An explorative study about the effect of pulsating lighting on stress-recovery

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Preface

The very beginning of this report consists of the last few sentences I type for this thesis of my graduation internship at Philips. As a late developer, I took a very long path getting to this point of my life. Now, it is almost time for me to say goodbye to my life as a student. Studying and living in Eindhoven is one of the unforgettable experiences in my life.

My internship at Philips involved the investigation of the effect of dynamic lighting and was very inspiring, hardworking, pleasant, fun and with a number of setbacks. I experienced these setbacks as most challenging and frustrating, but especially learn full and satisfying afterwards.

I am very grateful to get the chance to study and to graduate from Eindhoven University of Technology. For this I would like to thank a number of people. Above all, I would like thank the Dutch tax payers for making it possible for me to study for relatively low costs. I also want to thank Eindhoven University of Technology and its employees for being such a great place to study at. Many thanks to Philips Research and its employees for providing me the opportunity to experience Philips as work place and of being among smart and ambitious researchers. During my graduation I spoke with a number of persons about lighting, stress-recovery, measurement methods etc. I also want to thank those persons. My graduation was not possible without people participating in my experiment. For that I would like to thank the participants.

In particular, I would like to thank the following persons directly involved in my graduation project: Roel Cuppen for being such a motivator, helping me in the thought process and being clear and plain, Jaap Ham for his guidance, the sharing of thoughts and knowledge, Daniël Lakens for being an inspirator, an idea generator and a supervisor and Hans Weda for his involvement, optimism, insights, guidance and for being available for questions at nearly all times.

Next, I would like to thank my loving and caring parents for their support throughout my life, my sister and brother-in-law for their support, interest in and comments on my thesis and my girlfriend for her support, feedback on my thesis and for preparing the meals in the evenings.

In the end, I would like to thank you for reading my thesis and your interest in my graduation study.

Sze Ho Wan
28 November, 2011,’s-Gravenhage

Summary

The introduction into the health-care system and hospitalization can be experienced as very stressful. In addition, solely being in a hospital environment can be an important contributing factor to a person's stress level and makes the recovery from this stress difficult. However, this is not necessary, because environments can also be designed to calm and relax people. More specific, studies have shown that environmental elements like lighting can have a relaxing effect. Although dynamic lighting sources are used intuitively and extensively for a relaxing effect (for example candle light), no studies investigating the effect of this kind of lighting have been found. Therefore, this study will explore the possibilities of ambient dynamic lighting to support stress-recovery related with the thought of undergoing a medical procedure. Hereby, dynamic lighting is approached as a concept of positive distraction and as a factor to change the perceived atmosphere of the environment. This study is of interest, because the use of dynamic lighting could be a relatively easily adaptable solution to improve the patient's recovery from stress.

Two pretests and one experiment were conducted for this study. Based on literature and the first pretest, the orange colored lighting with medium paced (.125 Hz) pulsations was selected as the most appropriate ambient pulsating lighting setting to support relaxation. The results of the second pretest suggested that the hospital-related stressor manipulation was effective in inducing stress on psychological and physiological levels. In the experiment the stressor manipulation was used to induce stress, after which the effect of dynamic colored background lighting on stress-recovery on psychological and physiological level was investigated. Particularly, the experiment investigated the effect of lighting color (white vs. orange) and lighting dynamics (static vs. pulsating) on stress recovery.

The results partially showed that the orange pulsating background lighting can support stress-recovery. Furthermore, orange background lighting creates a more positive atmosphere. A reason for this could be that the background lighting provided positive distraction. Further research is needed to augment these findings, which can possibly lead to methods to change hospital environments into a cozier one that helps patients to relax from their stress, by simply adding ambient pulsating background lighting in it. Obviously, that would be a great gain for both patients and hospitals.

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1 Introduction

Stress is a part of our life. Although a small amount of stress can motivate and help us to be more productive, prolonged or large amounts of stress can have a negative effect on personal health (Wilke, Gmelch, & Lovrich, 1985). At this moment I am experiencing stress in such a manner that it helps me to be more productive in finalizing this graduation report on behalf of Philips Research. Although I manage to control this kind of stress, other causes of stress are more difficult to control for me. In general, the introduction into the health-care system and hospitalization can be experienced as very stressful. Many factors could be the cause of this stress experience such as uncertainties about their illnesses, separation from home, fear for diagnostic and therapeutic procedures, and so on.

The manner people experience and control stress differs per person (McEwen, 2007). Besides individual differences in stress experiences, being in a hospital environment can also be an important contributing factor to a person's stress level. For example, one can imagine that noise, crowdedness, sterile surrounding, formal appearance, and the negative associations people have with hospitals can induce stress. In such an environment, it can be assumed that it is very difficult for people to relax from their stress. However, this is not necessary, because environments can also be designed to calm and relax people. For example, a "Snoezelen Room" is specifically designed to do just that. This is a room that combines nearly all elements in the environment to create a calming and stimulating room for people with mental disabilities. Several studies suggested that these kinds of rooms can reduce stress (overview: Borland, 2010). Another exemplar study investigated the relaxing effect of a closed floatation tank (Forgays & Belinson, 1986). This tank combined the floating feeling, temperature and isolation of sounds to create a relaxing environment. This study suggested that an isolated flotation environment has a relaxation potential. One can say that these mentioned studies use a holistic concept of the environment by combining a variety of environmental elements such as, scent, sounds, colors, temperature and lighting. Oversimplified, one can say that the mentioned studies imply that a hospital environment should be transformed into a "Snoezelen Room" or a flotation tank in order to improve the support of stress-recovery of patients. In reality this is neither practical nor desirable.

Therefore, this study intends to shed a light on a more practical solution that could lead to stress-recovery in a hospital environment. In contrast to before mentioned holistic studies, the present study will focus on the relaxing effect of one specific environmental element, particularly lighting. Lighting is present in nearly all kinds of environments and easy and relatively cheap to adjust by adding or changing the lighting; therefore it is a more practical/logical design to induce relaxation than creating a whole holistic environment. In addition, by investigating the effect of one specific element, the individual contribution of this factor to relaxation can be determined, whereas in holistic studies the extent to which each individual factor contributes to the observed effect remains unknown.

Furthermore, knowledge about the psychological effects of lighting is of interest for companies like Philips. The lighting industries are undergoing a major change as the light emitting diode (LED) technologies are applied more to substitute older lighting technologies (e.g. incandescent, fluorescent and halogen). This is mainly because it offers the advantage of being more energy efficient and having a longer service life. Moreover, LED technologies also provide the possibility to change a broad range of settings effortlessly over time, also called dynamic lighting. With the increase of LED usage, it seems logical that dynamic lighting will be applied more often. So far, dynamic lighting settings using LED technology have depended on personal judgment of the designer and intuition. For example, tree decoration, changing lighting color effects in lounge bars or twinkling stars lighting effects in sauna's or airplanes. Although dynamic lighting sources are also used intuitively for a relaxing effect (e.g. candle light, fire place and lava lamp), no studies investigating this effect of dynamic lighting have been found. By gaining more knowledge about the effect of dynamic lighting on people and how it is perceived by people can help us to design dynamic lighting systems with specific purposes, like relaxation. Furthermore, applying this kind of knowledge in existing or newly developed lighting technologies aimed at supporting the wellbeing of humans is one of the core businesses of Philips. To sum up, there are several interesting reasons to explore dynamic lighting through scientific experimental experiments.

The present study will explore the possibilities of dynamic lighting to support stress-recovery. Specifically, this study will approached dynamic lighting as a concept of positive distraction and as a factor to change the perceived atmosphere of the environment (described in Section 2.5). Furthermore, to relate this study back to the stressful examples given before, this study will focus on the recovery from stress related to the thought of undergoing a medical procedure or examination. Lowering this stress can be of great benefit for hospitals and patients, which will be further described in Section 2.1. First, a literature study will be conducted to gain knowledge about stress and (dynamic) lighting (Chapter 2). Because of the limited scientific knowledge about dynamic lighting related to stress-recovery (Section 2.4), an explorative pretest (Appendix A) will be conducted to discover the preferred lighting settings. Also a second pretest (Appendix B) will be conducted to check the stressor manipulation (see Section 2.2). Chapter 2 is devoted to the description and results of the main experiment on the effect of pulsating lighting a form of dynamic lighting on relaxation. The report ends with a discussion.

2 Literature study

This chapter will describe some essential existing background information to specify the research scope of the current study. Because this study involves broadly used terms such as stress and dynamic lighting, it is important to specify the focus area of this study to prevent any misconceptions. The first two sections (2.1 & 2.2) will define and specify the term “stress” in this study and how this stress will be induced in laboratory experiment. The next section (0) will narrow down the possibilities of dynamic lighting settings this study involves. After that, existing literature about lighting and relaxation will be described (Section 2.4). The final section (2.5) will describe how dynamic lighting can be applied to support stress-recovery.

2.1 Stress and Relaxation

Stress is a subjective phenomenon that is experienced by all of us in our life. Because all individuals experience stress differently, it is difficult to define the term ‘stress’. However, this study defines stress by the definition formulated by McEwen (2007) namely that stress involves a stressor, which elicits a stress response. A stressor can consist of psychical (pharmacological stimuli, noise, cold, chemical exposure etcetera) or psychological experiences (unexpected events, frustration, pressure and so on) (McEwen, 2007). The present study is primarily concerned with the latter one. More specifically, stress related with the thought of undergoing a medical procedure or examination, because a hospital environment is a highly stressful environment (Weinberg & Creed, 2000). Lowering this stress can be of great benefit for both patients and hospitals (Barnason, Zimmerman, & Nieveen). For instance, a lower level of stress is associated with improved surgery outcomes, fewer complications and faster recovery (Mavros et al., 2011). Furthermore, hospitals are being more assessed on the quality of care, improving the wellbeing of patients is of great interest for hospitals. A stress response normally involves changes in four domains, namely: cognitive processing effects, behavioral effects, emotional effects and physiological effects (Borland, 2010). The present study focuses on the latter two effects, because generally people in a hospital environment are not challenged with cognitive or behavioral tasks, but are in a situation wherein they experience stress caused by prospects of medical procedures. Therefore, it can be assumed that psychological (e.g. emotional in this context) and bodily experiences of stress are the main experienced stress domains in these kind of situations. The emotional effects of stress involve feelings of anxiety, fear, distress and other emotions (Sarafino & Smith, 2011). Whereas the physiological effects of stress can trigger acute stress responses resulting in changes of the heart rate, blood pressure, saliva cortisol, perspiration, and body temperature (Hellhammer, Stone, Hellhammer, & Broderick, 2010). Therefore, in this study relaxation can be described as recovering from the emotional and physiological effects of stress.

2.2 Stressor manipulation

Because this study involves the recovery from medical related stress, a repeatable method to induce stress in a laboratory experiment is needed. Previous studies have shown several methods to induce stress in a lab setting with various kinds of stressors, for instance social stress (Kirschbaum, Pirke, & Hellhammer, 1993; Saab, Matthews, Stoney, & McDonald, 1989), workload stress (Gilhooly, 1978;

Locatelli et al., 1989) and stress from anxiety (Gilbert, Robinson, Chamberlin, & Spielberger, 1989; Holmes, James, Coode-Bate, & Deeprose, 2009; Qin, Hermans, van Marle, Luo, & Fernández, 2009; Verwoerd, Wessel, & de Jong, 2010). However, the present study focuses on stress related with the thought of undergoing a medical procedure or examination. Obviously, putting participants through a real medical procedure or examination is not ethical or desirable. For that reason, a new stressor will be assembled, using medical related material. Results of previous studies have shown that using affective pictures from the international affective picture system (IAPS) (Bradley, Cuthbert, & Lang, 1996; Smith, Bradley, & Lang, 2005) and video clips (Cousijn et al., 2010; Holmes, et al., 2009; Ossewaarde et al., 2011; Verwoerd, et al., 2010) can have an effect on physiological responses and subjective mood or anxiety scales. Therefore, a pretest will be conducted to check the effectiveness of a newly developed stressor with a combination of negative affective pictures from the IAPS (*Figure 1*) related to hospitalization and a negative affective movie scene (*Figure 2*) from “Awake” (Harold, 2007). Because this stressor consists of a sequence of computerized visual material it has a clear starting and ending point. This makes it easier to time lock the physiological recordings to a specific event in the experiment.

Figure 1. Examples of the selected IAPS pictures

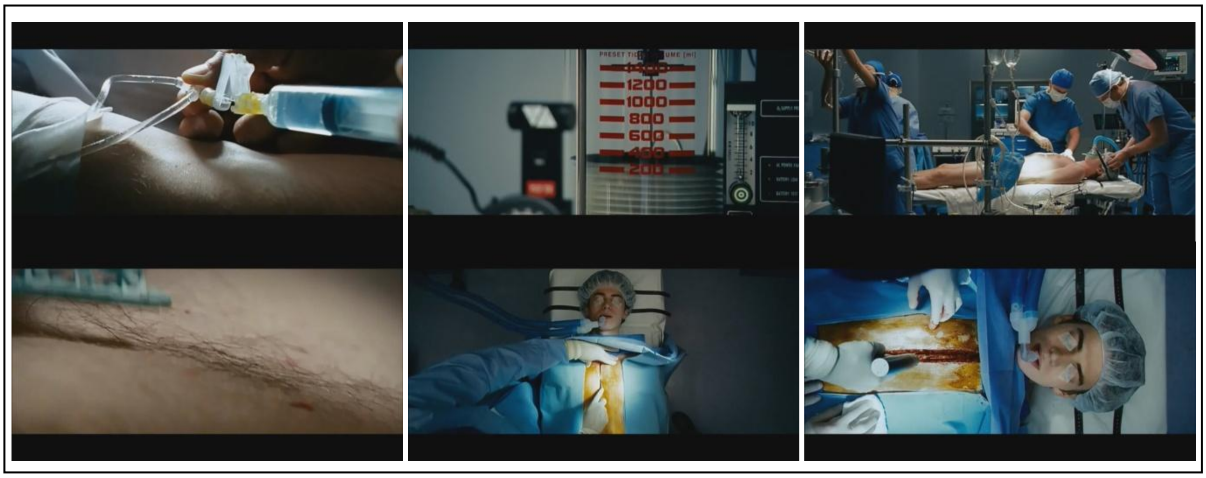

Figure 2. Screen shots of the used movie scene

2.3 Dynamic lighting parameters

The previous sections defined the type of stress that will be the focus of this study and the method to induce this kind of stress in an experiment. This section will move towards dynamic lighting. More specifically, the selected settings of dynamic lighting will be specified.

Innovations in lighting technologies, particular led emitting diode (LED) based lighting sources, make it possible to change a broad range of settings effortlessly. Dynamics in lighting can come in many forms by changing various settings over time, for example changing the direction of the light beam, changing the angle of light, changing colors and so on. Thus, dynamic lighting is a wide-ranging term including many parameters that can change, but also the frequencies of these changes. These frequencies include changes in lighting parameters varying from milliseconds till hours. However, this study intends to use dynamic lighting to have a relaxing effect. Therefore, frequencies of changes in this study will be between .05 – 3 Hz. Because it is probable that frequencies of changes slower than .05 Hz will not be perceived and faster frequencies (> 3 Hz) could lead to potential health risks (Wilkins, Veitch, & Lehman, 2010). In this study, the range of frequencies of changes will be described as pulsating lighting, as a form of dynamic lighting.

Recent study involving pulsating lighting to support paced breathing suggested that having dynamics in the functional (ceiling) lighting could be more arousing and stressing for people (Brandt, 2010). Therefore, the present study will apply LED based ambient light source that combines red, green and blue color components to create dynamic lighting. More specifically, wall-washers will be used as background lighting to color the walls in the room, while the functional lighting will remain unchanged. Settings of these light sources comprise three parameters: hue, brightness and saturation. Hue determines which pure color the light is. Brightness and saturation define the variations within the color. Brightness in general defines the perception of reflection (in terms of relatively lightness or darkness) of light from a source. In this case brightness defines the intensity of light from the source. The saturation describes the strength of purity of a color; see *Figure 3* for a hue brightness saturation model. The present study will create pulsating lighting by continuously changing these three parameters over time. Changing these parameters provides an enormous number of possible settings. To bring down this number of possible settings, a selection of lighting settings will be chosen based on findings from previous studies. The selected settings for the current study are described in the method Section 4.1.

Another study that is of interest to limit the number of settings, investigated the most optimal perceptual way to create a temporal color transitions. Findings from this study suggested that a linear transition in color space types CIE Lab and RGB are the most preferred for color transitions (Vogels, Sekulovskig, & Rijs, 2009). Other studies involving color, suggested that the color blue can be used to calm and relax people (Singh, 2006). Furthermore, a literature study concerning physiological color research suggested warm colors (like red and yellow) are more physically stimulating while cool colors (like blue and green) are more relaxing (Bellizzi, Crowley, & Hasty, 1983). In contrary, studies concerning colored lighting suggested that blue colored lighting is more activating than red colored lighting (Laufer, Láng, Izsó, & Németh, 2009; Lockley et al., 2006). In addition, another study tested 133 dynamic lighting settings in a user test. The results of this study suggested that the orange colored lighting setting with small changes of .2 Hz in saturation was the most preferred lighting setting for a home setting of the participants among the tested dynamic settings (Hartog, Cuppen, & Berkvens, 2010).

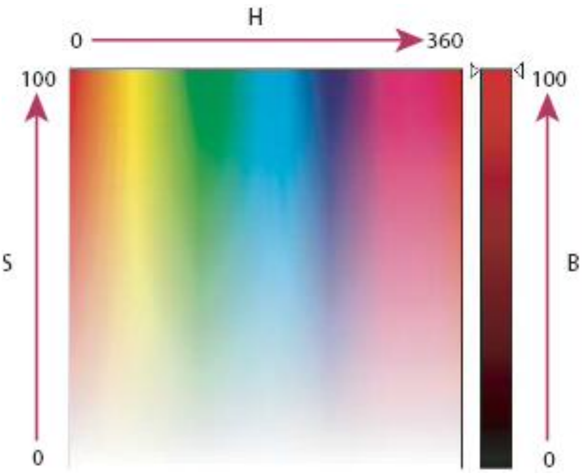

Figure 3. **H**ue **B**rightness **S**aturation (HSB) Model. Source: Adobe Photoshop, help section about color

Based on the information provided by the described studies, the current study will use linear transitions in the RGB color space for transitions of saturations as a form of relaxing pulsating lighting. As for the colors, due to the contradictory findings of the effect of color and lighting color, the present study will test whether blue or orange lighting colors is more suitable for relaxation. Moreover, the appropriate frequency within the pulsating range will be explored in a pretest (Appendix A).

2.4 Psychological effects of lighting

Like described before, the present study will focus on the relaxing effect of the environmental element, lighting. This section will describe why pulsating lighting could have the potential to influence a person's stress-level.

Until recently lighting research has focused on the visibility and visual comfort of lighting. However, in the past decade the amount of research about the psychological effects of lighting has steadily grown. A few studies suggested that the light intensity and/or the color temperature can affect a person's mood (Küller, Ballal, Laike, Mikellides, & Tonello, 2006; McCloughan, Aspinall, & Webb, 1999), which can be related to stress or relaxation. However, these studies involved static lighting and not dynamic lighting. Up until now studies only investigated dynamic lighting in very slow forms of dynamics in lighting with changes in periods of several hours to affect the circadian rhythm (e.g. de Kort & Smolders, 2010) or timed bright light exposure to affect the level of activation (Campbell et al., 1995). Other studies involved flashing forms of dynamic lighting, focused on the perception of danger in flashing warning signals (Chan & Ng, 2009) or used flashing light as a dramatic intensifier for certain scenes of movies (Truong & Venkatesh, 2001). In the latter study, it was observed that certain experiences within a movie can be enhanced with the speed, color and intensity of flashing lights (Truong & Venkatesh, 2001). However, little is known about the effect of pulsating light on relaxation.

Though little is known about the influence of pulsating lighting on relaxation, research has shown that other environmental elements, such as sound, can influence a person's state of mind. In particular, music can help people to relax, change their mood and lower anxiety (Evans, 2002; Good, 1996). Several studies have shown that features such as the intensity, timbre (texture of the music) and rhythm (the pattern of notes) of music are the main factors arousing different music moods. More specifically, two dimensions of mood can be differentiated for music, namely: stress dimension and energy dimension (Lie, Liu, & Hong-Jiang, 2006; Zhongzhe, Dellandrea, Weibei, & Liming, 2008). For instance, highly arousing music is defined as loud, difficult to predict, irregular and with quick tempo. Whereas low arousing music is defined as soft, predictable, monotonous and with slow tempo (Caldwell & Hibbert, 2002). These descriptions and characteristics of the music can be translated into dynamic colored lighting. For example, one can create a soft, predictable dynamic light atmosphere with slow changes. It can be expected that such light atmospheres will have comparable influences on a person's mood.

From the literature described above I expect that lighting can have an effect on mood. Furthermore, the mentioned literature involving music suggested that intensity, tempo and rhythm can have an effect on the arousal. When this knowledge is integrated, it can be expected that the tempo and intensity of pulsating lighting might have an effect on a relaxation.

2.5 Supporting stress-recovery through the environment

From the discussed literature it seems obvious that an environment and the lighting within that environment can have an effect on a person's stress-level, but how can pulsating lighting be applied to support stress-recovery? This section will connect findings concerning relaxation from environmental psychology to pulsating lighting.

The surrounding of a person is important when it comes to relaxation. An environment can be designed to support stress-restoration and improve the effectiveness in facilitating stress coping, also called a supportive design of the environment (Ulrich, 1991). Ulrich (1991) described a guideline for supportive designs, which consists of three components: sense of control, social support and positive distractions in physical environments. The first component involves that people have a strong need for control. A lack of control can make us feel negatively. The second component comprises that the environment should support social interaction among people. Social support is suggested to be an important factor in the recovery from stress. The third and final component involves that the physical environment should provide positive distractions. "The concept of positive distraction is an environmental feature that elicits positive feelings and holds attention and interest without taxing or stressing the individual, and thereby may block or reduce worrisome thoughts" (Ulrich, 1991).

Literature concerning the latter concept suggested that various elements in a hospital environment contributes to positive distraction and therefore reduces stress-levels (McCuskey Shepley, 2006). For example, having music in a hospital environment can reduce stress-levels of patients in a waiting room (Routhieaux & Tansik, 1997). Moreover, viewing nature can result in a faster recovery from stress than watching urban views (Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998; Ulrich et al., 1991). This effect could be explained because nature scenes or elements elicit positive feelings, reduce negatively toned emotions, effectively holds attention or interest and might block or reduce stressful thoughts (Ulrich, 1979). Like nature scenes or elements, I believe that pulsating lighting can have the same effect with the right lighting setting.

Besides providing positive distraction, lighting can also be used to create a certain atmosphere (Seuntiens & Vogels, 2009; Vogels, 2008). Vogels (2008) defined atmosphere as the experience of the surrounding in relation to ourselves, and developed a tool to measure this. This tool was able to discriminate between atmosphere dimensions such as coziness, liveliness, tenseness and detachment, in different lighting settings (in terms of color, intensity and dynamics) (Seuntiens & Vogels, 2009). Furthermore, this study suggested that white colored lighting should be warm colored (+/- 2700 K) to create a cozy and relaxing atmosphere (Seuntiens & Vogels, 2009). Although lighting can affect the perceived atmosphere of the environment, it does not necessarily give rise to a particular feeling, but it does have the potential of changing people's overall affective state (Vogels, 2008). To illustrate this, one can imagine that a person can feel stressed in a cozy atmosphere, but being in that atmosphere can help people to relax. However, being in a tensed atmosphere makes it very difficult for a stressed person to relax. Nevertheless, it does not directly affect the specific emotion underlying the stress that they recover from.

The current study will investigate the appropriate pulsating lighting settings to create a suitable atmosphere to relax in. Furthermore, the possibilities of pulsating lighting to function as a positive distraction and therefore support stress-recovery will be explored.

3 Pretests

The literature study specified the focus area of this study. However, the information of the literature study was not sufficient enough to determine the appropriate lighting settings to support stress-recovery. Furthermore, the assembled stressor manipulation has not been tested for its effectiveness to induce stress. Therefore, two pretests will be conducted. This chapter describes the pretests in short. For an extended description of the pretest, see Appendices.

The first pretest (see Appendix A) will investigate the psychological effects of pulsating lighting and appropriate pulsating lighting settings (in terms of color, saturation, intensity and frequency) for relaxation. Hypotheses for the main experiment will be developed based on the results of this pretest.

The second pretest (see Appendix B) tested the stressor manipulation (described in section 2.2). Like described before, relaxation in this study is defined as recovering from the psychological and physiological effects of stress. In order to investigate the effect on relaxation, an effective stressor manipulation is needed. Therefore, this pretest will investigate the effect of the stressor on psychological and physiological stress responses. Furthermore, this pretest will test the experimental setup and the duration of the experiment.

3.1 Summary of the pretest results

The results of pretest 1 suggested that the orange lighting color is more calming and elicits more positive feelings than the white and blue lighting colors. Furthermore, the results suggested that medium and slow lighting pulsations made the participants feel more positive and that it created a livelier environment than the static and fast lighting pulsations. Therefore, the main experiment will test the orange lighting color with medium pulsations on the effect of relaxation.

The results of pretest 2 suggested that the stressor manipulation was effective on eliciting stress responses on a psychological and physiological level. For that reason, the main experiment will apply the tested stressor manipulation to induce stress.

4 Main experiment: The effect of pulsating light on relaxation

Like described in section 2.5 a supportive design for facilitating stress-recovery includes the concept of positive distraction in a physical environment (Ulrich, 1991). As stated, we assume that pulsating lighting can function as a positive distraction and therefore support stress-recovery. In addition, the results of pretest 1 (see Appendix A) suggested that participants felt more positive in the lighting conditions with medium or slow pulsations and pulsating lightings was perceived livelier than static light. To test these preliminary results more thoroughly, the main experiment will test the influence of pulsating lighting vs. static lighting (control condition) on stress-recovery. The following is expected:

H1: Pulsating lighting has a stronger positive effect on stress-recovery than static lighting

Results of pretest 1 (see Appendix A) also revealed that the orange colored lighting settings are the most preferred settings for a relaxing atmosphere. In line with this result, a previous study suggested that a cozy and relaxing atmosphere should be warm colored (Seuntiens & Vogels, 2009). As a result, the main experiment will test the influence of orange lighting color vs. white lighting color (control condition) on stress-recovery. The following is expected:

H2: The orange lighting color has a stronger positive effect on stress-recovery than the white lighting color

Either having orange colored lighting or pulsating lighting will result in better stress-recovery than white static lighting. More specifically, it is expected that:

H3: The orange static lighting and the white pulsating lighting will have a stronger positive effect on stress-recovery than white static lighting

Besides the expected main effects formulated in hypotheses 1 and 2, it is assumed that the combination of both expected main effects will result in the strongest positive effect on stress-recovery. The following hypothesis can be stated based on this assumption:

H4: The orange pulsating light setting has the strongest positive effect on stress-recovery compared to the other lighting settings

An overview of the hypotheses is shown in Table 1.

Table 1: Expected positive effect of the lighting setting on stress-recovery

	Static	**dynamic**
White	++	+
Orange	+++	++

+ = positive effect on stress-recovery

4.1 Method

4.1.1 Participants and Design

The participants were asked beforehand for a history of a traumatic experience of hospilization or diseases and for regularly viewing extremely violent movies of playing violent computer games. This to make sure, that the content of the pretest does not shock the participants too much and that persons that are possible insensitive for the stressor manipulation are excluded.

82 Dutch participants (48 male and 34 female) with an age ranging from 18 to 59 years (*M*=28, *SD* = 11) from outside of Philips were recruited by e-mail retrieved from the participant database of Eindhoven University of Technology. The participants were invited to watch the pre-selected visual material in one of the selected light settings in a lab and were not aware of the actual purpose of the experiment. A 2 color (orange, white) x 2 lighting setting (dynamic, static) between subjects design of the experiment was used to investigate the hypotheses mentioned above. Each subject has participated in one of the four experimental conditions (Table 2). Several participants did not complete the experiment. Three persons terminated the experiment, by clicking the stop button, because of the stressor movie clip. Another three persons could not complete the experiment, because they passed out during the stressing phase of the experiment (more information is provided in Appendix C). The test lasted 40 minutes, for which participants were paid 7.50 Euros in cash.

Table 2: Experimental conditions

	Static	Dynamic
White	A	C
Orange	B	D

4.1.2 Apparatus

The experiment was conducted in the lighting lab of the technical University of Eindhoven (*Figure 4*). The NeXus-10 recording device and its accompanying sensors (Mind Media BV, Roermond, The Netherlands) was used to measure the physiological responses (i.e. electrodermal, and skin temperature). Skin conductance measurements have been conducted using EDA/GSR electrodes. The electrodes have been attached to the upper phalanxes of the index and ring finger of the left hand. HR (heart rate) measurements have been conducted using a Blood Volume Pulse Sensor at the middle finger of the left hand. Physiological measures are assessed continuously during the experiment. The MATLAB programming environment (2009a, The Mathworks, Natick, MA) will be used for the preprocessing of the physiological signals.

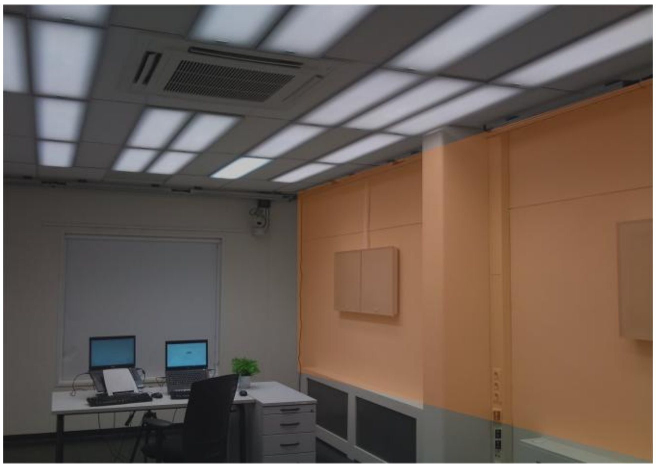

Figure 4. The lighting lab of the technical University of Eindhoven

A (19" wide-screen) monitor was connected to a laptop for playing video, and controlling and presenting the test procedure and questionnaires.

The lighting stimuli were projected to two sides in the lab. The fluorescent tube lighting in the ceiling was on during the pretest and did not change. Wall-washers, ColorGraze Powercore linear LED of Philips, were used to create a calming atmosphere with subtle forms of pulsating light. This study involves static lighting and slow dynamics of lighting varying in brightness and saturation with the pace of 0.125 Hz (Table 3).

4.1.3 Lighting Stimulus

The results of Pretest 1 suggested that the orange colored lighting setting with medium paced (.125 Hz) pulsations is the most preferred for relaxation. This lighting setting will vary in saturation. The white colored lighting condition will vary in intensity. The change in saturation will be in a linear transition in CIE color space mode (*Figure 5*). Table 3 shows the inserted RGB settings and the measured lighting colors in CIE color space values.

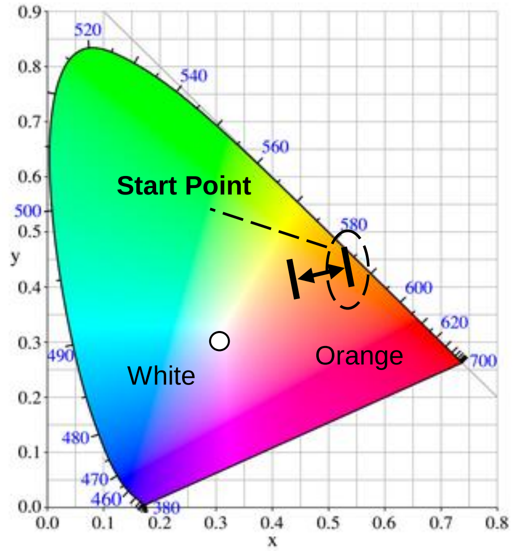

Figure 5. The lighting stimuli shown in the CIE color space model

Table 3: Setting and measurements of the experimental light conditions

Lighting condition	LED RGB setting				
	R	G	B	x	y
Orange pulsating (max)	135	80	0	0.5412	0.3986
Orange pulsating (min)	65	70	40	0.4624	0.3815
Orange static	120	75	30	0.4918	0.3839
White pulsating (max)	190	220	150	0.3286	0.3255
White pulsating (min)	115	140	100	0.3393	0.3259
White static	145	180	115	0.3336	0.3349

4.1.4 Measurements

Both physiological and psychological measurements were conducted during the experiment. The psychological measurements consisted of several questionnaires.

40 items were derived from the state-trait anxiety inventory (STAI) (α = .96) of Spielberger, Gorsuch and Lushene (1970). Because, the VAS is more suitability for frequent and repeated measures (van Duinen, Rickelt, & Griez, 2008) the inventory was presented in a VAS instead of the original four points scale. The VAS ranges from 0 to 100, whereas a high score indicates a highly anxious person and a low score a low anxious person.

The heart rate (HR), galvanic skin response (GSR) and skin temperature were recorded as physiological data. The HR was measured with NeXus-10 Blood Volume Pulse Sensor at the middle finger of the left hand. The GSR was measured with EDA/GSR electrodes at the index and ring finger of the left hand.

The perception of the atmosphere in the lighting lab was measured with the twelve items shortened version of the atmosphere perception (α = .79) presented in a seven points scale (Vogels, Sekulovski, Clout & Moors, 2009). A high score in of the atmosphere perception indicates a highly correspondence of one of the atmosphere dimensions, coziness, liveliness, tenseness or detachment.

Four additional questions were presented in a VAS posing questions about the subjective experience of the lighting in the lab, in terms of: negative distraction, salience, positive distraction and annoyance of the lab lighting. As for removed measurements, the skin temperature was excluded from the present experiment.

Demographical questions were presented asking participants about their age and gender. In the end, a semi-structured interview asked the participants about their experience of the experiment.

4.1.5 Procedure

All participants were seated in front of a desk with a viewing distance of 70 centimeters, in the lighting lab room of Eindhoven University of Technology. The participants are told that we are going to evaluate several medical related negative affected pictures and a video clip on their psychological and physiological responses for a campaign to increase the awareness of human vulnerability in the medical health care and that they have to pay full attention to the presented material, because there will be some questions about it in the end of the experiment. In the introductory session participants started to read through and sign the informed consent form (Appendix E) followed by the attachment of the physiological sensors, the signal quality was inspected visually and the physiological responses were measured continuously. Next, an aquatic video clip about underwater life (Hannan, 1992) was showed for 480 seconds to achieve baseline measures. Previous study suggested that an aquatic video is effective for achieving low baseline levels (Piferi, Kline, Younger, & Lawler, 2000) and used it as relaxation stimulus (Colamussi, Bovbjerg, & Erblich, 2007). After that, the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, & Lushene, 1970) was presented to the participant. The whole experiment was computerized, and instructions were presented on the screen (see Figure 6).

Figure 6. Graphical user interface of the computerized experiment

The participants were instructed to pay attention to the series of negative affected pictures and a video clip, because questions would be asked about the details of the showed material. Moreover, participants were reminded that they could stop the experiment and/or the presentation of the pictures and video at any time, by clicking the "Stop" button in the screen. When the participants were ready, they could start with the slideshow of ten negative affective pictures from the International affective picture system (each picture is shown 6 seconds), followed with one video clip of around 300 seconds showing a scene of the commercial available movie "Awake" (Harold, 2007). Directly after, participants filled in the state anxiety inventory. Next, participants were instructed to wait and relax for two minutes, followed with the state anxiety inventory. After that questions about the environment (the lab room), lighting and the presented material were presented to the participant, followed by demographic questions (gender, age). After the experiment was completed the participants were detached from the equipment and were debriefed about the true purpose of the shown material and study. The participants were informed that a company counselor/psychologist might contact them afterwards when the physiological recordings reveal any abnormalities. The participants were thanked for their participation in the end. All sessions of the experiment were different in lighting stimuli. The total duration of each experimental session including the instructions and the attachment and detachment from the physiological equipment took at max 60 minutes. The experimental procedure is showed in *Figure 7.*

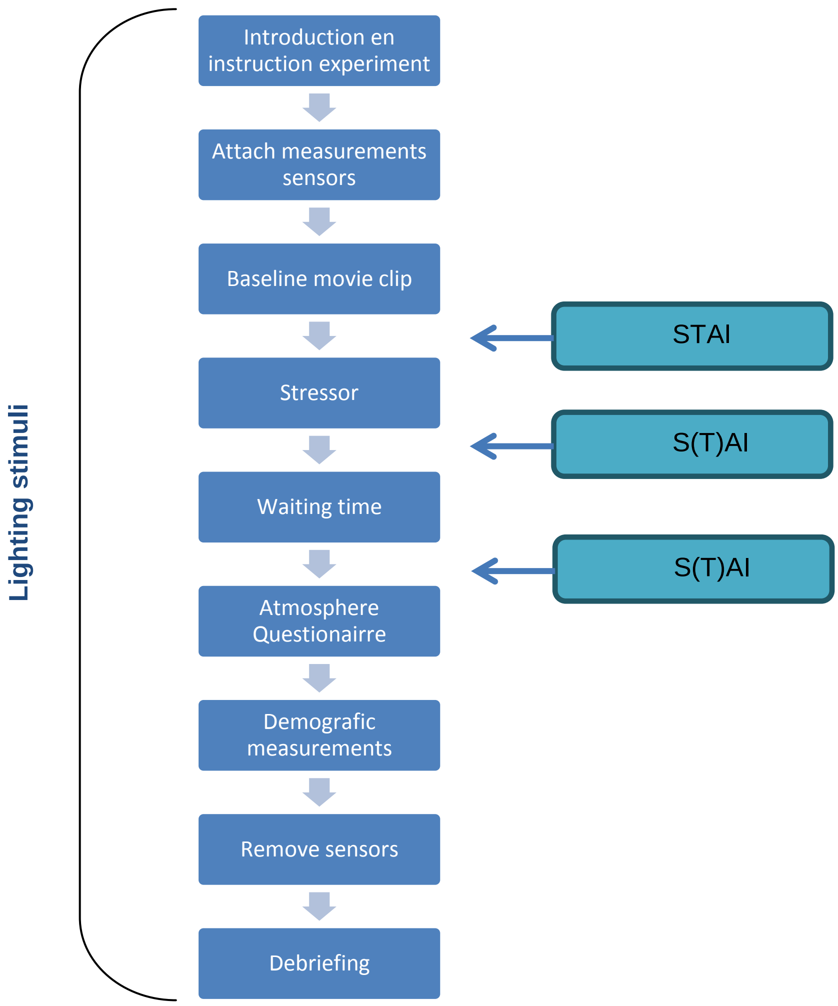

Figure 7: Overview of the experimental procedure

4.2 Results

The first section of the results describes the results of the psychological measurements. The second section describes the results of the physiological measurements. The results were analyzed with SPSS 19.

4.2.1 Psychological results

4.2.1.1 STAI

The STAI consist of a trait and a state part. The analysis starts with the state part followed by the trait part. Box plots of the state anxiety inventory (SAI) items scores were used to check the data for outliers. Scores per task greater than 1.5 interquartile range from the end of a box were computed into missing values to control for noise (Walfish, 2006). The results of the repeated measures analysis of variance of the state anxiety inventory (SAI) showed no gender effect, $F(1, 75) = 1.22$, $p = .27$. Moreover, like in the pretest, the stressor manipulation showed a main effect on the SAI scores within-subjects, $F(1.37, 104.29) = 79.38$, $p < .01$. As shown in the graph below (*Figure 8*), participants scored higher on the SAI after the stressor compared to before the stressor and after two minutes waiting after the stressor.

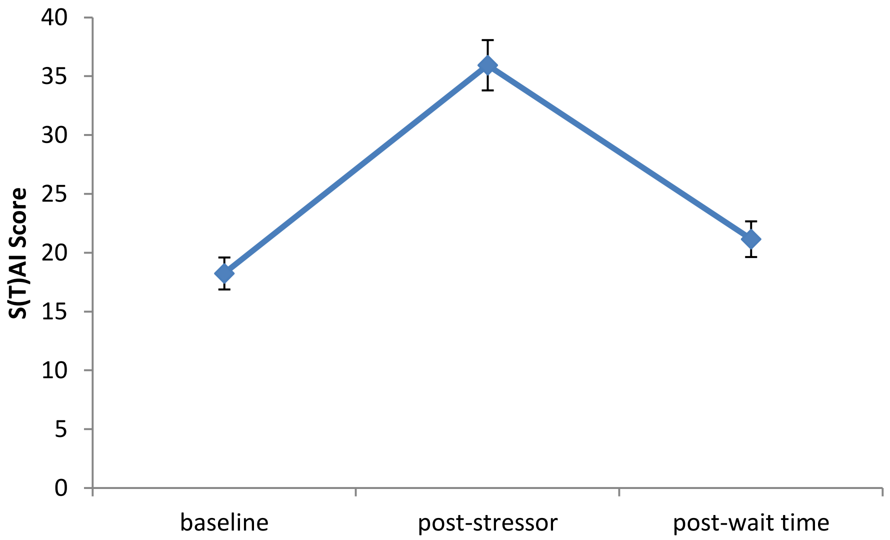

Figure 8. Mean SAI scores with standard error (*SE*) in different periods of the experiment

The results showed no between subjects effect of the color of the lighting, $F(1, 73) = .09$, $p = .76$. Moreover, no effect was shown between the static lighting and the pulsating lighting, $F(1, 73) = .04$, $p = .84$. Furthermore, no interaction effect was shown between the lighting colors and the lighting dynamics, $F(1, 73) = 2.45$, $p = .12$. However, an three-way interaction effect was found between stressor time, lighting colors and lighting dynamics, $F(1.45, 105.73) = 3.70$, $p < .05$. Participants in the white static lighting condition and orange dynamic condition scored lower on the SAI in the post-baseline and post-wait time periods (*Figure 9*).

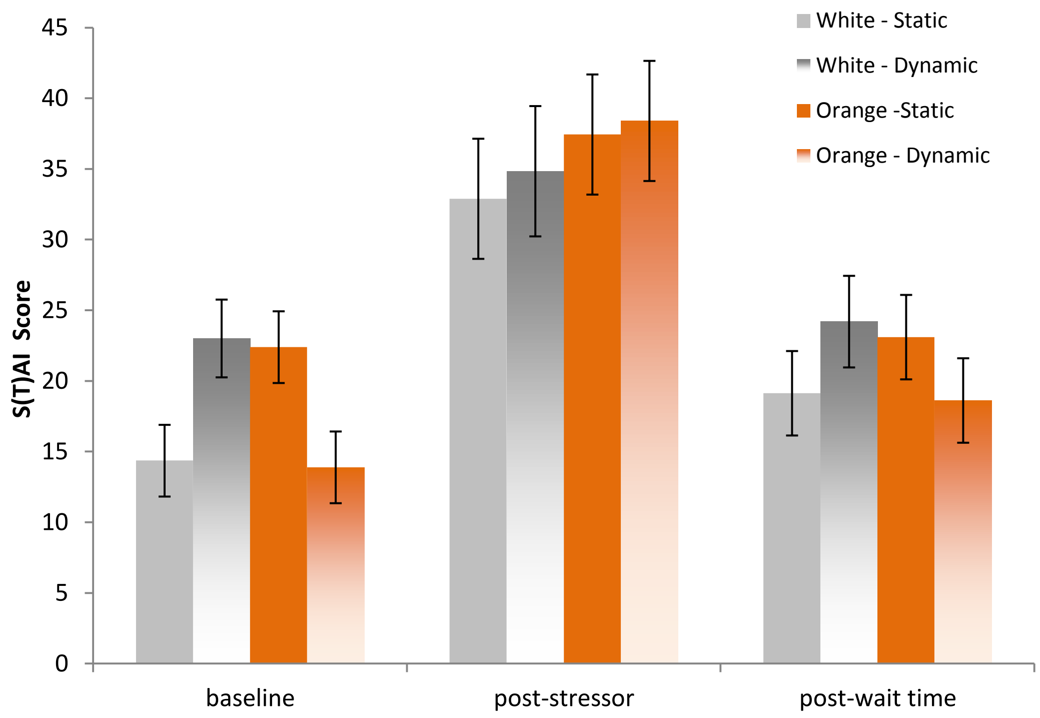

Figure 9. Mean SAI scores with *SE* lighting colors * lighting dynamics in different periods of the experiment

Results of a bivariate correlation showed strong correlation between the trait anxiety inventory (TAI) and the state anxiety inventory (SAI) scored pre-stressor, $r(80) = .76$, $p <.001$ and between the TAI and SAI post wait time, $r(75) = .65$, $p <.001$. The group of participants was not split up in high trait anxiety and low trait anxiety groups, because the results suggests that state and trait part of the inventory were interpreted almost the same.

4.2.1.2 Atmosphere perception

Four dimensions were derived from the atmosphere perception questionnaire. Each dimension consisted of three items. These items were added together and entered as dependent variables in a multivariate general linear model to compare the effect of the color and dynamics in different lighting conditions. The results showed a main effect of the lighting colors on the dimensions coziness, $F(1, 73) = 13.96$, $p < .01$, detachment, $F(1, 73) = 34.91$, $p < .01$ and marginally significantly effect on liveliness, $F(1, 73) = 3.12$, $p = .08$. However, no effect was shown of the lighting colors on tenseness, $F(1, 73) = .62$, $p = .43$. The graph (*Figure 10*) below shows the differences in the total scores of the four dimensions of the atmosphere perception questionnaire.

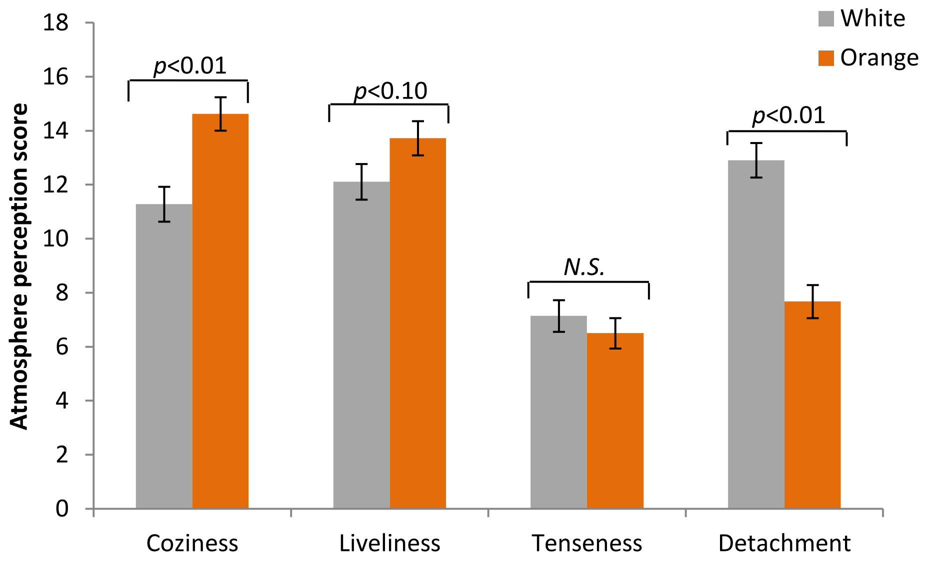

Figure 10. Total scores atmosphere perception dimensions with *SE* in different lighting colors conditions of the experiment

The results showed an effect of lighting dynamics on liveliness, $F(1, 73) = 4.25$, $p < .05$. However no effects were shown on coziness, $F(1, 73) = .79$, $p = .38$, tenseness, $F(1, 73) = .01$, $p = .91$, and detachment, $F(1, 73) = .43$, $p = .51$ (*Figure 11*).

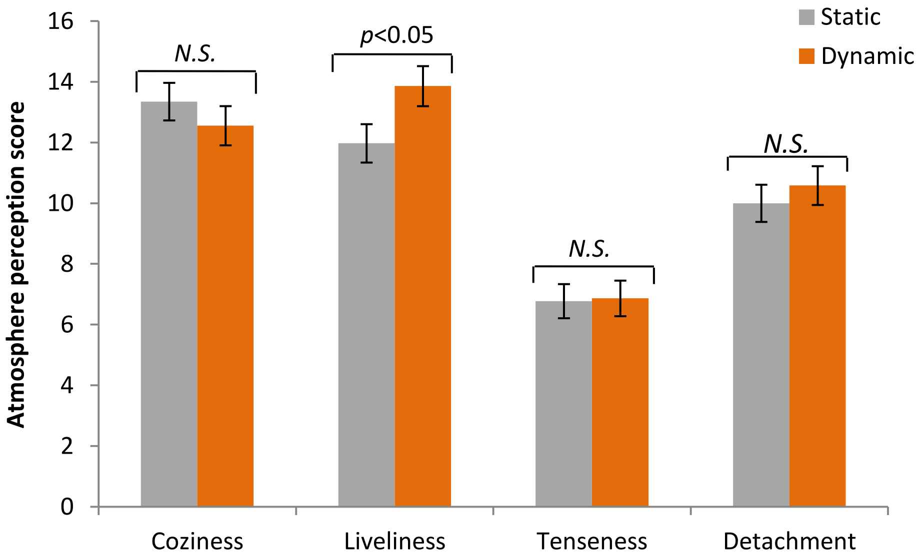

Figure 11. Total scores atmosphere perception factors with *SE* in different lighting dynamics conditions of the experiment

A marginally significantly interaction effect was shown between the lighting colors and the lighting dynamics on atmosphere tenseness, $F(1, 73) = 2.93$, $p = .09$ (*Figure 12*). However, no interaction effects were found on the dimensions cozines, $F(1, 73) = 1.39$, $p = .24$, liveliness, $F(1, 73) = 1.62$, $p = .21$, and detachment, $F(1, 73) = .04$, $p = .85$.

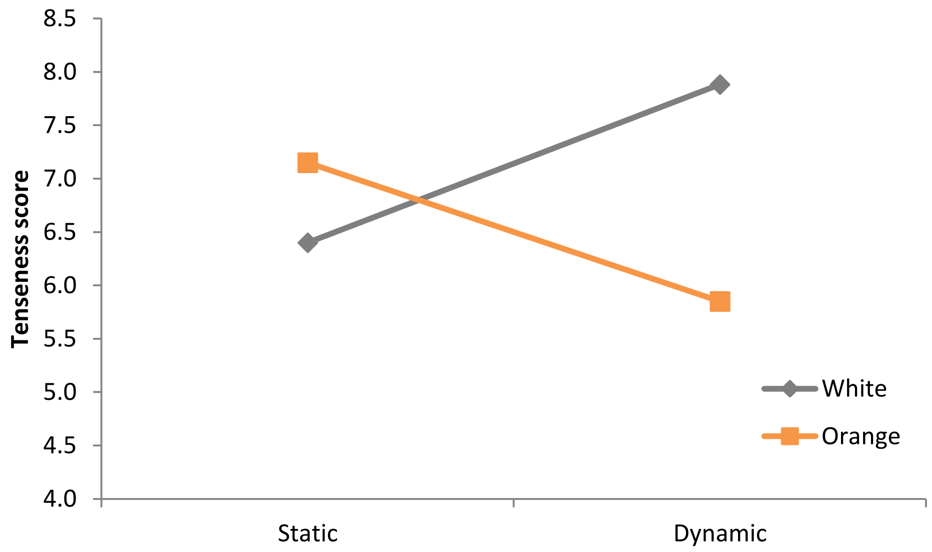

Figure 12. Interaction effect lighting colors x lighting dynamics on the total tenseness score

4.2.1.3 The Experience of lighting

Four questions asked participants about their experience of the negative distraction, salience, positive distraction and annoyance of the lab lighting. Results of the multivariate general linear modeling analysis showed an effect of lighting colors on the saliency of the lab lighting, $F(1, 73) = 3.92$, $p = .05$. The saliency score was higher in the orange colored lighting condition ($M = 70.75$, $SE = 5.27$) than the white colored condition ($M = 57.68$, $SE = 5.50$). Furthermore, a marginally significantly effect was found of lighting colors on the positive distraction, $F(1, 73) = 2.92$, $p = .09$. More specifically, participants in the orange colored lighting conditions scored the positive distraction of the lighting higher ($M = 41.13$, $SE = 4.29$) than in the participants in the white colored conditions ($M = 30.53$, $SE = 4.48$). The results showed no effect of lighting colors on the distraction, $F(1, 73) = .88$, $p = .35$, and the annoyance of the lighting, $F(1, 73) = .05$, $p = .83$. The results showed no effect of the dynamics of lighting on the annoyance, $F(1, 73) = 2.19$, $p = .14$, and positive distraction, $F(1, 73) = .01$, $p = .93$, of the lighting. However, an effect was found of the dynamics of lighting on the distraction, $F(1, 73) = 4.65$, $p < .05$, and the saliency of the lighting, $F(1, 73) = 16.51$, $p < .01$. More specifically, participants in the dynamic lighting conditions scored the distraction ($M = 27.59$, $SE = 3.93$) and the saliency ($M = 80.68$, $SE = 5.50$) of the lighting higher than the participants in the static conditions, namely distraction ($M = 15.85$, $SE = 3.77$) and saliency ($M = 49.75$, $SE = 5.27$).

4.2.2 Physiological results

The raw data from the physiological measurements will be checked individually and combined in group means for the effect of the stressor, before starting the analyses. A total of eight participants were excluded from the analyses because of the incomplete data caused by a bluetooth connection problem (ppn13, ppn65), termination of the experiment (ppn2, ppn50, ppn66) and fainting during the experiment (ppn16, ppn75, ppn78).

4.2.2.1 Galvanic skin response

First, the raw data from the galvanic skin response (GSR) measurements was filtered for artifacts and checked for outliers. Raw data showing little or no changes during the whole timeline of the experiment were excluded from the analysis. The proper GSR-plot of a participant should look like the graph below (*Figure 13*). Two participants were excluded from the analyses. One (ppn14) was excluded based on the little or no changes of the raw GSR data during the whole experiment. This a known phenomena and it is called "nonresponders", there are approximately 10% nonresponders in the normal population (Dawson, Schell, & Filion, 2007). Another participant (ppn51) was excluded because of the very high skin conductance (25-50 µS). A value between 2 and 20 µS is typical in the normal population (Dawson, et al., 2007).

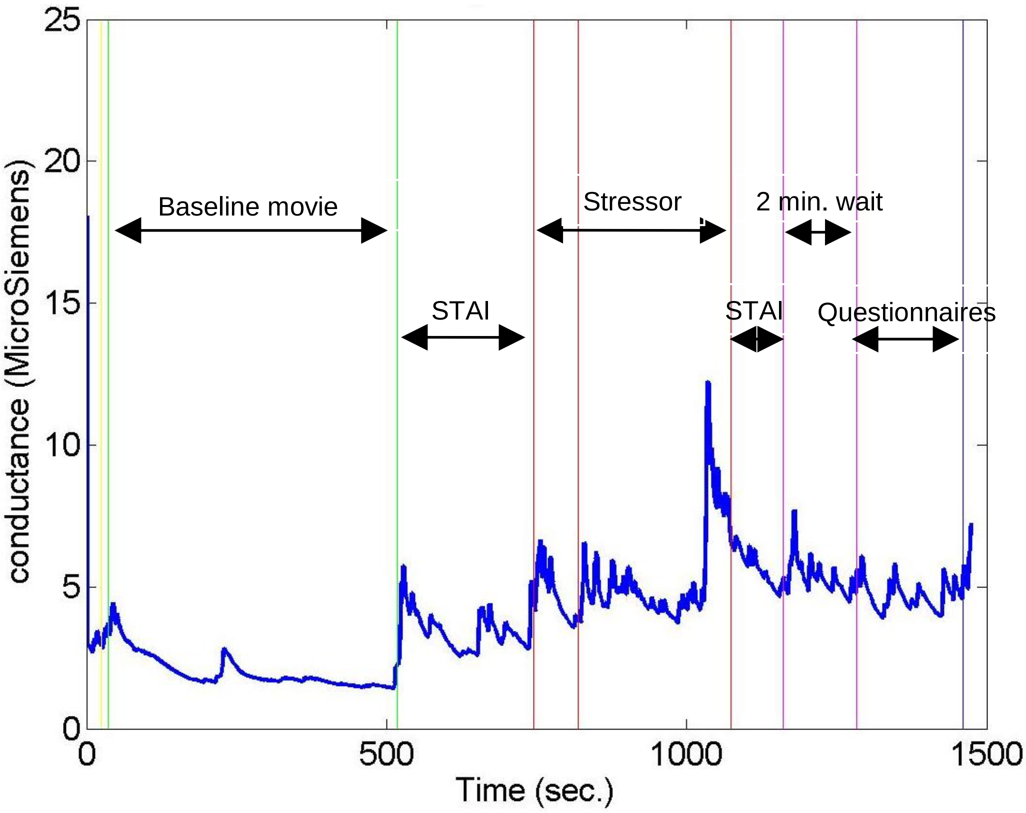

Figure 13. A good example of a GSR plot from one participant during the experiment

Second, four periods of 60 seconds were selected and the means of those periods were entered as within subjects variables in a repeated measures analysis of variance (Table 4).

Table 4. Sampling periods mean GSR

Sample periods	Range
Begin baseline movie	Start baseline -> 60 sec+ Start baseline
End baseline movie	End baseline -60 sec -> End baseline
Stressor movie end phase	End stressor – 60 sec -> End stressor
Wait time	End wait time -60 sec -> End wait time

4.2.2.2 *Standardized Galvanic skin response*

To take into account the large individual differences of GSR among participants, an additional analysis was run with standardized GSR values and calculated as follows:

$$\text{standardized GSR value} = \frac{\text{GSR Sample value} - \text{Mean End baseline}}{\sigma} \qquad \sigma = \text{individual standard}$$

A repeated measures analysis was conducted again with the standardized values using the same means of the periods showed in Table 4. Results of the analysis showed a main effect of the stressor manipulation, $F(3, 213) = 68.68$, $p < .01$, (*Figure 14*). The results showed no gender effect on the standardized GSR, $F(1, 70) = 2.89$, $p = .09$.

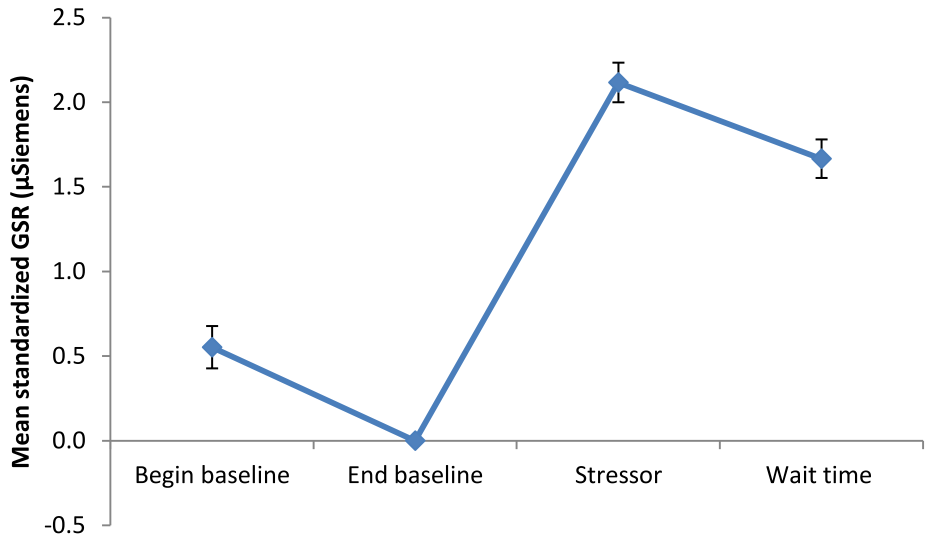

Figure 14. Stressor manipulation effect on the standardized skin conductance with the *SE* in different periods of the experiment

The results of the analysis showed no main effect of the lighting colors on the standardized GSR, $F(1, 68) = .01$, $p = .98$. Furthermore, no main effect was found of the lighting dynamics on the standardized GSR, $F(1,68) = .18$, $p = .67$. Moreover, no interaction effect of the lighting colors and lighting dynamics was shown on the standardize GSR, $F(1, 68) = .02$, $p = .89$.

4.2.2.3 Inter-beat interval

Same as in the GSR analysis, four periods of 60 seconds were selected from the inter-beat interval (IBI), the means of those periods were calculated and were entered as within subjects variables in a repeated measures analysis (Table 4). The results of the analysis showed a main effect of the stressor manipulation on the mean of IBI, $F(1.53, 109.93) = 6.72$, $p < .01$. The results showed a gender effect on the mean of IBI, $F(1, 71) = 4.48$, $p < .05$. More specifically, females have a lower IBI and therefore a higher heart rate than males. Moreover, an interaction effect was shown between the stressor time and gender, $F(1.58, 112.02) = .19$, $p < .05$, showing that females have an increase of the IBI at the end baseline period, while males have a decrease of the IBI (*Figure 15*). The variable gender was added as one of the predictors in the analysis.

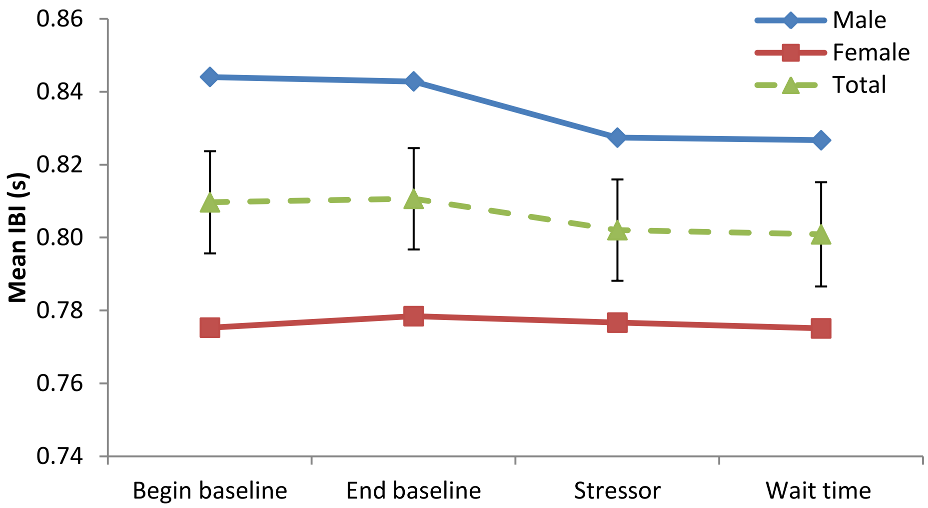

Figure 15. Gender and stressor manipulation effect on the mean of the IBI with the *SE* in different periods of the experiment

Results of the analysis showed no main effect of lighting colors on the IBI, $F(1, 65) = .03$, $p = .87$, and no interaction effect was shown between the lighting colors and the lighting dynamics, $F(1, 65) = .19$, $p = .67$. However, the results showed a marginally significantly main effect of the lighting dynamics on the IBI, $F(1, 65) = 3.48$, $p = .07$, (*Figure 16*).

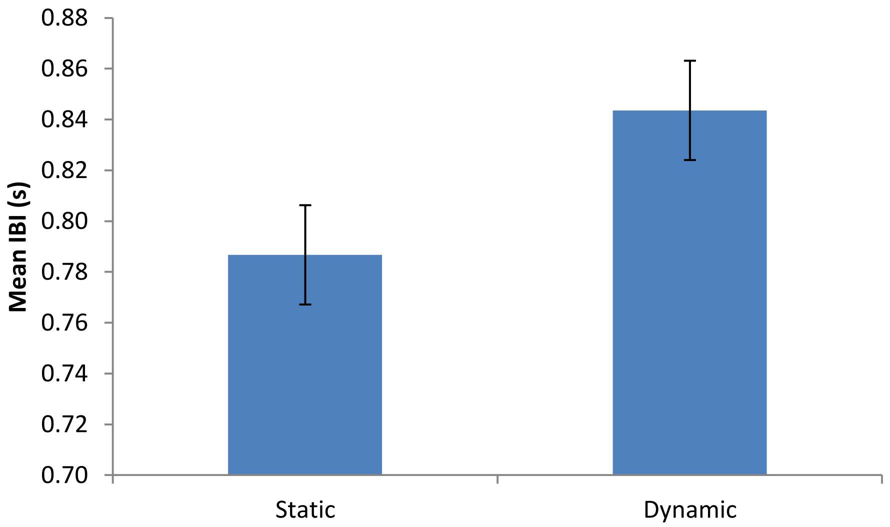

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Figure 16. The mean IBI with the *SE* in static or dynamic lighting conditions

No interaction effect of the stressor time and the lighting colors was shown, $F(1.84, 119.59) = 2.02$, $p = .14$, and no interaction effect was shown of the stressor time and lighting dynamics, $F(1.84, 119.59) = .17$, $p = .83$. Moreover, no interaction effect was shown between the stressor time, the lighting colors and the lighting dynamics, $F(1.84, 119.59) = .21$, $p = .80$. However, an interaction effect of stressor time, lighting dynamics and gender was shown, $F(1.84, 119.59) = 7.14$, $p < .01$. More specifically, females in the static lighting condition showed a decrease of the IBI, while females in the dynamic lighting conditions showed an increase of the IBI during the stressor period (*Figure 17*).

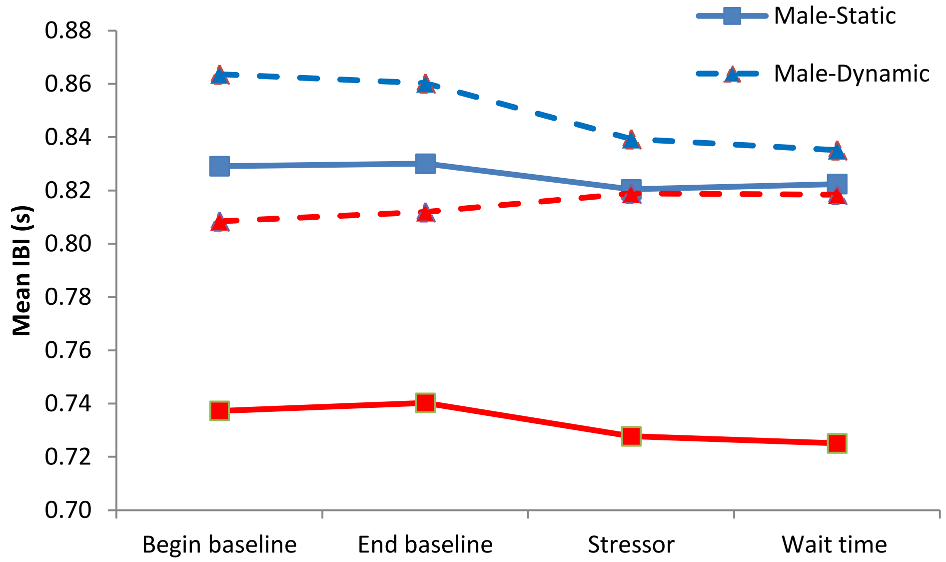

Figure 17. The mean of the IBI of the genders in different experiemental periods

5 Discussion

In general, the introduction into the health-care system and hospitalization can be experienced as very stressful. Besides individual differences in stress experiences, being in a hospital environment can also be an important contributing factor to a person's stress level. It can be assumed that it is very difficult for patients to relax from their stress in such an environment. However, this is not necessary, because environments can also be designed to calm and relax people. Therefore, this study is one of the first studies that explored the possibility of using pulsating colored lighting to create a calming environment to support stress-recovery on a psychological and physiological level.

Based on the literature and the results of pretest 1, the following effects on stress-recovery were expected: First, that pulsating lighting will have a stronger positive effect than static lighting (H1). Second, that the orange lighting color will have a stronger positive effect than the white lighting color (H2). Third, that orange static lighting and white pulsating lighting will have a stronger positive effect on stress-recovery than white static lighting (H3). Lastly, that the orange pulsating lighting setting will have the strongest positive effect compared to the others lighting settings (H4).

In partial support with hypothesis 1 (H1), results of the interbeat interval (IBI) revealed that participants in the pulsating lighting conditions had a higher IBI than participants in the static lighting conditions, which indicated that the participants were more relax in the pulsating lighting conditions than the static lighting conditions. Nonetheless, the other measurements from the psychological and physiological data did not correspond with this finding. All together, there is not enough evidence to entirely conclude that having pulsations in the lighting supports stress-recovery (H1). Furthermore, the orange colored background lighting did not result in better stress-recovery than the white colored lighting (H2). Having orange colored static lighting or white colored pulsating lighting is not better than the white colored static lighting to support stress-recovery (H3). An explanation for this could be that orange static was experienced lighting unusual and the white pulsating lighting was distractive, but not positive distractive and therefore supportive in stress-recovery. In contrary to the expectation, results of the state trait anxiety inventory (STAI) showed a lower anxiety score of the participants in the white colored static lighting condition after the recovery time from stress than participants in the orange static lighting and white pulsating lighting conditions. This suggests that white static lighting is better for stress-recovery in comparison to orange static lighting. Although the orange pulsating lighting setting was expected to have the strongest positive effect on stress-recovery than the others light settings (H4), results of the STAI suggested that both orange pulsating lighting setting and white static lighting setting were the most promising to support stress-recovery. To sum up, hypotheses H2, H3 and H4 were not confirmed. This could be due to the fact that the hypotheses were not founded for valid reasons, because the hypotheses were partly based on pretest 1. This pretest was conducted in a within participants design, consequently susceptible to social desirability bias. Nonetheless, the results did reveal some interesting findings.

The results of the STAI revealed an interaction effect between lighting colors and dynamics. This effect indicated that adding slow pulsations to orange colored lighting can support the relaxing effect of the baseline movie clip and support the stress-recovery while waiting. On the other hand, adding slow pulsations to white colored lighting can elicit an opposite effect that is, lowering the effect of the baseline movie clip and reducing the recovery from stress while waiting. These findings suggest that one should consider the possible effect of adding slow pulsations to lighting.

In addition, results of the IBI data showed a gender effect and suggested that the pulsations in lighting can lower the stress experience during the stressor of female participants, but not of male participants. Even though this gender effect suggests that one should take into account the gender of target person before applying pulsating lighting, more research is needed to confirm this gender effect.

Furthermore, in line with pretest 1, results of the main experiment of the atmosphere perception showed that orange lighting settings were perceived cozier and less detached than white colored lighting settings. Moreover, pulsating lighting settings were perceived as livelier than static lighting settings. These findings correspond with the previous study stating that the atmosphere perception measurement is a more stable concept than mood measurements(Vogels, 2008), because both pretest 1 and the main experiment revealed similar findings. An interaction effect was revealed between lighting color and lighting dynamics on the perceived tenseness of the room. This effect suggested that adding slow pulsations to orange colored lighting makes a room perceived less tensed. While adding slow pulsations to white colored lighting showed an increase in the perceived tenseness of the room. This finding corresponds with the results of the STAI, suggesting that adding pulsations to orange colored lighting can result in a positive effect, while adding pulsations to white colored lighting can results in a negative effect (more tense). Altogether, when someone wants to create a cozy and less detached atmosphere in an environment with orange colored lighting, slow pulsations should be added to the lighting to support stress-recovery.

As for the concept of positive distraction (Ulrich, 1991), results suggested that simply adding pulsations to lighting is not sufficient as a positive distractor. One should consider whether the lighting elicits positive feelings and can subtlety distract people from their stressing thoughts, because not all lighting colors with pulsations elicits positive feelings. The results suggested that orange colored lighting with pulsations was suitable as a positive distractor, while the white colored lighting with pulsations was not suitable as positive distractor. A reason for this could be because the lighting color orange elicits more positive feelings than the white colored lighting (pretest 1). This is in line with the theory that the distractor should elicit positive feelings. In short, results in this study suggest that the selected orange color elicits positive feelings and the selected form of pulsations is able to distract people from their worrisome thoughts without taxing or stressing the individual. Therefore this lighting can function as a positive distractor.

Results of the physiological data did not correspond with the results of the psychological data. Using GSR and HR to detect changes in the light stimuli are relatively easy methods to apply for objective data, because no extra tasks need to be performed by the participants. Nonetheless, there are some disadvantages of using these methods of measurements; the effects of lighting stimuli are easily masked by other unintended stimuli and/or by internal events (Rautkylä, Teikari, Puolakka, & Halonen, 2009). Furthermore, preparing the participant for the measurements (attaching electrodes and sensors) is quite obtrusive; the procedure itself can be stressful and influences the measurements. These disadvantages and the fact that the applied lighting stimuli were very subtle could be the reasons why the HR and GSR did not show similar findings as the findings from the STAI. One the other hand, the differences between the psychological and physiological measures can also be caused by the fact that the lighting stimuli only have an effect on a person consciously and not the on the bodily responses.

This study involved a newly assembled stressor manipulation from images and a movie clip. Although results of pretest 2 and the main experiment suggested that the stressor was effective, the ecological validity should be taken into account. This stressor was intended to resemble the stress related with the thought of undergoing a medical procedure or examination. However, the present study was conducted in a laboratory setting in a totally different situation. This makes it difficult to estimate how much the laboratory stress resembles the stress in situ. To add up, this study only involved a selection of pulsating lighting settings. Therefore, findings of this study cannot be generalized to other pulsating lighting settings. Besides this limitation in generalization, it is probable that the stressor has induced such a large stressing effect that it nearly cancelled out the influence of the subtle forms of lighting stimuli during the experiment. The fact that participants in this study terminated the experiment and the fainting of a few participants indicated a highly stressing effect of the stressor. Perhaps, using a less effective stressor is more appropriate to reveal the effect of the lighting stimuli even during the stressor.

Another limitation of this study is that it used light projection to the wall in both the pulsating and the static lighting conditions. Due to this, no comparison between light projection to the wall vs. no light projection on the wall was studied. It could be possible that light projection itself can have an effect on stress-recovery.

In further research, it would be useful to explore other objective measurements of stress than the used physiological recordings. Although this study involved two manipulations (lighting stimuli and stressor), the bodily responses were dominated by the intense effect of the stressor. The lighting stimuli seem to be too subtle to detect on a physiological measurable level. Other objective methods to measure a person’s stress level could be more suitable for studies like this. Perhaps, the implicit association test (Greenwald, McGhee, & Schwartz, 1998) could be appropriate as a measurement method for stress and more able to detect changes in the lighting stimuli.

In addition, this study only tested a few sets of lighting parameters for the effect on relaxation. Future studies should focus on investigating the boundaries of settings in terms of hue, saturation and tempo, when pulsating lighting is perceived from positive distractive to annoying. Also, while this study revealed some interesting stress-recovery effects on a specific type of stressor, further study could investigate the effect of pulsating lighting with the use of other kind of stressors. For instance, work related stressors.

To sum up, this was one of the first studies exploring the possibilities of pulsating lighting to support stress-recovery, in specific in a hospital environment. This study revealed preliminary results that suggest that pulsating lighting can support stress-recovery. Further research is needed to augment these findings, which can possibly lead to designing an environment in hospitals that help patients to relax. Obviously, that would be a great gain for both patients and hospitals.

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Appendices

Content

Appendix A. Pretest 1: Exploration

A pretest is conducted to investigate the psychological effects of dynamic lighting and to find the appropriate dynamic lighting setting. Hypotheses will be developed based on the results of this pretest. Next, these hypotheses shall be tested in the main experiment. Pretest 1 will study which dynamic lighting setting is perceived relaxing of activating. Based on the literature mentioned before, I expected that slow tempo of lighting dynamics will be perceived as relaxing, while fast tempo will be perceived as activating.

1 Method

1.1 Design and Participants

The current pretest consists of two parts. The first part is a 3 color (orange, white, blue) x 4 speed (fast, medium, slow, static) within subject design. Each of the twelve lighting conditions (Table 5) was provided, followed by the measurements. The second part will be used to confirm the findings of the first part and will provide more information of the preference of lighting settings of the participants. Two tasks will be presented to participants. First, participants will be asked to set the dynamic lighting in terms of color, intensity and frequency of changes for relaxation. Second, the same parameters as the first task could be changed, but this time the participants provided the settings for activation. Eleven undergraduate and graduate Dutch students (8 male and 3 female) between the age of 20 and 26 (*M* = 23, *SD* =2) from within Philips participated in the explorative user test. The user test lasted about 45 minutes.

Table 5: Experimental lighting conditions

		Pace of changes			
		Fast	Medium	Slow	Static
Color	Orange	1	2	3	4
	White	5	6	7	8
	Blue	9	10	11	12

1.2 Measurements

Several variables are of interest in the current experiment. The current study will investigate the effect of pulsating lighting on the subjective mood of the participants, using a six-item short scale based on the multidimensional mood questionnaire (MDMQ) (α = .98) (Wilhelm & Schoebi, 2007). Six bipolar items measured three dimensions (valence, calmness and energetic arousal) of mood. Wherein, high scores indicate a more positive valence, higher calmness or higher energetic arousal. Furthermore, the perception of the atmosphere of the lighting in the lab was measured with the twelve items shortened version of the atmosphere perception (α = .79) presented in a seven points scale (Vogels, Sekulovski, Clout & Moors, 2009). A high score in of the atmosphere perception indicates a highly correspondence of the lighting on one of the atmosphere dimensions, coziness, liveliness, tenseness or detachment. A factor analysis using a principal components extraction with a Varimax rotation of 12 items from the atmosphere perception scale was conducted. The analysis confirmed the structure of the shortened version of the atmosphere perception (Vogels, Sekulovski, Clout & Moors, 2009). Four factors with initial Eigenvalue higher than .9 were revealed, specifically the factors: tenseness explained 38.4% of the variance, detachment 19.5%, liveliness 12.1% and coziness 7.9%.

Moreover, with a semi-structured interview (Appendix D) participants were asked about the participant's associations, ideas and evaluations of the presented lighting conditions.

In the end, participants provided their preferred setting for lighting color, lighting intensity and frequency of changes for relaxation and activation. The participant could provide their preferences of settings to the experimenter (present in the same room). These setting were shown at the same moment and can be adjusted until the participants found their preferred setting.

1.3 Apparatus

The pretest was conducted in the productivity lab of Philips (Figure 18). This an experience lab used for representing a work place research facility where the behavior of people living in this house is observed and usage patterns are collected by researchers that are investigating methods for merging new technologies with user-centered design (Aarts & Diederiks, 2006).

Wall-washers were used to create dynamic light on two sides in the lab. The lighting in the ceiling was on during the pretest and did not change. More specifically, the ColorGraze Powercore linear LED lights of Philips are attached on two sides of the walls in room, able to project a full range of RGB colors on the walls. Furthermore, a (17") monitor connected to a laptop was used to run the computerized user test.

Figure 18: Lab setting

1.4 Lighting Stimulus

Lighting settings were changed to create a certain ambiance in the lab. The functional lighting remained unchanged, therefore this user test only comprised the background lighting. Wall-washers were used to project dynamic light on the walls. Orange colored conditions (taken from a previous graduation study Hartog (2010)) and blue colored conditions vary in terms of saturation. The white colored condition varies in intensity. Like described before (Section 5), changes in saturation will be in a linear transition in CIE color space model (Figure 19). Figure 19 shows the changes in color of the lighting conditions, varying from one color to the other. The fast paced setting varied in frequencies of .5 Hz, medium paced .125 Hz, and slow paced .067 Hz.

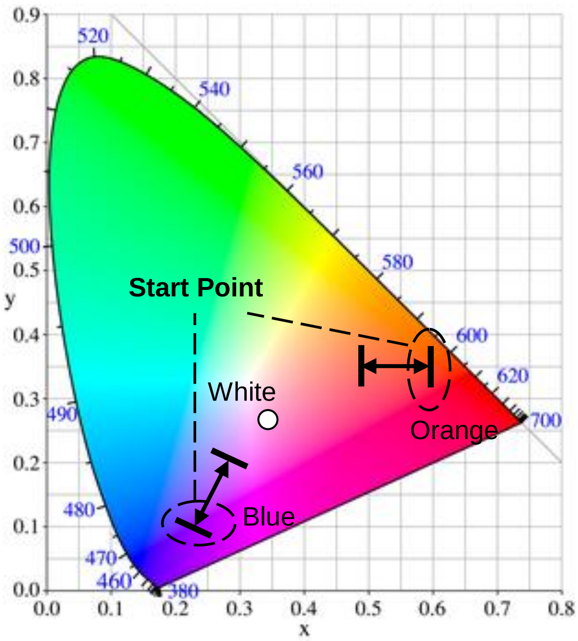


Figure 19: The lighting stimuli on the CIE color space diagram, the arrows shows the changes between two colors

1.5 Procedure

Participants (all Philips employees) were invited to the experiment to evaluate several dynamic lighting settings. The experiment started with presenting and signing the informed consent form, followed with the instruction. A large part of the experiment was computerized (Figure 20), except for the interview part.

Figure 20. Graphical user interface computerized pretest

Preset lighting settings were shown in a random order, each lighting setting was shown for 15 seconds, after that the questionnaires was presented, followed by the interview about their opinion and thoughts on the presented lighting setting. This was repeated for twelve lighting settings. After that, participants were asked to provide their preferred lighting setting, in terms of color, intensity and frequency of changes, for relaxation and activation. These setting was inserted and shown at that moment. Next, participants were asked to provide demographic data (age and gender). The experiment ended with a general interview asking the participants about their experience with the experiment and thanked them for their participation. The pretest procedure is shown in Figure 21.

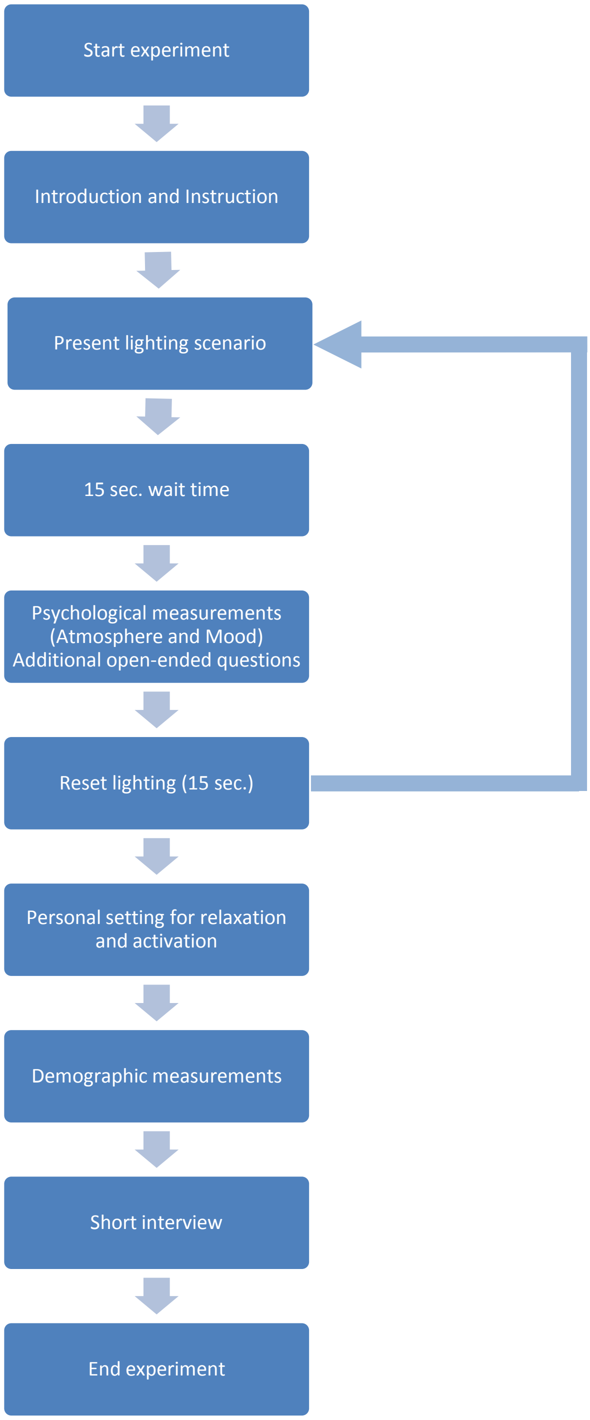


Figure 21: Schematic overview of the experimental session

2 Qualitative results

After presenting the pre-set lighting setting, a short interview was held to ask the participants about their opinion, associations and their idea of application of the presented lighting.

2.1 Opinion about the presented lighting

The answers of this question have been categorized into three groups: positive, neutral and negative. Examples of responds:

Positive respond: *“pleasant, it makes me feel more relaxing” / “prettig, ik word er meer ontspannen van”*

Neutral respond: *“the color was too saturated, but it was pretty” / “de kleur was te verzadigd. Verder was het wel mooi”*

Negative respond: *“unpleasant, the changes were awful, because of the speed. It felt very restless. Too salient” / “onplezierig, wisselingen zijn te snel, voelt erg onrustig aan.Te aanwezig”*

By subtracting the negative reactions from the positive reactions, the valence of the lighting condition in total are represented (*Figure 22*). As shown in *Figure 22*, participants reacted more negative in the fast paced condition than the other conditions. Most of the participants think that the fast pulsating of lighting is to obtrusive, annoying and frustrating. The participants experienced the color orange as the most positively among the three different colors. Orange was perceived as pleasant, and the changes in the orange conditions were perceived more subtle than in the white and blue conditions. The color blue was perceived too saturated, too intense and the difference of change was too large. In the conditions blue-medium and blue-slow, six of the eleven participants mentioned that the color blue was too intense and therefore did not like it. In general, most participants mentioned that the extreme color of the lighting should not be too intense / saturated and the range of changes in the dynamic lighting should be small and subtle instead large and prominent.

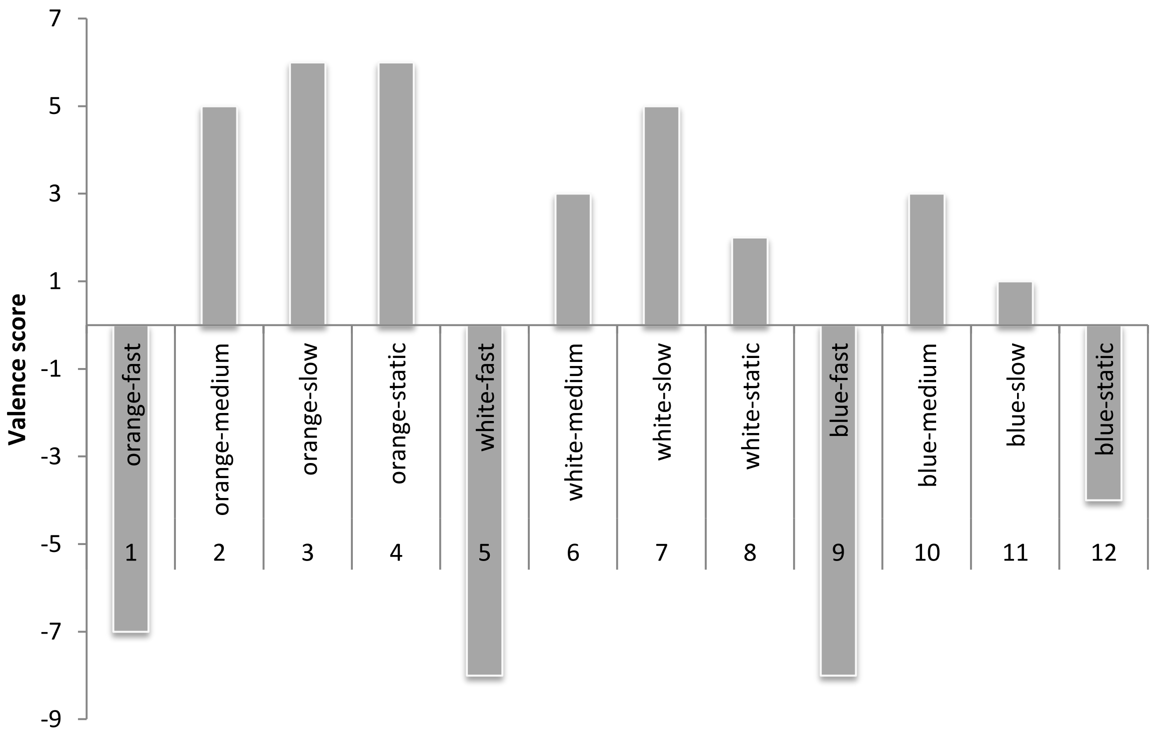


Figure 22: Column chart showing the total of reactions of the lighting conditions

2.2 Associations of the presented lighting

Figure 23 shows what participants associate the preset lighting conditions with. The participants associated each lighting condition with a broad range of different things. Each association is linked to a lighting condition. Associations mentioned by more than one participant are shown in bold.

Most of the associations were mainly based on the lighting color and little by the lighting dynamics. For instance, the orange colored light was associated with sunset several times, white was associated with daylight a few times and blue with a disco or bar.

2.3 Ideas of application with the presented lighting

Participants were asked for an idea of application for the shown pre-set lighting. The mentioned applications are shown in Figure 24. Applications mentioned twice or more by different participants are shown in bold. A broad range of applications for the different lighting settings were named. The general finding from the results is that the orange colored setting, except for the fast dynamics, is more appropriate for home settings.

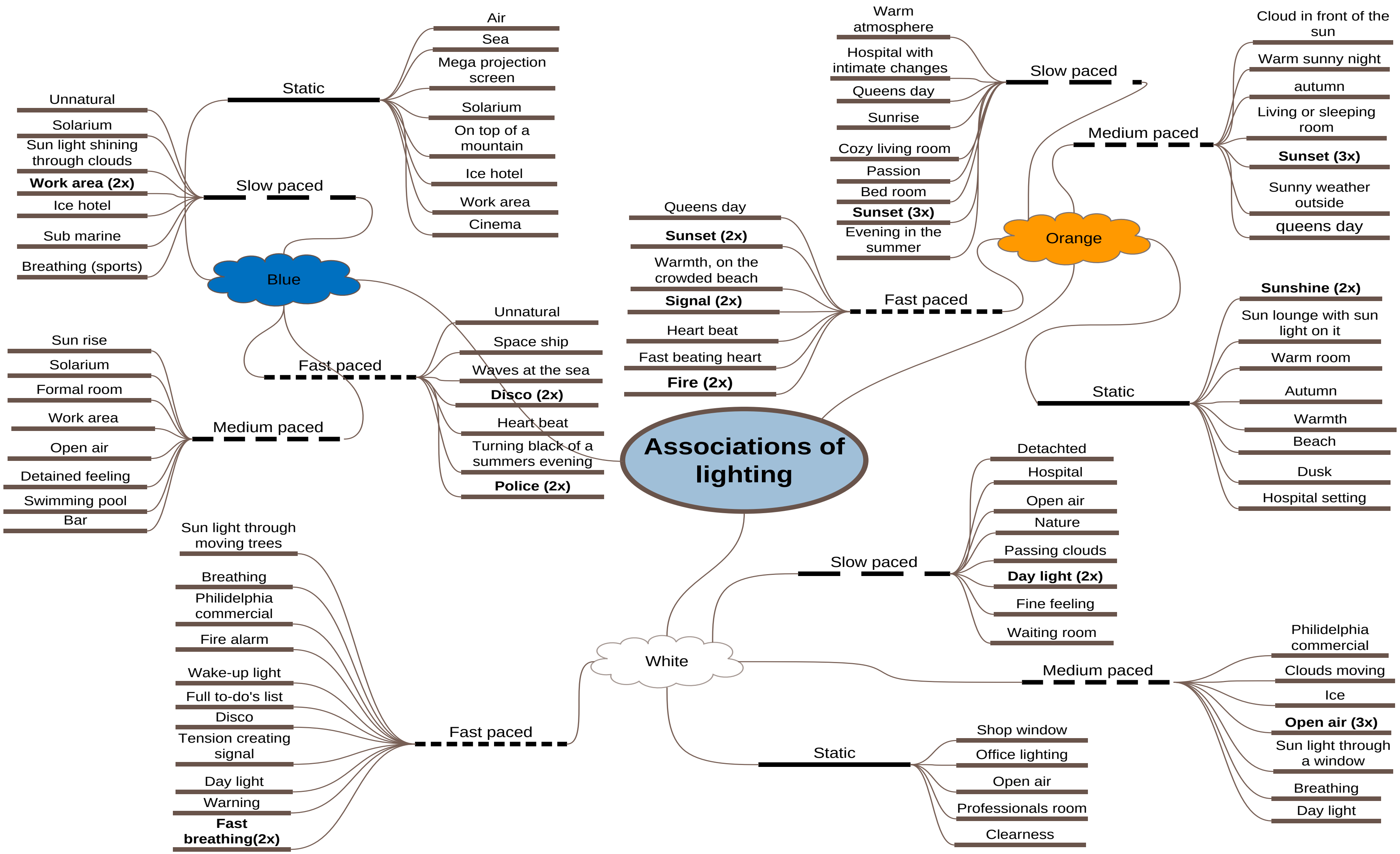


Figure 23. Diagram showing the named assosciations of each pre-set lighting conditions

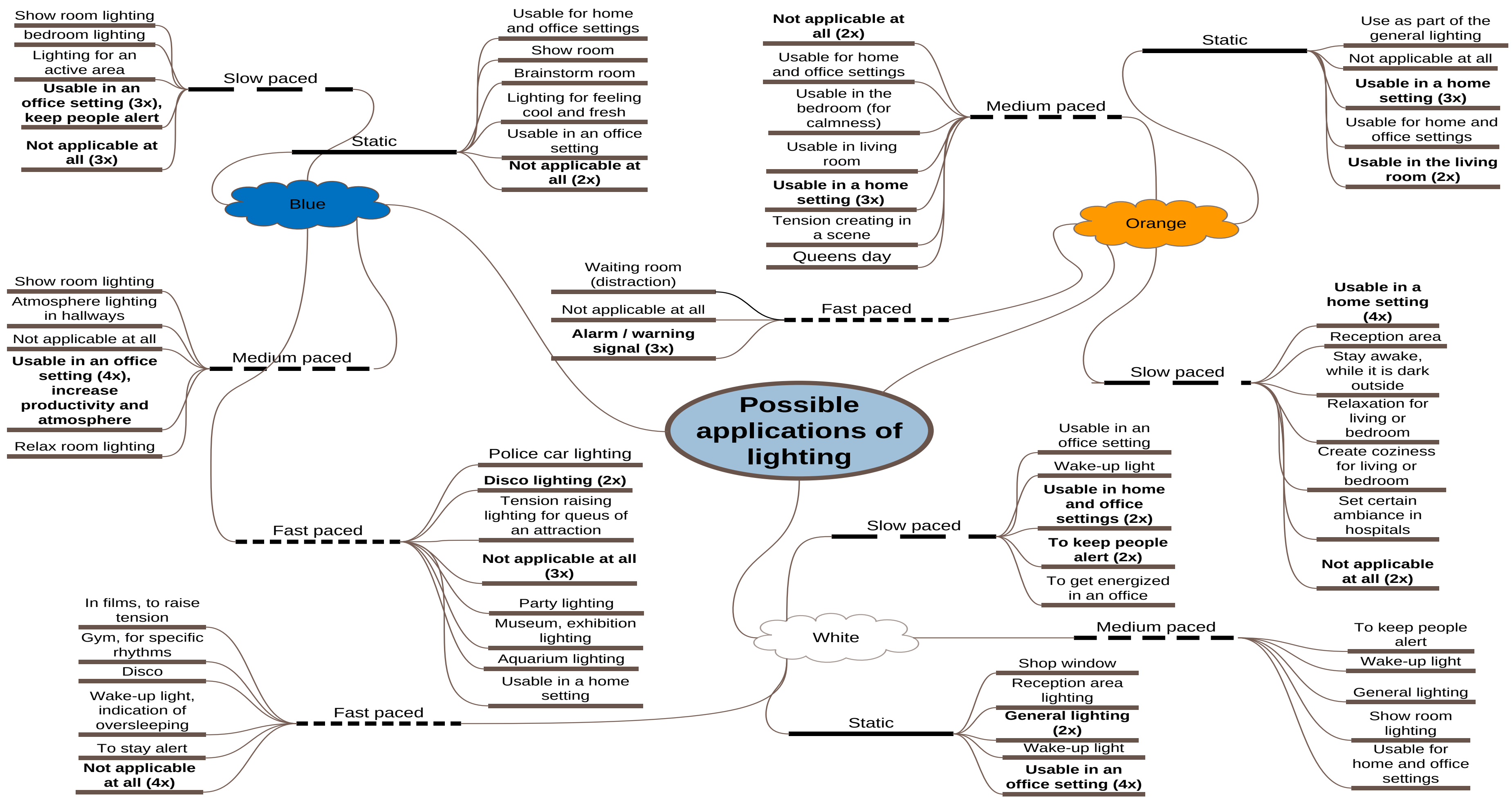


Figure 24. Diagram showing the named applications of each pre-set lighting condition

3 Quantitative results

Several questionnaires were presented to measure the atmosphere and mood of the participant. This analysis explored the differences of these measurements among the pre-set lighting conditions.

3.1 Atmosphere perception

The atmosphere perception questionnaire consisted of the following dimensions: coziness, liveliness, tenseness and detachment. These dimensions were analyzed in a repeated measures analysis of variance.

The results showed a main effect of atmosphere dimensions on the atmosphere perception, $F(3, 20) = 24.15$, $p < .01$. These results suggested that the dimensions differed in scores. However, the results showed no main effect of the light color on atmosphere perception, $F(2, 20) = 2{,}53$ $p = .11$, and no main effect of the pace of light changes on atmosphere perception, $F(3, 30) = 1{,}17$ $p = .34$. An interaction effect between atmosphere dimension and the light color on the atmosphere perception was revealed, $F(6, 60) = 16{,}79$ $p < .01$. The results showed that the participants perceived orange colored light as cozier, livelier, less tensed and less detached than the other light colors (*Figure 25*).

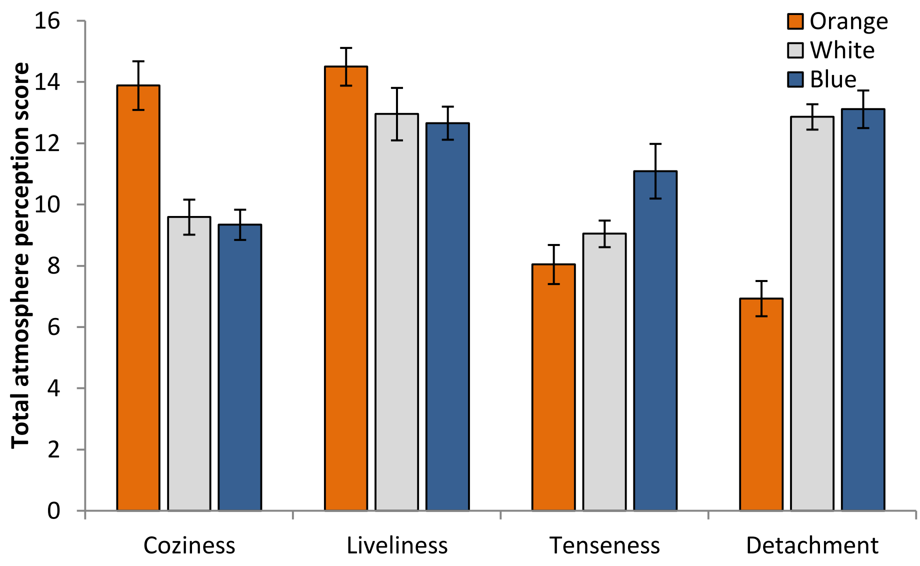


Figure 25. Atmosphere perception score per dimension in different lighting colors

Moreover, an interaction effect was revealed between the atmosphere dimension and the pace of light changes on the atmosphere perception, $F(9, 90) = 16{,}81$ $p < .01$. *Figure 26* shows that the fast paced lighting dynamics are perceived as less cozy than the other lighting dynamics. Furthermore, both medium and slow lighting dynamics were perceived as livelier than the static and fast paced lighting dynamics. The fast paced lighting dynamics was perceived as more tensed than the other lighting dynamics. In addition, the fast paced lighting dynamics was perceived as the least detached than the other lighting dynamics. The medium paced lighting dynamics was perceived as less detached than the static lighting dynamics (*Figure 26*).

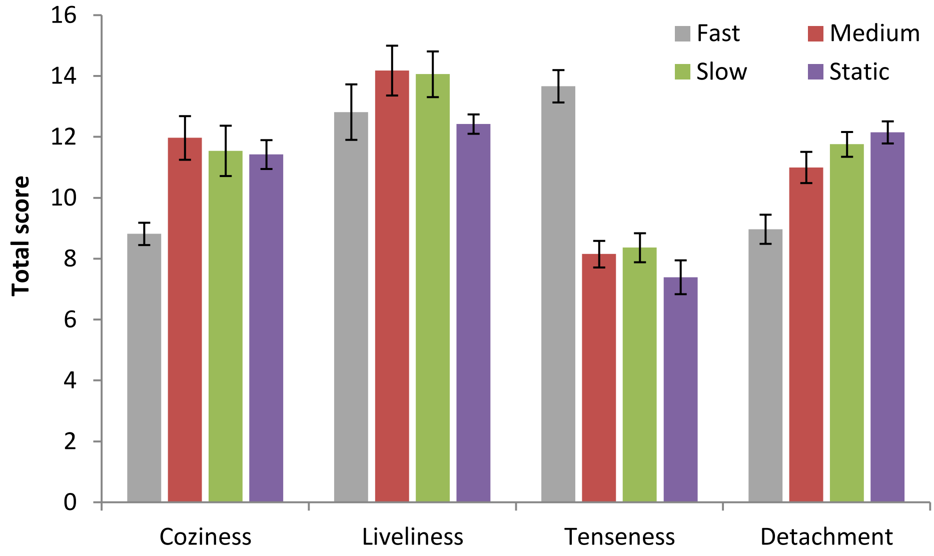


Figure 26. Atmosphere perception score per dimension in different lighting dynamics

Furthermore, a marginally significantly four-way interaction effect was shown between the atmosphere dimension, the light color and the pace of light changes on the atmosphere perception, $F(18, 180) = 1{,}51$ $p = .09$.

3.2 Multidimensional mood questionnaire

The multidimensional mood questionnaire consists out of three factors; energetic arousal, valence and calmness.

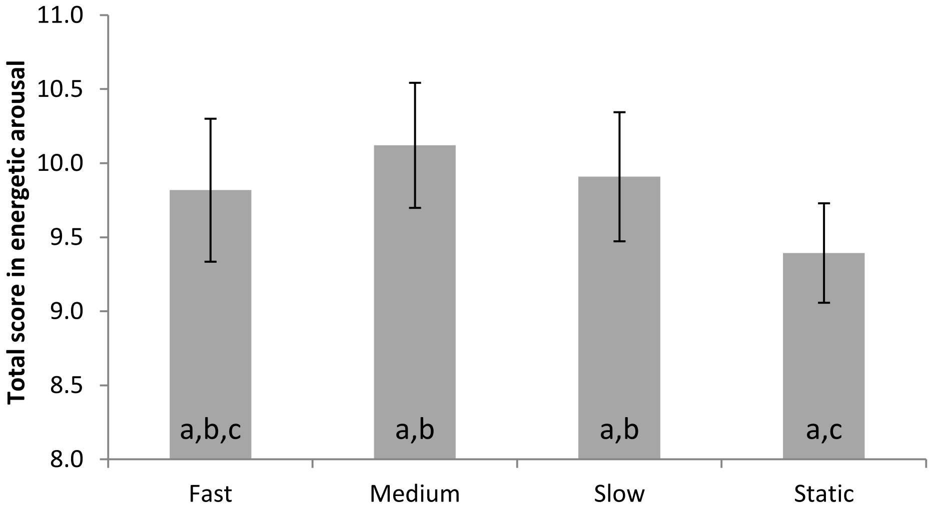
3.2.1 Energetic arousal

The energetic arousal factor from Wilhelm and Schoebi (2007) consist two items. The scores on this factor in different light settings are shown in Table 6 and *Figure 27*. The results showed no main effect of color, $F(2, 20) = 1.53$, $p = .24$, and marginal significant effect of the pace of changes, $F(3, 30) = 2.54$, $p = .08$, on the energetic arousal score.

Table 6: Scores on energetic arousal in different light color settings

Orange	White	Blue
mean (SD)	mean (SD)	mean (SD)
9.66 (.39)	10.09 (.52)	9.68 (.33)

Results of the post-hoc comparison using LSD revealed that participants in the static lighting conditions scored significantly lower on energetic arousal than participants in the medium paced conditions, $p < .05$, and slow paced conditions, $p < .01$ (*Figure 27*).



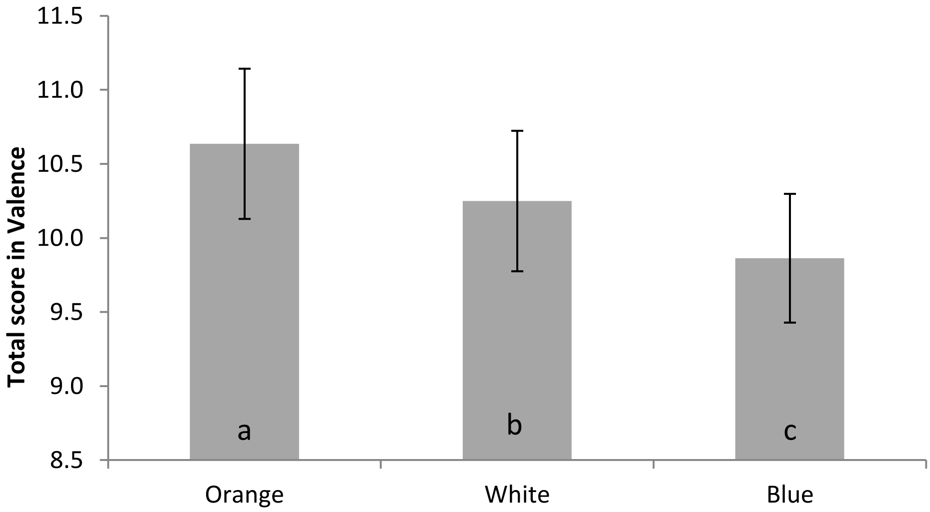
Note: means with different letters are significantly different at p < .05.

Figure 27. Total energetic arousal scores with SE in different lighting dynamics

The results of the energetic arousal score showed no interaction effect between the lighting color and lighting dynamics, $F(6, 60) = .70$, $p = .65$.

3.2.2 Valence

The results showed main effects of color, $F(2, 20) = 5.51$, $p < .05$, and the pace of changes, $F(3, 30) = 6.05$, $p < .01$, on the valence score. Results of the post-hoc comparison using LSD revealed that participants in the orange colored lighting conditions scored marginal significantly higher on valence than participants in the white colored lighting conditions, $p = .12$, and scored significantly higher than participants in the blue colored lighting conditions, $p < .05$. Furthermore, participants in the blue colored lighting conditions scored marginal significantly lower than participants in the white colored lighting conditions, $p = .07$ (*Figure 28*).



Note: means with different letters are significantly different at p < .13.

Figure 28. Total valence scores with SE in different lighting colors

The fast paced light setting score significantly lower on valence than the medium paced, $p < .01$, slow paced, $p < .05$, and static, $p < .05$, light setting (*Figure 29*).

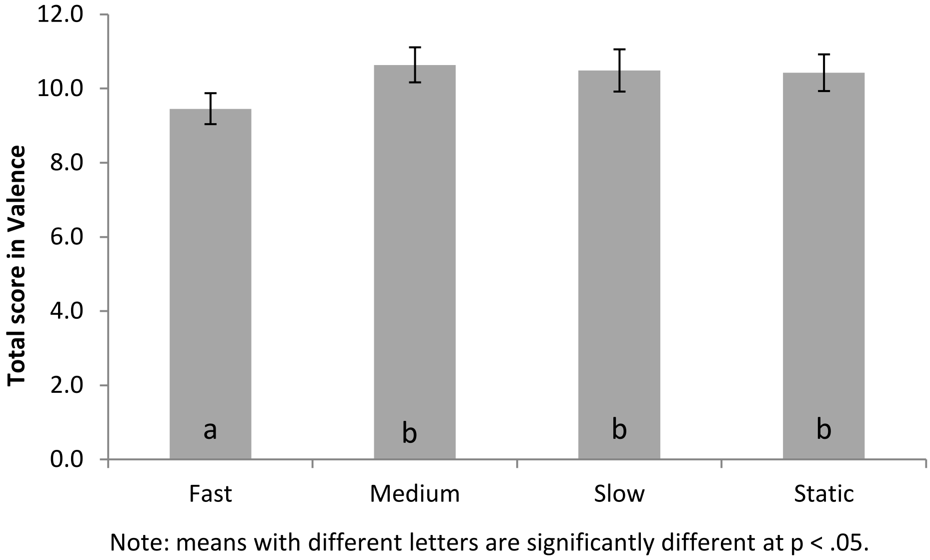


Figure 29. Total valence scores with SE in different lighting dynamics

3.2.3 Calmness

The results showed main effects of color, $F(2, 20) = 8.74$, $p < .01$, and the pace of changes, $F(3, 30) = 9.32$, $p < .01$, on the calmness score. Results of the post-hoc comparison using LSD revealed that participants in the orange colored lighting conditions scored significantly higher on calmness than participants in the white colored lighting conditions, $p < .05$, and blue colored conditions, $p < .01$. Furthermore, participants in the white colored lighting conditions scored marginal significantly lower on calmness than participants in the blue lighting conditions, $p = .07$ (*Figure 30*).

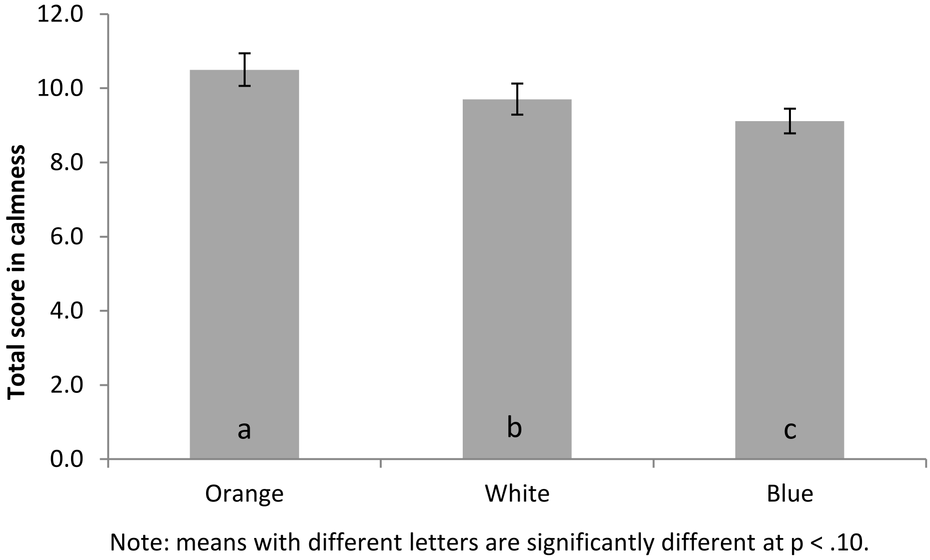


Figure 30. Total calmness scores with SE in different lighting colors

The participants in fast paced lighting conditions score significantly lower on calmness than participants in the medium paced conditions, $p < .01$, slow paced conditions, $p < .01$, and static conditions, $p < .01$ (*Figure 31*).

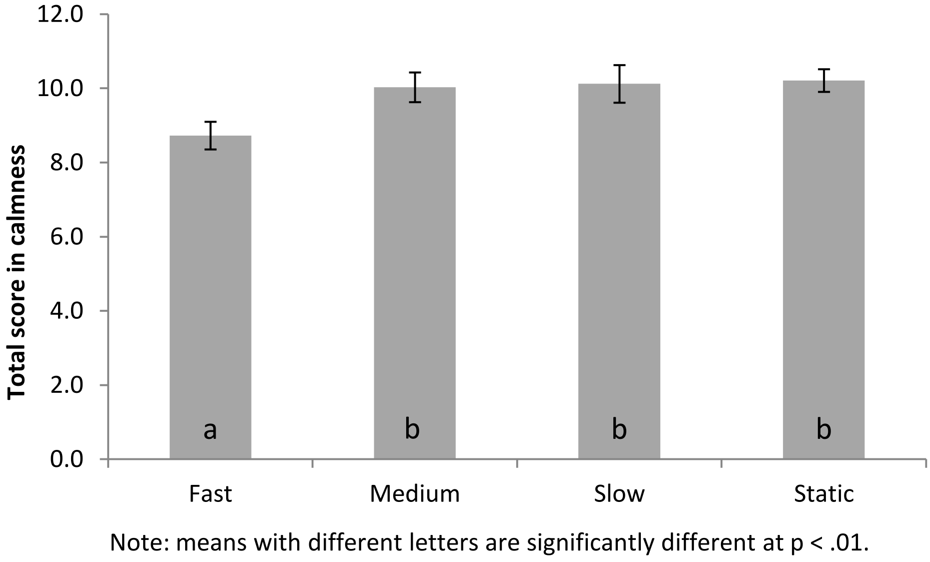


Figure 31. Total calmness scores with SE in different lighting dynamics

The results of the calmness scores showed no interaction effect between lighting color and lighting dynamics, $F(6, 60) = .79$, $p = .58$

3.3 Visual analogue scale

A visual analogue scale (VAS) was used to measure relaxation, alertness and valence.

3.3.1 Relaxation

The results showed main effects of color, $F(1.31, 13.08) = 4.83$, $p < .05$, and the pace of changes, $F(1.64, 16.64) = 9.32$, $p < .01$, on the relaxation. Results of the post-hoc comparison using least significant difference (LSD) revealed that participants in the orange colored lighting conditions scored marginal significantly higher on relaxation than participants in the white colored lighting conditions, $p = .06$, and significantly higher than participants in blue colored lighting conditions , $p < .05$ (*Figure 32*).

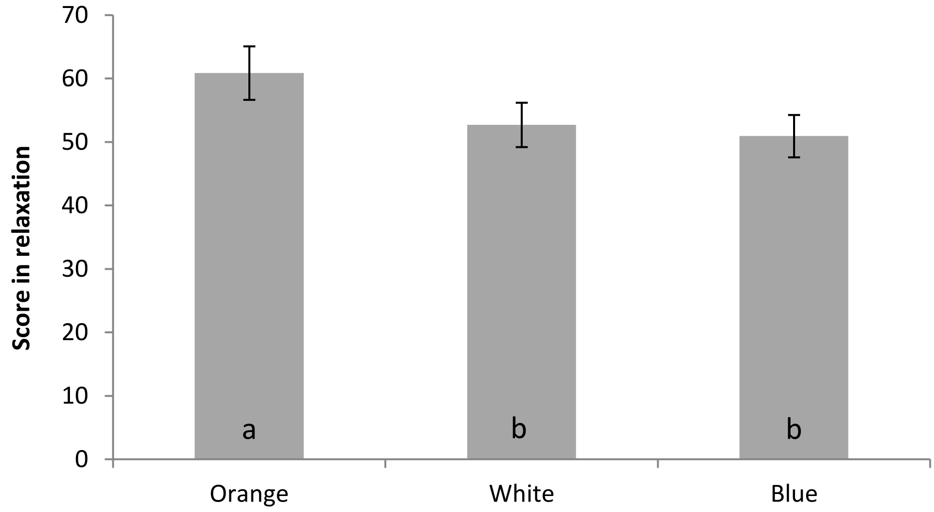


Figure 32.Relaxation score with SE in different lighting colors

Participants in the fast paced lighting conditions scored significantly lower on relaxation than participants in the medium paced conditions, $p < .01$, slow paced conditions, $p < .01$, and static conditions, $p < .01$ (*Figure 33*).

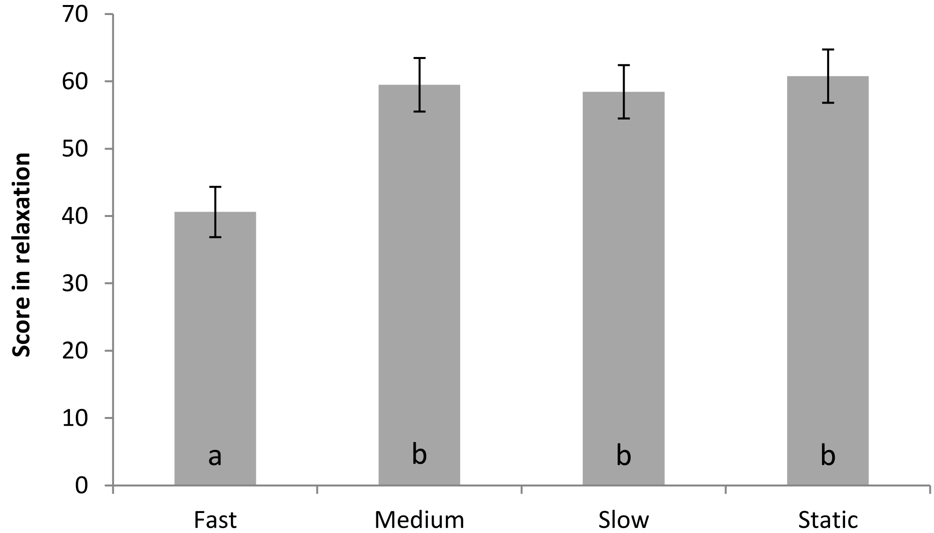


Figure 33. Relaxation score with SE in different lighting dynamics

Results of the relaxation score showed no interaction effect between lighting color and lighting dynamics, $F(3.44, 34.44) = .60$, $p = .64$.

3.3.2 Alertness

The scores on alertness in different lighting colors are shown in Table 7. The results showed no main effect of color on alertness, $F(2, 20) = 1.17$, $p = .33$. However the pace of changes did show a main effect on alertness, $F(3, 30) = 4.21$, $p < .05$.

Table 7: Scores on alertness in different light color settings

Orange	White	Blue
mean (SD)	mean (SD)	mean (SD)
56.37 (3.25)	60.73 (5.09)	59.72 (4.15)

Results of the post-hoc comparison using LSD revealed that participants in the fast paced lighting conditions score significantly higher on alertness than participants in slow paced conditions, $p < .05$, and static conditions, $p < .05$ (*Figure 34*). Furthermore, participants in the static lighting conditions scored marginal significantly lower on alertness than participants in the medium paced lighting conditions, $p = .06$ (*Figure 34*).

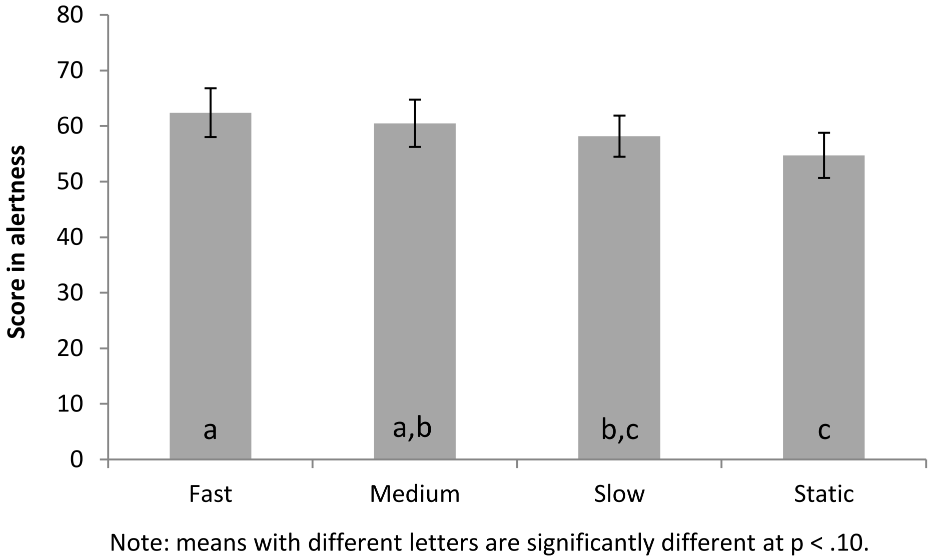
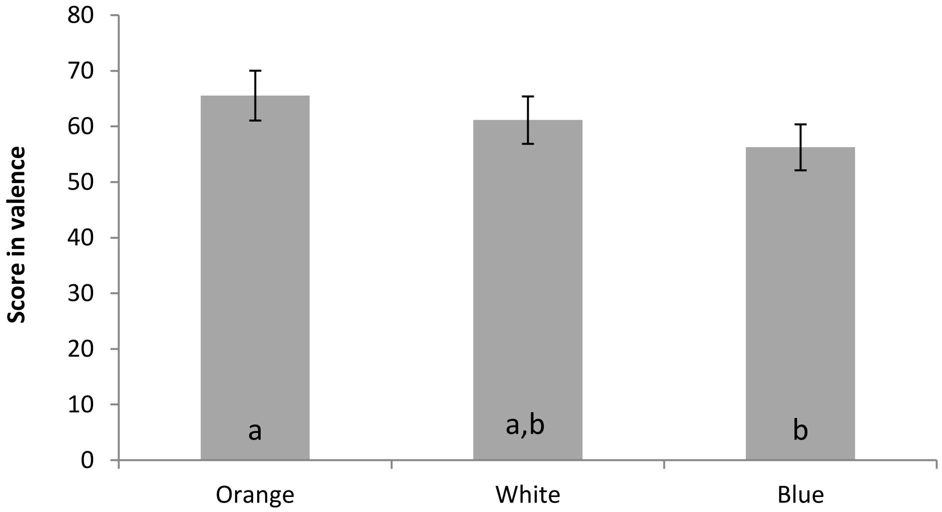


Figure 34. Alertness score with SE in different lighting dynamics

Results of the alertness score showed no interaction effect between lighting color and lighting dynamics, $F(6, 60) = .72$, $p = .63$

3.3.3 Valence

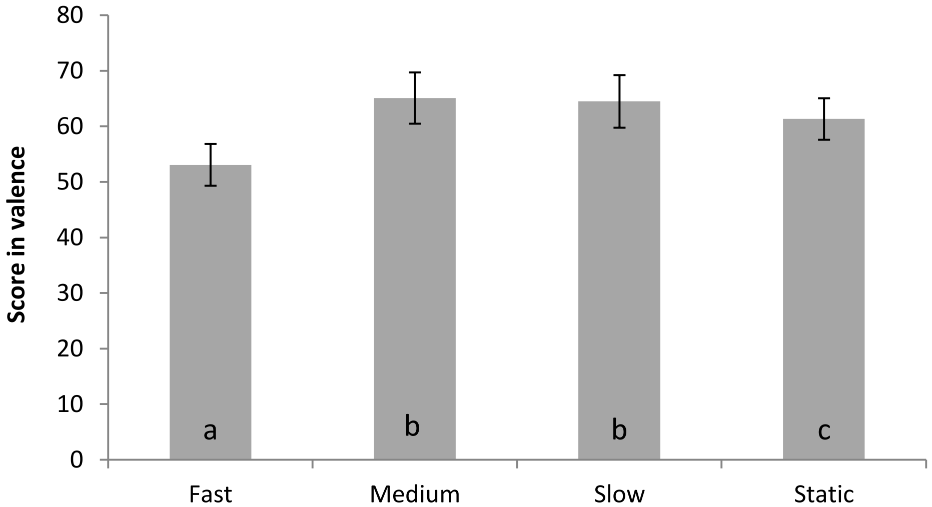
The results showed a marginal significant main effect of color on valence, $F(2, 20) = 3.27$, $p = .06$. Furthermore the pace of changes showed a significant main effect on valence, $F(1.55, 15.49) = 5.81$, $p < .01$. Results of the post-hoc comparison using LSD revealed that the participants in the orange colored lighting setting rated their self significantly more positive than participants in the blue colored lighting conditions, $p < .05$ (*Figure 35*).



Note: means with different letters are significantly different at p < .05.

Figure 35. Valence score with SE in different lighting colors

Participants in the fast paced lighting conditions significantly rated their self significantly less positive than participants in the medium paced, $p < .05$, slow paced, $p < .05$, and static conditions, $p < .05$. Furthermore, participants in the static lighting conditions marginal significantly rated their self less positive than in the medium paced conditions, $p = .14$, and slow paced conditions, $p = .10$ (*Figure 36*).



Note: means with different letters are significantly different at p < .15.

Figure 36. Valence score with SE in different lighting dynamics

3.4 Conclusion

The present experiment explored which dynamic lighting settings are perceived relaxing or activating. More specifically, different lighting settings in terms of color and pace of changes in saturation or intensity of light were presented in each condition. Data was gathered qualitatively, with a semi-structured interview, and quantitatively, by means of questionnaires.

Results of the interview provided insights about the associations with the pre-set light settings and inspiration for a possible application of the lighting settings. One of the factors mentioned by participants was the naturalness of lighting. Too saturated lighting colors will make it look unnatural and less preferred. Overall, the light color orange was mentioned to be more applicable for home-settings, while the other colors were more applicable for office setting. Furthermore, the fast paced light changes were experienced negatively and was suggested to not apply these kinds of lighting settings.

As for the results of the questionnaires, a few main findings can sum up the results of the explorative study. First, the fast lighting dynamics scored the most negative among the other lighting dynamics. Second, the lighting color was experienced the most positive than the other lighting colors. Third little differences were shown by the results between the static lighting dynamics and medium / slow lighting dynamics, except that the results suggested that medium/slow paced lighting conditions were livelier and less detached than the static lighting condition.

Results of the subjective measures suggested that the orange lighting color is more calming and elicits more positive feelings than the white and blue lighting colors. Furthermore, the results suggested that medium and slow lighting dynamics made the participants felled more positive and created a livelier environment than the static and fast lighting dynamics. The next experiment will test the orange lighting color with medium dynamics on the effect of relaxation.

Appendix B. Pretest 2: The stressor manipulation

The second pretest investigated the effect of pulsating lighting on the effect of pulsating lighting on relaxation. Like described before, relaxation in this study is defined as recovering from the psychologically and physiological effects of stress. In order to investigate the effect on relaxation, an effective stressor manipulation is needed. Before the start of the main experiment, a stressor manipulation was created and tested to make sure that the stressor is effective. This pretest investigated the effect of the stressor manipulation (described in section 2.2) on psychological and physiological stress responses. Furthermore, this pretest tested the experimental setup and the duration of the experiment.

1 Method

1.1. Participants

The participants were asked for a history of a traumatic experience of hospilization or diseases and for regularly viewing extremely violent movies of playing violent computer games. This to make sure, that the content of the pretest does not shock the participants too much and that persons that are possible insensitive for the stressor manipulation are excluded. Fourteen participants (5 male and 9 female) with ranging from the age of 22 to 58 years (*M*= 38*, SD* = 17) were invited to watch the pre-selected visual material in a lab. One female participant terminated the experiment using the stop-button, because of the content of the stressor manipulation. The pretest lasted 40 minutes, for which participants were paid 10 Euros in VVV-vouchers.

1.2. Apparatus

The pretest was conducted in the lighting lab of the technical University of Eindhoven (*Figure 37*). The NeXus-10 recording device and its accompanying sensors (Mind Media BV, Roermond, The Netherlands) was used to measure the physiological responses (i.e. electrodermal, and skin temperature). Skin conductance measurements have been conducted using EDA/GSR electrodes. The electrodes have been attached to the upper phalanxes of the index and ring finger of the left hand. HR (heart rate) measurements have been conducted using a Blood Volume Pulse Sensor at the middle finger of the left hand. Skin temperature has been measured with the NeXus-10 thermistor skin temperature sensor at the upper phalanx of the little finger of the left hand using adhesive tape. Physiological measures are assessed continuously during

Figure 37. The lighting lab of the technical University of Eindhoven

the experiment. The MATLAB programming environment (2009a, The Mathworks, Natick, MA) will be used for the preprocessing of the physiological signals.

A (19" wide-screen) monitor was connected to a laptop for playing video, and controlling and presenting the test procedure and questionnaires.

1.3. Measurements

Both physiological and psychological measurements were conducted during the experiment. The psychological measurements consisted of several questionnaires. 40 items were derived from the state-trait anxiety inventory (STAI) (α = .97) of Spielberger, Gorsuch and Lushene (1970). Because, the VAS is more suitability for frequent and repeated measures (van Duinen, et al., 2008) the inventory was presented in a VAS instead of the original four points scale. The VAS ranges from 0 to 100, whereas a high score indicates a highly anxious person and a low score a low anxious person.

The heart rate (HR), galvanic skin response (GSR) and skin temperature were recorded as physiological data. The HR was measured with NeXus-10 Blood Volume Pulse Sensor at the middle finger of the left hand. The GSR was measured with EDA/GSR electrodes at the index and ring finger of the left hand. The skin temperature was measured with the NeXus-10 thermistor skin temperature sensor at the upper phalanx of the little finger of the left hand using adhesive tape.

Demographical questions were presented asking participants about their age and gender. In the end, a semi-structured interview asked the participants about their experience of the experiment.

1.4. Procedure

All participants were seated in front of a desk with a viewing distance of 70 centimeters, in the lighting lab room of Eindhoven University of Technology. The participants are told that we are going to evaluate several medical related negative affected pictures and a video clip on their psychological and physiological responses for a campaign to increase the awareness of human vulnerability in the medical health care and that they have to pay full attention to the presented material, because there will be some questions about it in the end of the experiment. In the introductory session participants started to read through and sign the informed consent form followed by the attachment of the physiological sensors, the signal quality was inspected visually and the physiological responses were measured continuously. Next, the participants viewed an aquatic video clip about underwater life (Hannan, 1992) for 240 seconds to achieve baseline measures. Previous study suggested that an aquatic video is effective for achieving low baseline levels (Piferi, et al., 2000) and used it as relaxation stimulus (Colamussi, et al., 2007). After that, the State-Trait Anxiety Inventory (STAI) (Spielberger, et al., 1970) was presented to the participant. The whole experiment was computerized (Figure 38), and instructions were presented on the monitor.

Figure 38: Graphical user interface of the computerized experiment

Participants were instructed to pay attention to the series of negative affected pictures and a video clip, because questions would be asked about the details of the showed material. Moreover, participants were reminded that they could stop the experiment and/or the presentation of the pictures and video at any time, by clicking the “Stop” button in the screen. When the participants were ready, they could start with the slideshow of ten negative affective pictures from the international affective picture system (each picture is shown 6 seconds) and one video clip of around 300 seconds showing a scene of the commercial available movie “Awake” (Harold, 2007). Directly after this the participants filled in the state part of the STAI on the computer. The experiment ended with questions asking about the participant’s age and gender. The session of pretest 2 is shown in *Figure 39*.

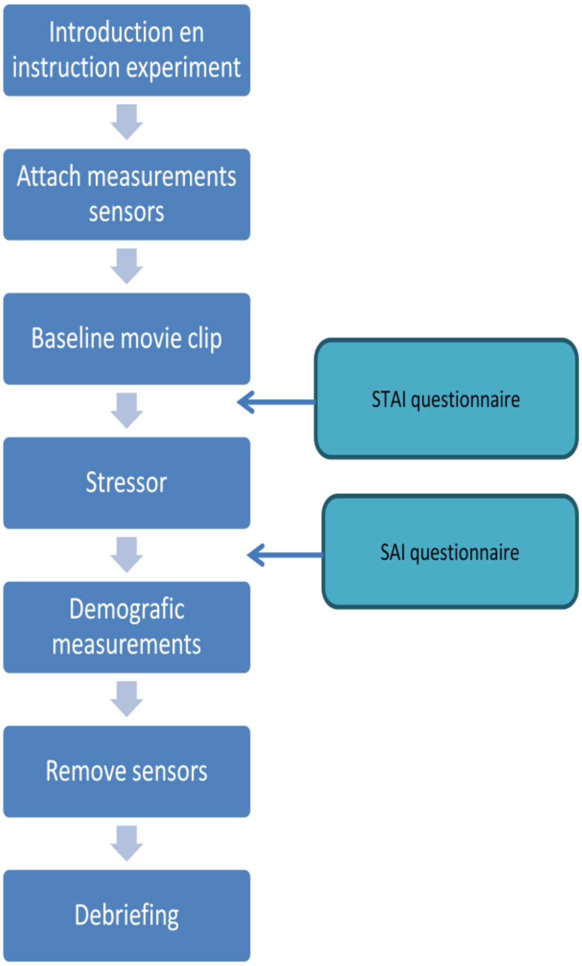


Figure 39. Diagram of the pretest 2 session

2. Results

Before the analysis of physiological data started the raw data was inspected. Next, the mean of the total baseline period and the mean the total stressor period were calculated and used in the analysis. After that the data was analyzed briefly to check for the effect of the stressor.

2.1. STAI

The STAI consist of a trait and a state anxiety inventory (SAI). We are more interested in the results of the state part of the STAI, because the state part reflects the anxiety level of a person at that moment. The repeated measures analysis revealed an effect of the stressor on the SAI, $F(1, 11) = 10.06$, $p < .01$. More specifically, participants were feeling less anxious before the stressor than after it (*Figure 40*).

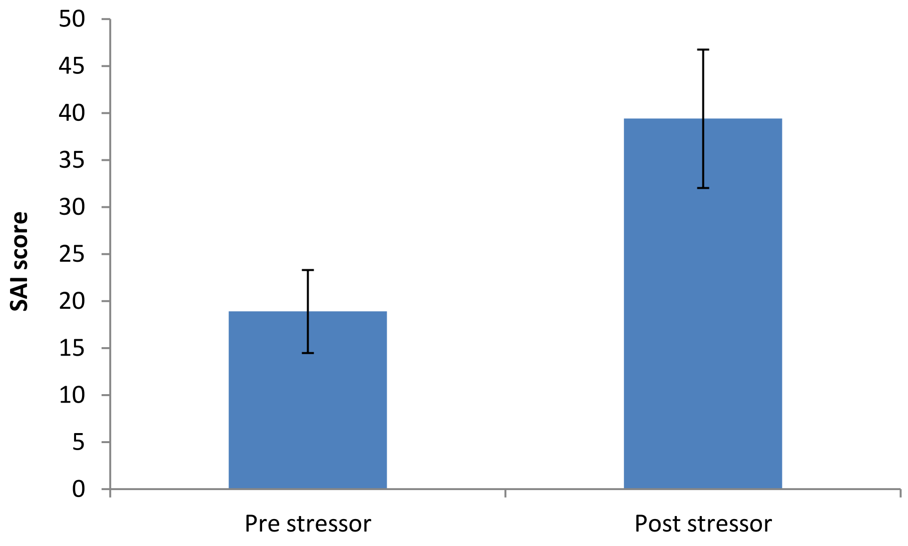


Figure 40. Mean SAI score with SE pre- and post-stressor

2.2. Galvanic skin response

The raw data of the GSR of each participant was plotted and inspected, before the analysis. Artifacts (undesired unlikely signals) were removed from the GSR data. Furthermore, the effect of the stressor was checked manually in the GSR plots. *Figure 41* shows a clear stressor response of the GSR, showing a higher skin conductance in the stressor period than the baseline period.

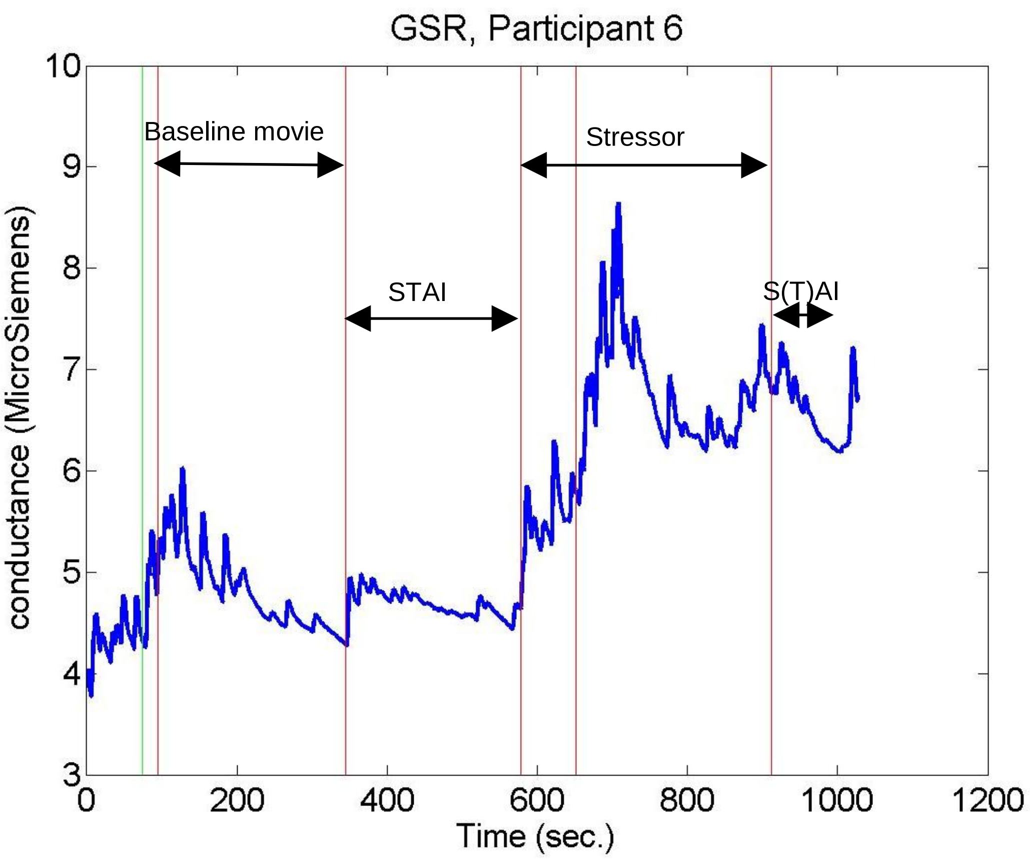


Figure 41. A GSR plot with a clear effect of the stressor from one participant during the experiment

The repeated measures analysis revealed an effect of the stressor on the GSR, $F(1, 12) = 5.89$, $p < .05$. More specifically, participants had a higher GSR before the stressor than after the stressor (*Figure 42*).

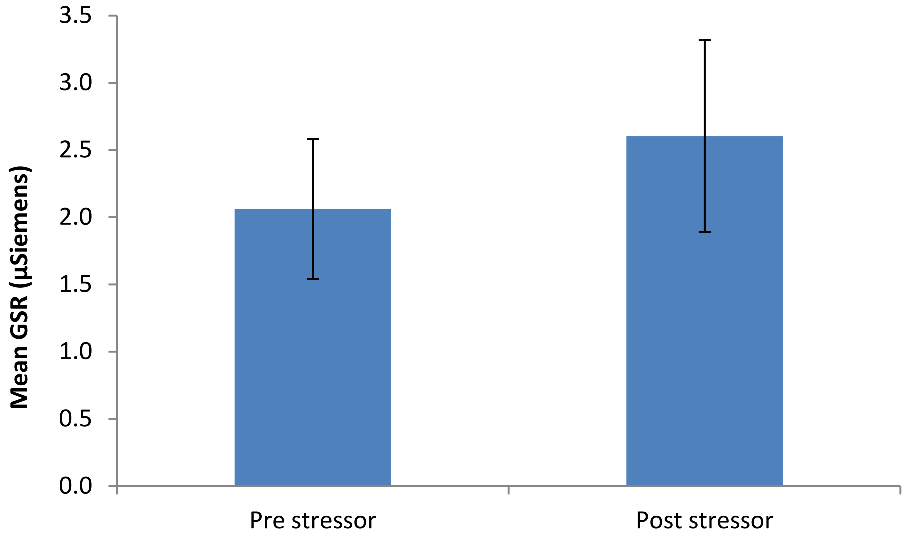


Figure 42. Mean GSR with SE pre- and post-stressor

2.3. Inter-beat interval

The raw data of the IBI was plotted and checked for the stressor response. One participant (ppn 11) was excluded from the analysis, because the IBI could not be extracted from the HR. Furthermore, the IBI data of five participants showed a clear stress response in the IBI plot (e.g. in Figure 43).

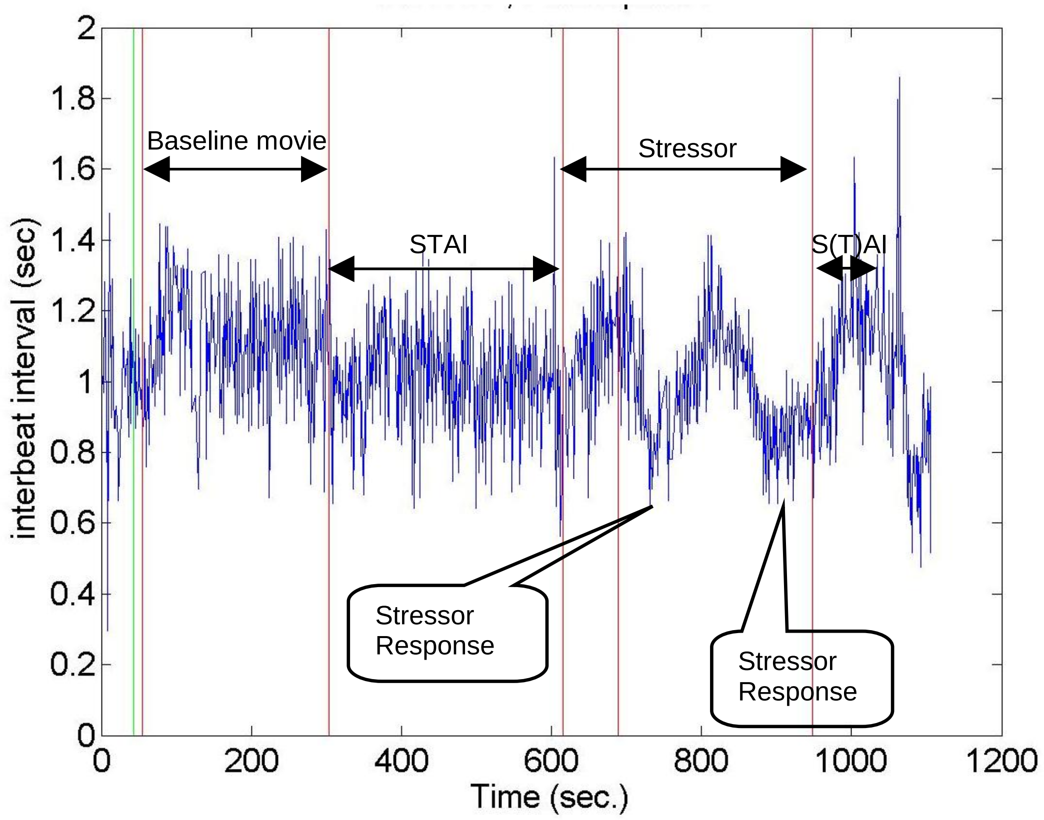


Figure 43. An IBI plot with a clear effect of the stressor from a participant during the experiment

The mean of the IBI of the participants showed a higher IBI pre stressor than post stressor (*Figure 44*). However, the repeated measures analysis revealed that this effect was not significant, $F(1, 11) = .26$, $p = .62$.

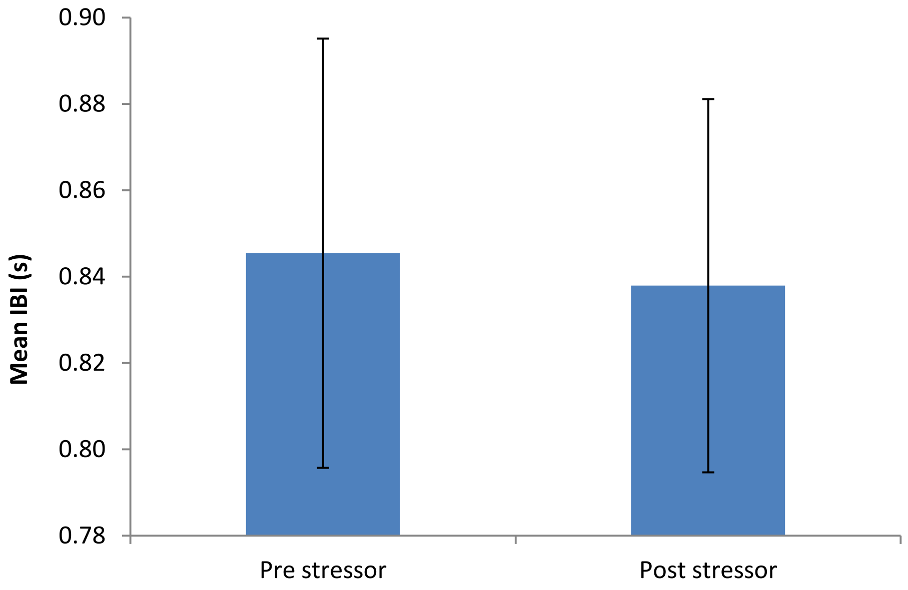


Figure 44. Mean IBI with SE pre- and post-stressor

2.4. Skin temperature

The plots of the raw data from the skin temperature showed no stressor response of most of the participants. The results of the skin temperature data showed no effect of the stressor, $F(1, 12) = .13$, $p = .72$. The mean of the skin temperature before and after the stressor are shown in *Figure 45*.

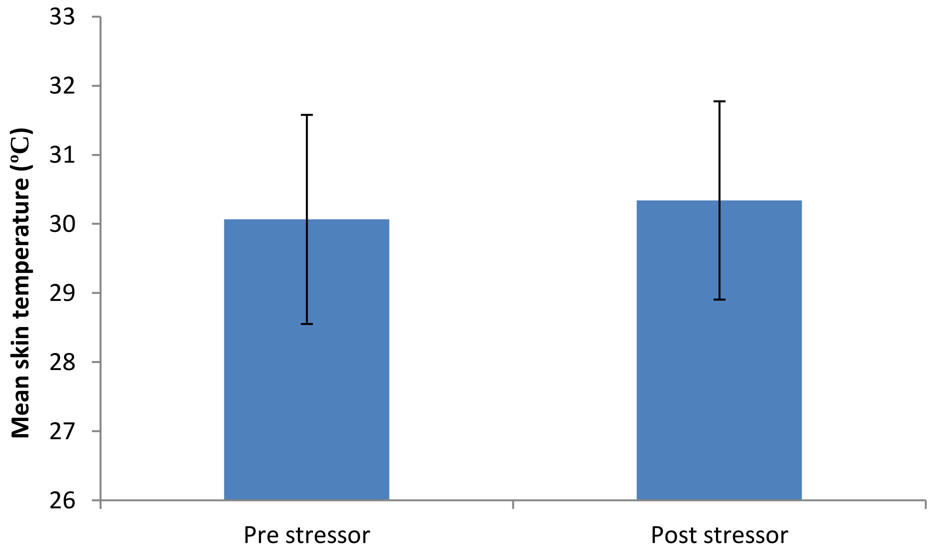


Figure 45. Mean skin temperature with SE pre- and post-stressor

3. Conclusion

This pretest investigated the effect of the stressor manipulation on the psychological and physiological stress responses. Results of the pretest suggested that the stressor had an effect on STAI and the GSR. However, the analyses of the physiological data did not show an effect of the stressor on the IBI and the skin temperature. Although no significant effect was shown on the IBI, the plots of the raw data showed a clear response of the stressor. More specifically, several participants showed a lower heart rate and smaller deviations in IBI during the stressor period. Therefore, it can be assumed that the stressor also affected the IBI of the participants. As for the skin temperature, no effect was shown of the stressor. A cause for this could be the possibility that the skin temperature needed more time to respond to the stressor, since the skin temperature reacts slower on stressors than GSR and HR. Therefore, the skin temperature measurement will be excluded from the main experiment.

The duration of the pretest was on average 30 minutes. Because this is shorter than expected, the base line movie in the main experiment is extended to eight minutes instead of four. This was done by editing a scene of eight minute from the aquatic movie (Hannan, 1992).

To sum up, this pretest suggested that the stressor manipulation was effective on psychological and physiological responses. The main experiment will therefore make use of the tested stressor manipulation. The skin temperature will be excluded from the main experiment, because no response was shown by the skin temperature on the stressor manipulation.

Appendix C. Evaluation participants getting unwell during the experiment: Support stress-recovery through subtle forms of pulsating light (proposal: 11-153)

Name reviewer	Function reviewer	Review date	Signature
Jettie Hoonhout	*Senior Research Scientist*		
Hans Weda	*Senior Research Scientist*		

Name Author	Function Author
Sze Ho Wan	Internship student

1 Post experiment report

This report describes three unfortunate events during the experiments from August to September 2011 at the lighting lab of the Technical University of Eindhoven (TU/e). Three persons fainted during the experiment, but were unharmed. To learn from these events, a detailed description is provided in this report. First, the experimental procedure is described, including the taken precautions to prevent participants from feeling too uncomfortable during the test. Second, the situation of these events and the aftercare are described. Finally, some recommendations are made.

2 Pretest of the stressor

Before the start of the main experiment, a stressor manipulation was created and tested to make sure that the stressor is effective. This pretest investigated the effect of the stressor manipulation on psychological and physiological stress responses. Furthermore, this pretest tested the experimental setup and the duration of the experiment. Fourteen participants (5 male and 9 female) with ranging from the age of 22 to 58 years (*M*= 38*, SD* = 17) were invited to watch the pre-selected visual material in a lab. One female participant terminated the experiment using the stop-button, because of the content of the stressor manipulation. The other thirteen participants went through the pretest without any problem, none of them became unwell.

3 The experiment

This experiment was conducted to investigate whether pulsating light can have a positive effect on stress-recovery and stress reduction of a stressor. Pulsating light will be compared with static lighting. The stress levels will be measured by means of skin conductance, heart rate and questionnaires.

Procedure

The experiment has been thoroughly discussed and prepared by the author, Sze Ho Wan, in close collaboration with:

- Hans Weda and Roel Cuppen, experienced researchers and supervisors at Philips Research
- Jaap Ham and Daniel Lakens, experienced researchers and supervisors at TU/e
- Jettie Hoonhout, as representative of the ICBE
- The study has been formally approved by the ICBE.

4 Method

4.1 Participants and Design

Eighty participants from outside of Philips have been recruited by e-mail retrieved from the participant database of Eindhoven University of Technology. The participants were not aware of the detailed purpose of the experiment, but were informed on the procedure, and signed a written informed consent before participating. A 2 color (orange, white) by 2 light setting (dynamic, static) between subjects design of the experiment has been used. Each subject has participated in one of the four experimental conditions (Table 2).

Table 8: Experimental conditions

	Static	Dynamic
White	A	C
Orange	B	D

4.2 Apparatus

Physiological measures cover autonomic nervous system reactions (i.e. electrodermal, and skin temperature, that are measured with the NeXus-10 data recorder and its accompanying sensors (Mind Media BV, Roermond, The Netherlands). Skin conductance measurements have been conducted using EDA/GSR electrodes. The electrodes have been attached to the upper phalanxes of the index and ring finger of the left hand. HR (heart rate) measurements have been conducted using a Blood Volume Pulse Sensor at the middle finger of the left hand. Physiological measures are assessed continuously during the experiment. The MATLAB programming environment (2009a, The Mathworks, Natick, MA) will be used for the preprocessing of the physiological signals.

Wall-washers, D-LED D-LINE series, are used to create a calming atmosphere with subtle forms of pulsating light. This study involves static lighting and slow dynamics of lighting varying in brightness and saturation with the pace of 0.125 Hz (Table 3).

Table 9: Setting and measurements of the experimental light conditions

LED setting				
R	**G**	**B**	**X**	**Y**
135	80	0	0.5412	0.3986
65	70	40	0.4624	0.3815
120	75	30	0.4918	0.3839
190	220	150	0.3286	0.3255
115	140	100	0.3393	0.3259
145	180	115	0.3336	0.3349

4.3 Measurements

Several variables are of interest in the current experiment. The current study will research the effect of dynamic lighting on the following variables:

- Subjective anxiety/stress measurement → State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, & Lushene, 1970)
- Physiological measurements → Skin conductance and Heart rate

4.4 Stressor

Previous studies have shown several methods to induce stress in a lab setting with different kinds of stressors, for instance social stress (Kirschbaum, Pirke, & Hellhammer, 1993; Saab, Matthews, Stoney, & McDonald, 1989), workload stress (Gilhooly, 1978; Locatelli et al., 1989) and stress from anxiety (Gilbert, Robinson, Chamberlin, & Spielberger, 1989; Holmes, James, Coode-Bate, & Deeprose, 2009; Qin, Hermans, van Marle, Luo, & Fernández, 2009; Verwoerd, Wessel, & de Jong, 2010). The present study focuses on temporal stress caused by threat and the lack of control. For instance, hospitalization can elicit stressful experiences, caused by the environment, diagnostic procedures, uncertainties about their health and so on. Results of previous studies have shown that using affective pictures from the international affective picture system (IAPS) (Bradley, Cuthbert, & Lang, 1996; Smith, Bradley, & Lang, 2005) and video clips (Cousijn et al., 2010; Holmes, et al., 2009; Ossewaarde et al., 2011; Verwoerd, et al., 2010) can have an effect on physiological responses and subjective mood or anxiety scales. The present user test will use a combination of negative affective pictures from the IAPS (*Figure 46*) related to hospitalization and a negative affective movie scene (*Figure 47*) from "Awake" (Harold, 2007) related to hospitalization to induce stress. This form of stressor is suitable for this user test, because it provides a clear starting and ending point of the stressor.

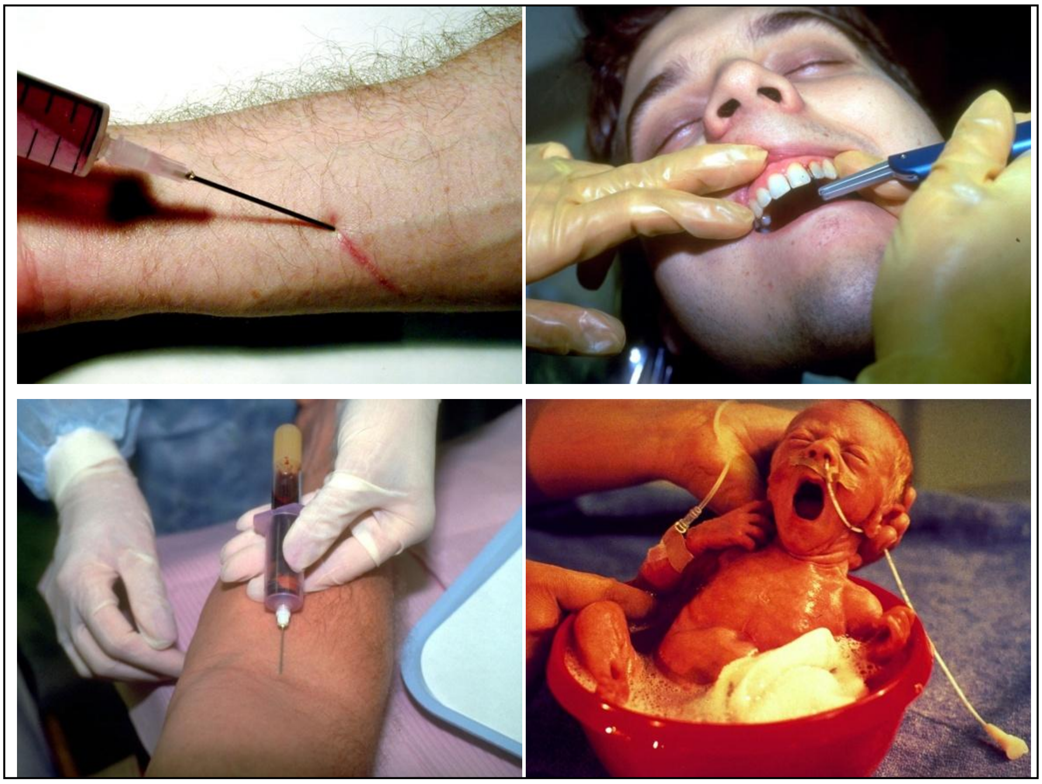


Figure 46. Examples of the selected IAPS pictures

Figure 47. Screen shots of the used movie scene

4.5 Procedure

The participants have been checked for a history of a traumatic experience of hospilization or diseases and for regularly viewing extremely violent movies of playing violent computer games. All participants were seated in front of a desk, in a lab room of Eindhoven University of Technology. The participants are told that we are going to evaluate several medical related negative affected pictures and a video clip on their psychological and physiological responses for a campaign to increase the awareness of human vulnerability in the medical health care and that they have to pay full attention the presented material, because there will be some questions about it in the end of the experiment.

In the introductory session participants started to read through and sign the informed consent form followed by the attachment of the physiological sensors, the signal quality was inspected visually and the physiological responses were measured continuously. Next, an aquatic video clip about underwater life (Hannan, 1992) was showed for 480 seconds to achieve baseline measures. After that, the State-Trait Anxiety Inventory (Spielberger, et al., 1970) was presented. The whole experiment was computerized, and instructions for each part were presented on the monitor. The participants were instructed to pay attention to the series of negative affected pictures and a video clip, because questions would be asked about the details of the showed material. Moreover, the participants were reminded that they can stop the experiment and/or the presentation of the pictures and video at any time, by clicking the “Stop” button in the screen. When the participants were ready, they could start with the slideshow of ten negative affective pictures from the IAPS (each picture is shown 6 seconds) and one video clip of around 300 seconds showing a scene of the commercial available movie “Awake” (Harold, 2007). Directly after this the state anxiety inventory was presented on the monitor and filled out. Next, questions about the environment (the lab room), lighting and the presented material were presented followed by the state anxiety inventory and the demographic questions (gender, age). After the experiment was completed the participants were detached from the equipment and were debriefed about the true purpose of the shown material and study. The participants were informed that they can contact our company counselor/psychologist Joke Fastenau-Barreveld if they feel any caused discomfort by this experiment afterwards. The participants were thanked for their participation in the end. All sessions of the experiment were different in lighting stimuli. The total duration of each experimental session including the instructions and the attachment and detachment from the physiological equipment took at max 60 minutes. The experimental session is showed in *Figure 48.*

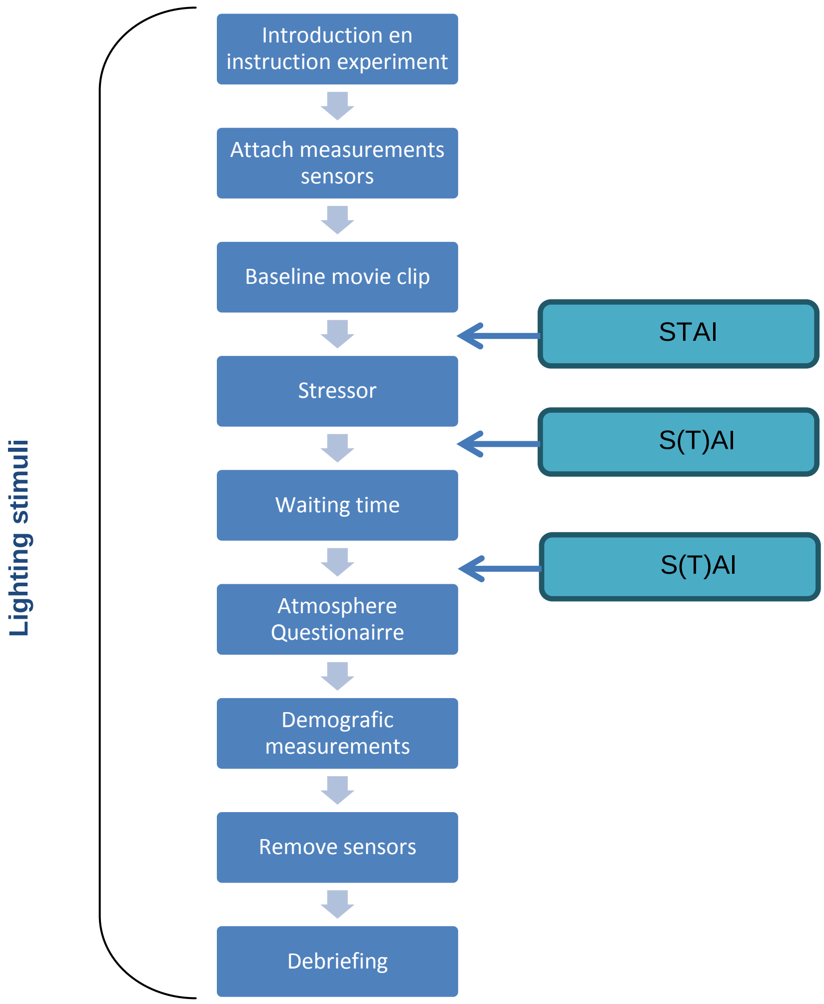


Figure 48: Overview of the experimental session

5 Precautions to prevent or lower hazards and risks

Several measures were used to lower or prevent certain risk of participants of feeling uncomfortable and unwell, these were:

- Informing persons about the content of the stressor before they register for the experiment;
- Asking participants about a history of traumatic experiences of hospilization or diseases, and excluding them from the experiment;
- Including a clickable stop button in the computerized experiment for participants to terminate the experiment once it gets too much.

6 The fainting of three participants

82 participants (48 male and 34 female) with ranging from the age of 18 to 59 years (*M*=28, *SD* = 11) were invited to watch the pre-selected visual material in one of the selected light settings in a lab. Three persons terminated (using the stop button) the experiment, because of the content of the stressor film clip. Furthermore, three male students with the age of around 20 years fainted during the most tensed part of the stressor movie clip. All three of them passed out while seated and remained seated for 10 to 20 seconds and slowly regained consciousness while looking dazed. None of them

was harmed or injured, and none of them could provide a cause of their fainting. All three of them said that they did not enjoy watching the stressor movie, but it certainly was not the first time they watched something like this and they did not think of the movie to be shocking.

The first person fainted on Friday the 26th of August during the experiment at TU/e was participant number 16, an 18 years old male student. When the signals were checked from the NeXus-10, his heart rate was slightly above average (between the 1.5 and 2 pulses per second). The participant was asked about how he felled, his health and whether he had to hurry. Everything was fine according to the participant, so the experiment continued. Everything went fine until the most tensing part of the stressor movie. I saw the participant hanging on the chair through the observation monitor. At that moment the experiment was stopped and I rushed into the lab to check the participant. The participant was checked for his breathing and his name was called to check for any responds. After about 20 seconds the participant was able to respond. After that I was getting some water for him and asked him what happened. He could not explain what happened and told me that it was the first time he experienced something like this. After he felled better, he stood up and left the lab. In the end I suggested him to visit a doctor to get a physical examination. Because I thought that this occurrence was coincidence, I decided to continue the experiment.

The experiments went fine until the last experimental day on Friday the 2nd of September. Two male participants, participant 75 of the age of 20 years and participant 78 of the age of 21 years, fainted in the same manner as described above. However, one of them mentioned that he had fainted before at the hairdresser, also without a clear explanation. All of them described that they felt totally fine before they fainted and that their vision suddenly went black before they passed out. In these three cases the experiment was stopped immediately and the participants were provided with the time they needed to recover while seated. The participants were emailed afterwards to check on their condition. They are all doing fine. Moreover, the supervisors at the TU/e plan to call or email these participants in the near future to check once again.

7 Recommendations

Due to the extensive preparation and the precautions taken, no one expected that participants would faint during this experiment. Luckily, no one panicked and none of the participants got injured. Nevertheless the experimenter should be better prepared to act upon in these situations, for example by explicitly informing him/her what to do if someone gets unwell. Moreover, clear information with emergency numbers and list of persons with first aid training should be provided nearby the TU/e laboratories. Since, the experiment was conducted at the TU/e, these matters will certainly be discussed and hopefully will lead to better preparations and protocols, when participants happen to faint.

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Appendix D. Semi structured interview

Pre-set lighting conditions

Open-ended questions after each setting

- Wat vindt u van de verlichting in de ruimte?
- Waar doet de verlichting u aan denken? Heeft u een bepaalde associaties bij?
- Waarvoor denkt u dat deze verlichting gebruikt kan worden?

User controlled preferred lighting setting

Nu kunt u zelf de amplitude en snelheid van de dynamische verlichting instellen. Hoe wilt u de verlichting ingestel hebben wanneer u een relaxte/activerende omgeving wilt creeren?

Final open-ended questions

Inleiden dynamische verlichting voorbeelden laten zien.

Open-ended questions in the end

- Zou u dynamische verlichting thuis willen?
- Waarvoor zou u de dynamische verlichting gebruiken?
- Wat vindt u van het idee van dynamische verlichting?
- Wat vindt uw van deze test?
- Wat er nog verbeterd kunnen worden aan deze test?
- Heeft u nog opmerkingen of suggesties?

Appendix E. Informed consent form (with cover up story)

Effect of negative affective pictures and video clips on psychological and physiological responses

I have been asked to participate in the data gathering user test researching psychological and physiological responses to negative affective pictures and video clips.

The purpose and objective of this investigation is to investigate the effect of negative affective pictures and video clip on psychological and physiological responses.

Volunteer

- ✓ I have read and understood the information mail about this research project and all my questions have been answered by the responsible researcher. The aim and the content of the experiment were explained to me explicitly.
- ✓ I had sufficient time to consider my participation in this project and I am fully aware that my participation in this project is voluntarily.
- ✓ I know that I can decide not to participate or stop my participation at any time without giving any reason for this decision.
- ✓ I understand and agree that personal data about me will be collected, encoded and then used and processed, either manually or by computer, by the responsible researcher and other parties that are involved in the research project.
- ✓ I know that my encoded personal data will be stored for at least 5 years.
- ✓ I know that I have the right to inspect the personal data that have been collected about me and the right to have errors corrected.
- ✓ I agree that an independent medical advisor will inform me about findings related to my medical condition if these are detected during the research project.
- ✓ I agree to participate as a volunteer in this research project.

______________________ ____________________ __________
Name Signature Date

Responsible researcher

- ✓ I have answered all questions about the research project and discussed the meaning and scope of this informed consent and signed it in the presence of the volunteer.

Sze Ho Wan______________ ____________________ __________
Name Signature Date