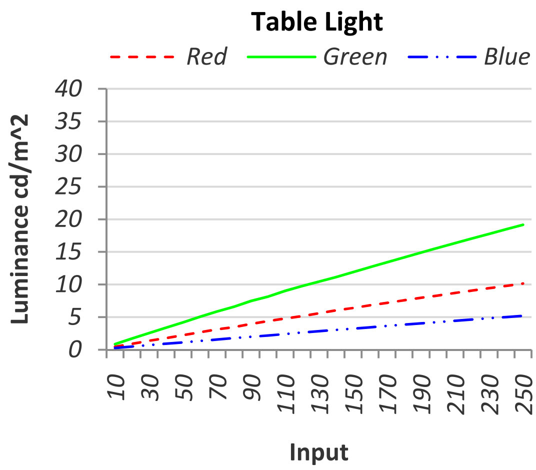
Figure A-3: Results of the measurements for the characterization of the Living Color Lamp is depicted above. The figure on the left illustrates the luminance measurements of the red, green and blue color channels in relation to the input values of the control software. The table on the right shows the measured chromaticity coordinates of the color primaries and white point in the CIE 1931 XYZ color appearance model.



Chromaticity Coordinates Gemini

	X	Y	Z
R	45.86	19.66	0
G	8.881	25.01	1.113
B	15.85	14.57	91.61
White	69.95	48.63	90.37

Figure A-4: Results of the measurements for the characterization of the Gemini light source is depicted above. The figure on the left illustrates the luminance measurements of the red, green and blue color channels in relation to the input values of the control software. The table on the right shows the measured chromaticity coordinates of the color primaries and white point in the CIE 1931 XYZ color appearance model.



Chromaticity Coordinates Table light

	X	Y	Z
R	21.96	10.19	0.0053
G	4.563	19.94	2.057
B	12.38	5.299	71.04
White	32.37	28.75	58.02

Figure A-5: Results of the measurements for the characterization of the Table Light is depicted above. The figure on the left illustrates the luminance measurements of the red, green and blue color channels in relation to the input values of the control software. The table on the right shows the measured chromaticity coordinates of the color primaries and white point in the CIE 1931 XYZ color appearance model.

Appendix B: stimuli design white light sources

Results of the measurements for the designed tunings of the white light sources in the "cosy" and "activating" atmosphere.

B.1 Cosy atmosphere

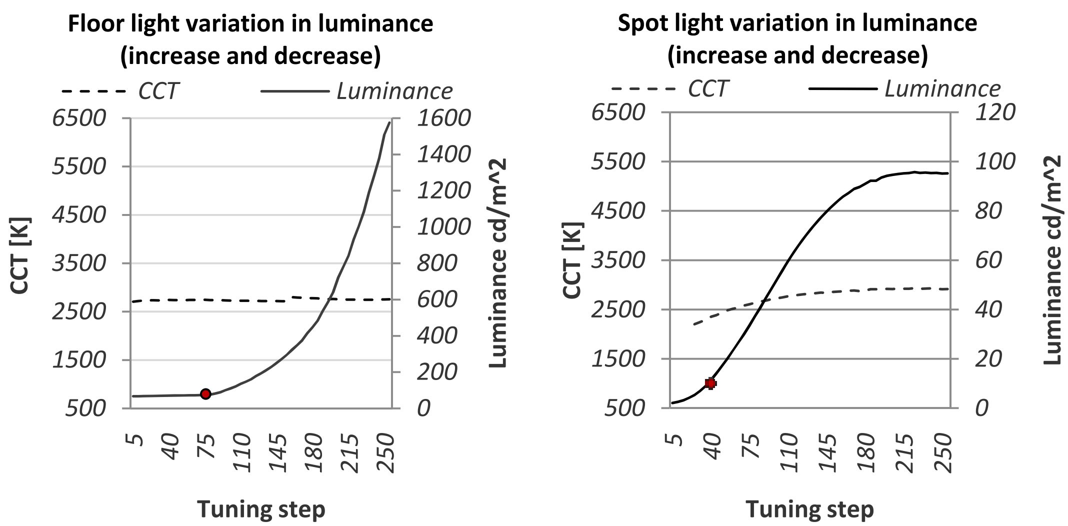


Figure B-1:Measurements of the designed tuning steps for the variation in luminance of the floor (left) and spot lights (right) in the "cosy" atmosphere while keeping the color temperature level stable across the tuning steps. The red dot indicates the initial luminance level.

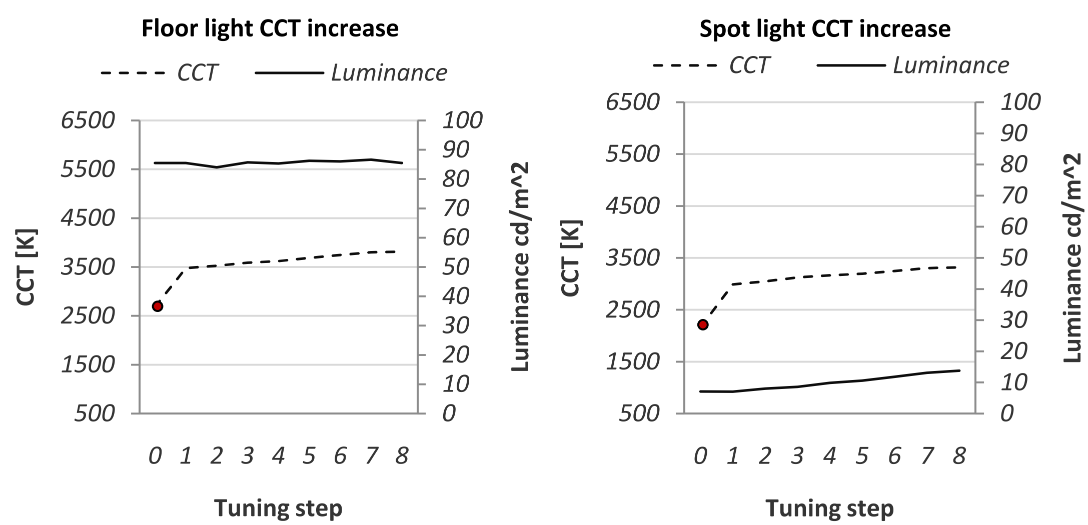


Figure B-2: Measurements of the designed tuning steps for the increase in color temperature of the floor (left) and spot lights (right) in the "cosy" atmosphere while keeping the luminance stable across the tuning steps. The red dot indicates the initial color temperature level.

B.2 Activating atmosphere

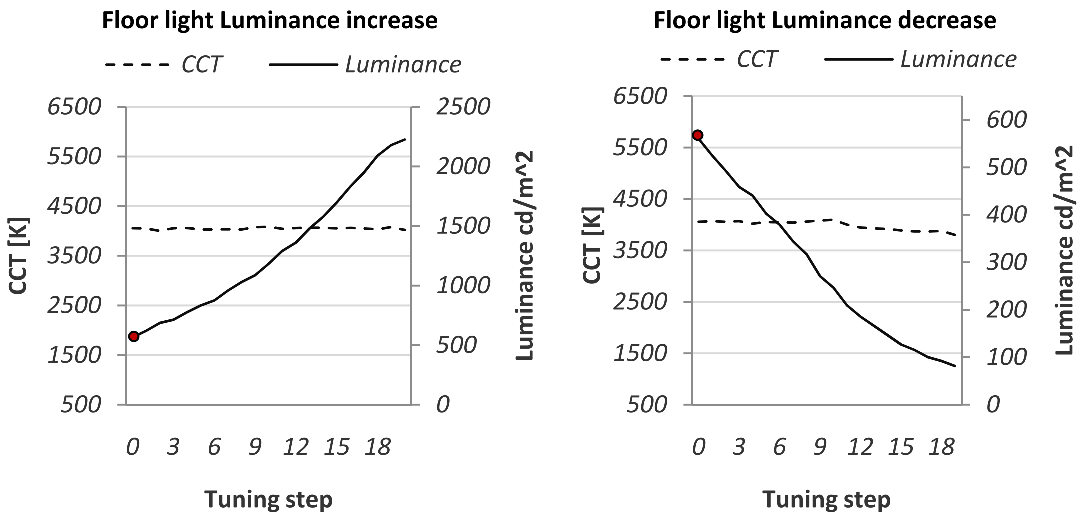


Figure B-3:Measurements of the designed tuning steps for the increase (right) and decrease (left) in luminance of the floor lights in the "activating" atmosphere while keeping the color temperature level stable across the tuning steps. The red dot indicates the initial luminance level.

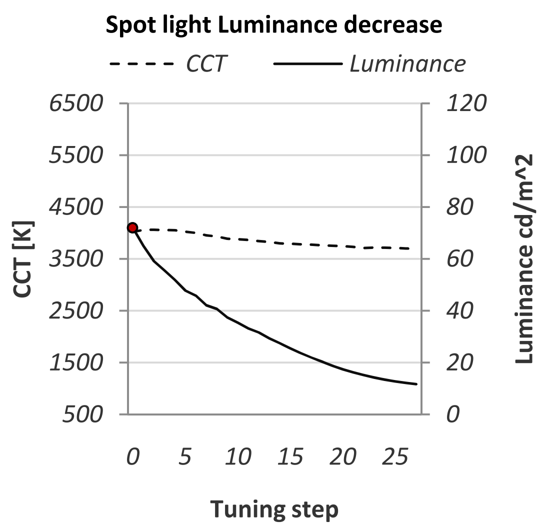
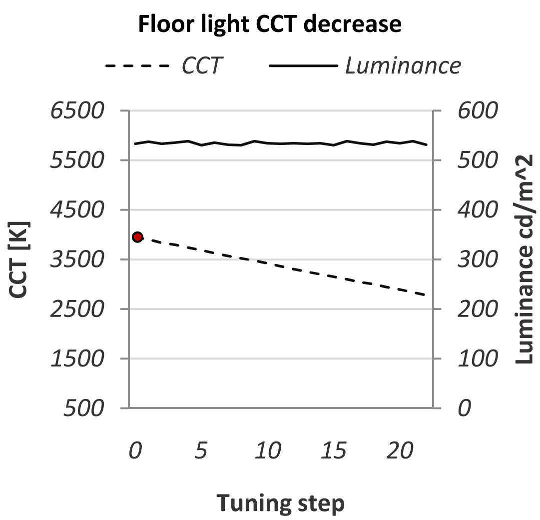


Figure B-4: Measurements of the designed tuning steps for the decrease in luminance of the spot lights in the "activating" atmosphere while keeping the color temperature level stable across the tuning steps. The red dot indicates the initial luminance level.



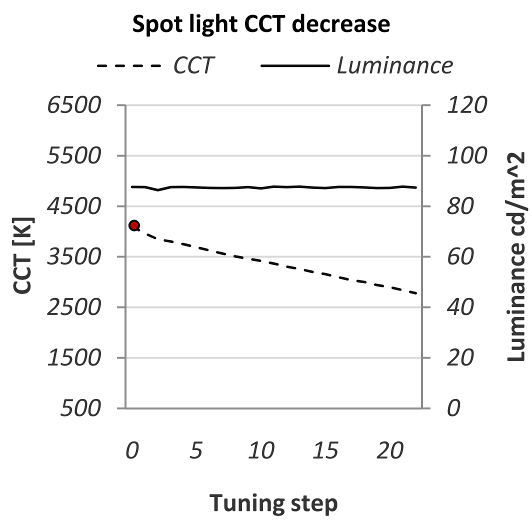


Figure B-3:Measurements of the designed tuning steps for the increase (right) and decrease (left) in luminance of the spot lights in the "activating" atmosphere while keeping the color temperature level stable across the tuning steps. The red dot indicates the initial luminance level.

Appendix C: atmosphere questionnaire

The template of the atmosphere questionnaire used in the present research is presented below. The $[Q]$ should be replaced with the corresponding questionnaire term "Intiem", "Levending", "Beangstigend" or "Formeel".

Geef aan in welke mate dit woord van toepassing is op de **sfeer** van de ruimte ten opzichte van de referentie.

	Niet $[Q]$			Neutraal			Erg $[Q]$
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
1. $[Q]$	❍	❍	❍	❍	❍	❍	❍
2. $[Q]$	❍	❍	❍	❍	❍	❍	❍
3. $[Q]$	❍	❍	❍	❍	❍	❍	❍
4. $[Q]$	❍	❍	❍	❍	❍	❍	❍
5. $[Q]$	❍	❍	❍	❍	❍	❍	❍
6. $[Q]$	❍	❍	❍	❍	❍	❍	❍
7. $[Q]$	❍	❍	❍	❍	❍	❍	❍
8. $[Q]$	❍	❍	❍	❍	❍	❍	❍
9. $[Q]$	❍	❍	❍	❍	❍	❍	❍
10. $[Q]$	❍	❍	❍	❍	❍	❍	❍
11. $[Q]$	❍	❍	❍	❍	❍	❍	❍
12. $[Q]$	❍	❍	❍	❍	❍	❍	❍
13. $[Q]$	❍	❍	❍	❍	❍	❍	❍
14. $[Q]$	❍	❍	❍	❍	❍	❍	❍
15. $[Q]$	❍	❍	❍	❍	❍	❍	❍

	Niet [Q]			Neutraal			Erg [Q]
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
16. [Q]	❍	❍	❍	❍	❍	❍	❍
17. [Q]	❍	❍	❍	❍	❍	❍	❍
18. [Q]	❍	❍	❍	❍	❍	❍	❍
19. [Q]	❍	❍	❍	❍	❍	❍	❍
20. [Q]	❍	❍	❍	❍	❍	❍	❍
21. [Q]	❍	❍	❍	❍	❍	❍	❍
22. [Q]	❍	❍	❍	❍	❍	❍	❍
23. [Q]	❍	❍	❍	❍	❍	❍	❍
24. [Q]	❍	❍	❍	❍	❍	❍	❍

Hebt u nog op- of aanmerkingen?

Appendix D: non-significant results third study

D.1 Cosy atmosphere

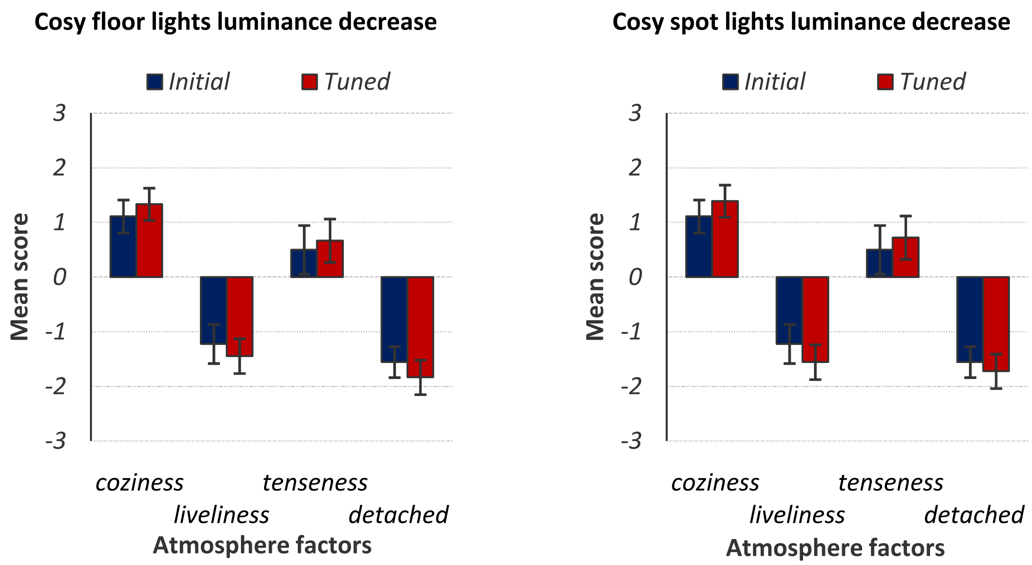


Figure D-1: The average questionnaire scores the decrease in luminance of the floor (left) and spot (right) lights in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

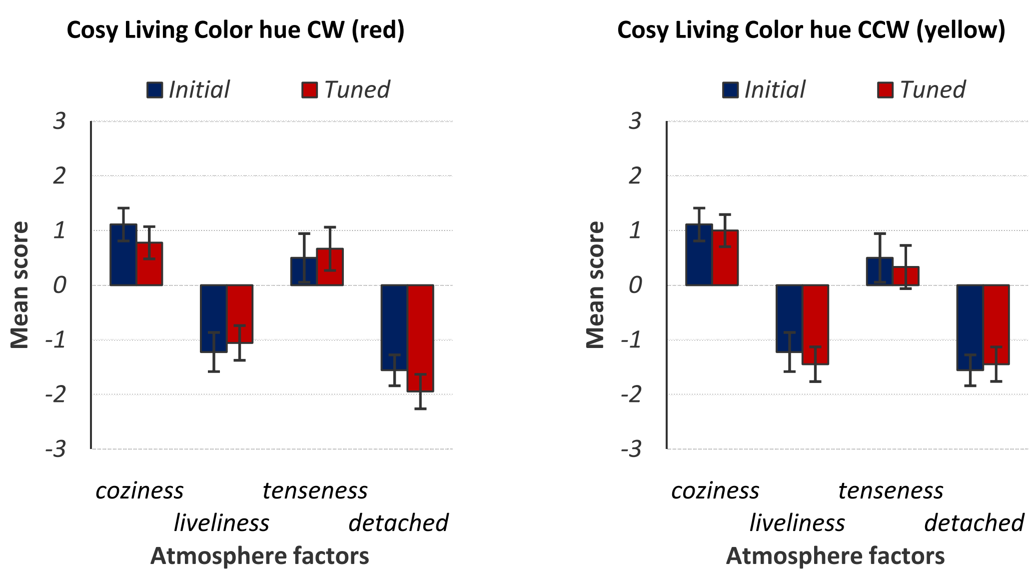


Figure D-2: The average questionnaire scores for the CW and CCW variation in hue of the Living Color lamps in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

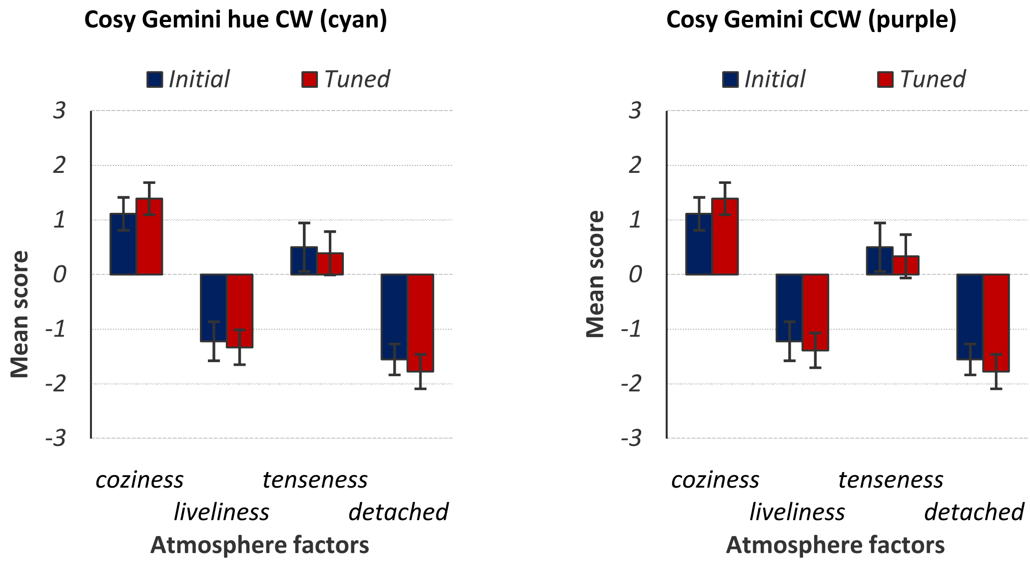


Figure D-3: The average questionnaire scores for the CW and CCW variation in hue of the Gemini light source in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

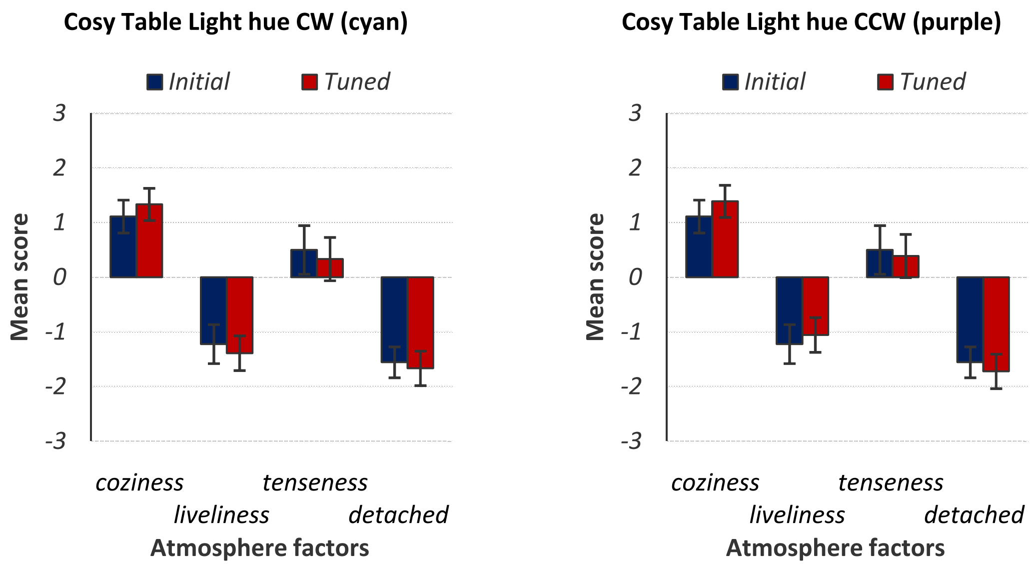


Figure D-4: The average questionnaire scores the CW and CCW variation in hue of the Table Light in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

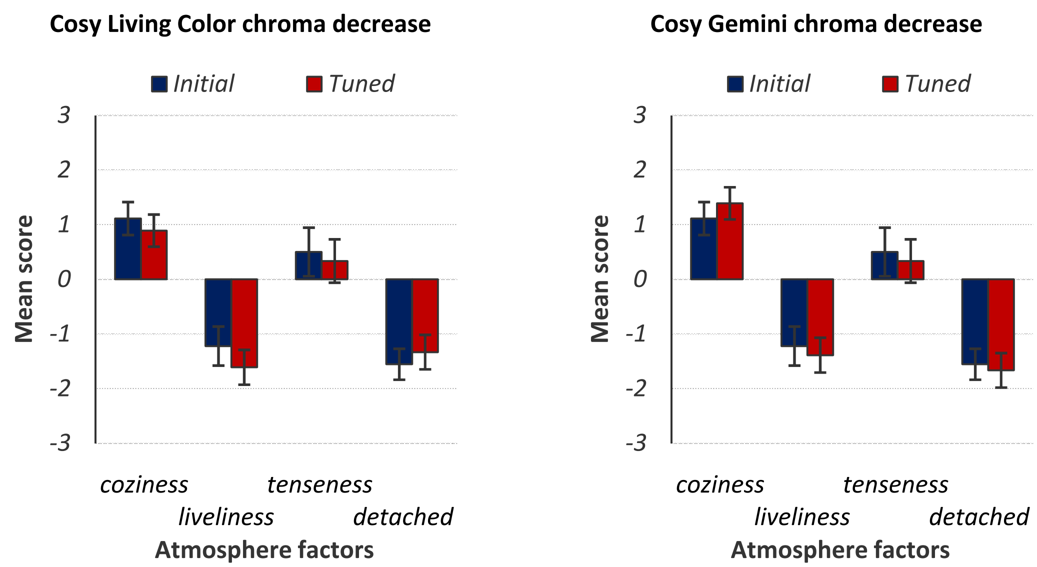


Figure D-5: The average questionnaire scores for the decrease in chroma of the Living Color lamps (left) and Gemini light source (right) lights in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

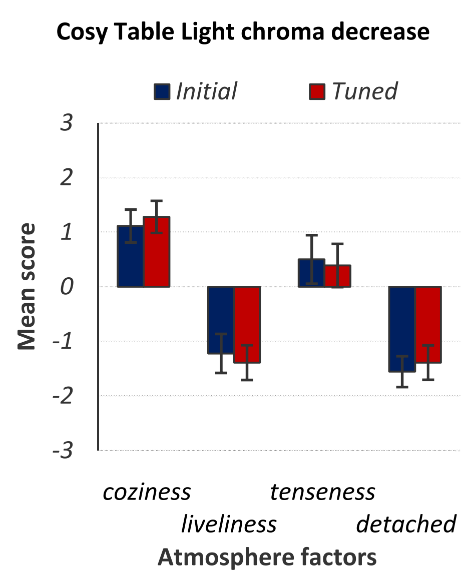


Figure D-6: The average questionnaire scores for the decrease in chroma of the Table Light in the "cosy" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "cosy" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

D.2 Activating atmosphere

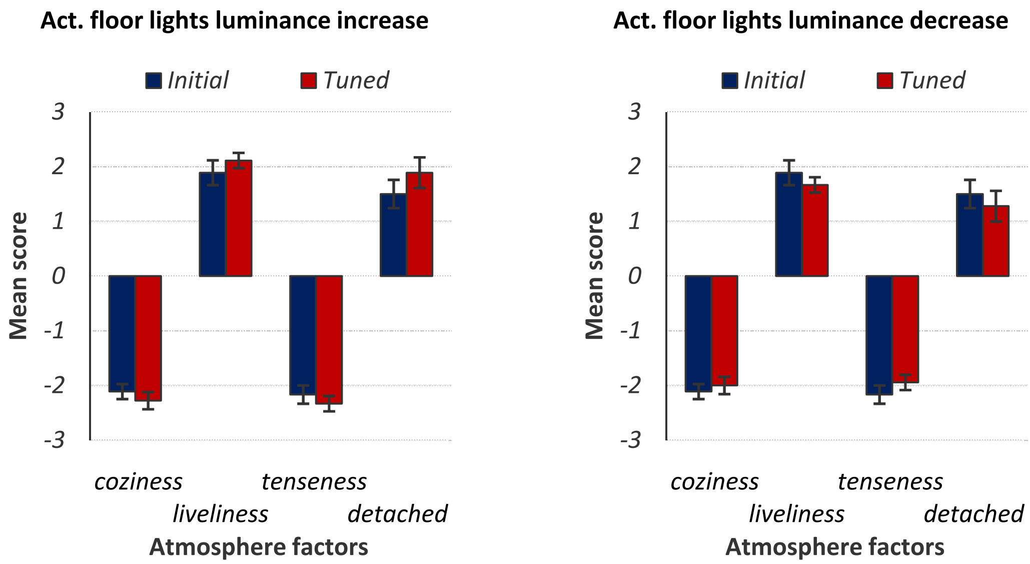


Figure D-7: The average questionnaire scores the increase (left) and decreases (right) in luminance of the floor lights in the “activating” atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial “activating” atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

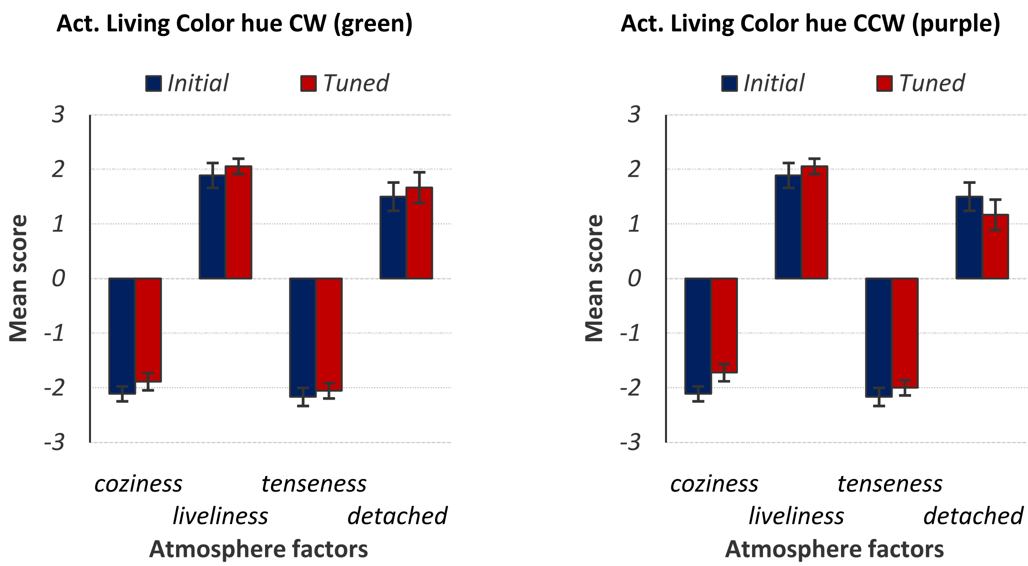


Figure D-8: The average questionnaire scores for the CW and CCW variation in hue of the Living Color lamps in the “activating” atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial “activating” atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.

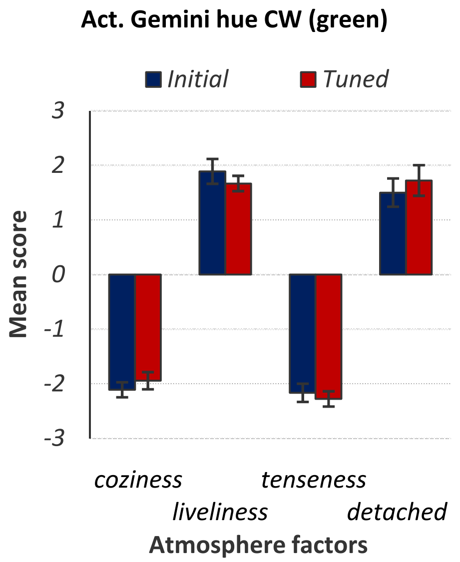
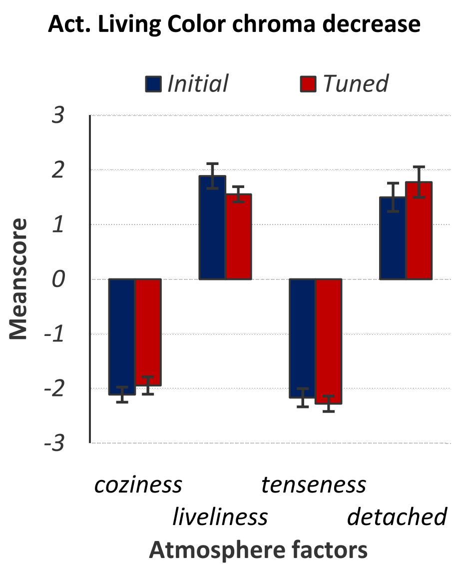


Figure D-9: The average questionnaire scores for the CW variation in hue of the Gemini light source in the "activating" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "activating" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.



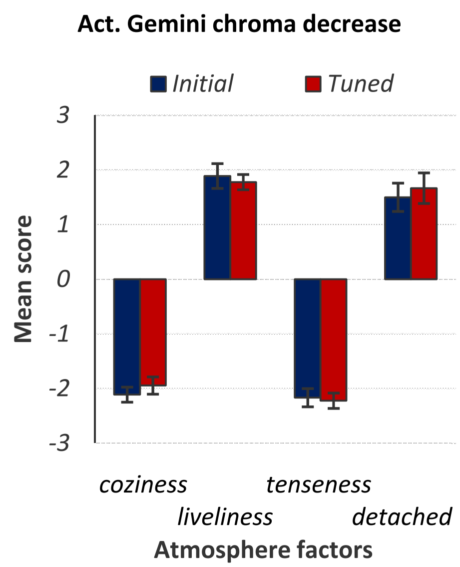


Figure D-10: The average questionnaire scores for the decrease in hue of the Living Color lamps (left) and Gemini light source (right) in the "activating" atmosphere are depicted above. The blue bars indicate the average questionnaire scores in the initial "activating" atmosphere. The red bars indicate the average questionnaire scores in the tuned light setting. The error bars correspond to one standard error.