Color is not to be taken lightly
The difficulties of showing affective influences of colored light

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Master's Thesis

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Abstract

Nowadays, computing is becoming affective as well as ubiquitous, and might therefore be used to create smart environments. So far, it seems that combining affective and ubiquitous computing has not yet been done. One medium which might be of interest to be integrated in affective ubiquitous computing is colored light. However, the influence of colored light on affect needs to be clarified first. This thesis presents an experiment designed to address this issue. The effects of saturation, lightness, and hue on both subjective evaluations and psychophysiological measurements were investigated. Pictorial primes were used to associate color with an affective load. Results showed that priming had no effect on either the subjective evaluations or the psychophysiological measurements. Furthermore, the psychophysiological measurements were not severely affected by the colored lights: only skin conductance showed slight effects. On the other hand, subjective valence and arousal showed numerous effects of the colored lights. The question remains whether these latter effects are reflections of experienced feelings, or just assessments of based on personal experience without instantaneously experiencing these feelings.

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List of Abbreviations

Blue-set Set with the four blue light stimuli
Green-set Set with the four green light stimuli
OneHue-set Overall reference to the three sets with one hue
Red-set Set with the four red light stimuli
RG-set Set with the four red and four green light stimuli
RGB-set Set with the red and green low-lightness, and the blue high-lightness stimuli

BVP Blood Volume Pulse
COH Respiration-Heart Rate Coherence
HR Heart Rate
HRV Heart Rate Variability
IBI Inter-Beat Interval
LED Light-Emitting Diode
RD Respiration Depth
RR Respiration Rate
RSP Respiration
SC Skin Conductance
SCL Skin Conductance Level
SCR Skin Conductance Response
#SCR Number of Skin Conductance Responses per Minute
SEM Standard Error of the Mean
ST Skin Temperature
$\overline{x}$**ST** Skin Temperature Mean
∇**ST** Skin Temperature Slope

Chapter 1

Introduction

Imagine that you are trying to have an intimate dinner with your partner, while the romantic environment is missing. To create a more appropriate environment and strengthen the romance, you have to interrupt the dinner and keep your partner waiting. This may disturb your affective state and consequently have a negative influence on the dinner. Would it not be ideal when an intelligent system is able to change the environment based upon your affective state without you and your partner being interrupted?

Many other situations for which different kinds of environmental settings are appropriate can be thought of (e.g. relaxing in your living room or having a party). Not only can enhancing a (positive) affective experience be a function of such system. It can also be an option to implement functions that reduce the affective value of an experience. An example of a function could be to decrease ones activity level when one is stressed out.

To create such an intelligent system, variables have to be explored that can be used to adjust environments to (influence) our affective state. Color is a variable often thought to have an influence on ones affective state. As will be argued in section 3.2.2, there is little consensus about the influence of color on affect. This thesis will report on an experiment which has the goal to verify whether different characteristics of colored light can be used to influence both the emotional aspect of affect as reflected in psychophysiological measurements and the feeling aspect of affect as reflected by subjective evaluations (the terminology is explained in chapter 3).

Chapter 2 of this thesis introduces affective and ubiquitous computing, and addresses the relevance of this thesis for these two domains. Chapter 3 provides background information on affect and colored light. Thereafter, it discusses the relevant literature regarding the influence of colored light on affect. Chapter 4 provides an outline of the experiment.

Then, chapter 5 specifies the methodology of the conducted experiment. Chapter 6 and 7 describe the data preprocessing and the results of the experiment respectively. Finally, chapter 8 discusses the results, and the implications for affective and ubiquitous computing.

Chapter 2

General Background

This chapter will start with a section on affective computing, followed by a section on ubiquitous computing. Both sections will first give an introduction to the topic, followed by challenges and examples. A third section will discuss the possibilities of combining affective and ubiquitous computing, which has to my knowledge not been done before.

2.1 Affective Computing

Emotions are an important part of human life. They influence everyday tasks like communication and decision-making. *Affective computing* tries to use this human quality to enrich communication between humans and computers, and to enable computers to better serve people's needs (Picard, 2003). The idea is to give computers functions to recognize, model, adapt to, and influence human affect. You might say it tries to give computers emotional intelligence. The Affective Computing Group from MIT defined the term affective computing as follows[1]:

> "Affective computing is computing that relates to, arises from, or deliberately influences emotion or other affective phenomena."

The Microsoft Office Assistant *Clippit* (Figure 2.1) is a great example to illustrate why affective computing is important. This software agent is very intelligent when it comes to Office. However, people often find Clippit very annoying and stupid, which is in part caused by the lack of abilities to evaluate and respond to people's feelings. The agent has no idea what the user is feeling

Figure 2.1: Clippit.

[1] http://affect.media.mit.edu/

when trying to accomplish a job, and cannot react appropriately. Introducing functions to computers in order to recognize human affect and react sensibly will improve interaction between humans and computers. A more extended commentary on the lack of emotional intelligence in Clippit is given by Picard (2007).

It is also shown experimentally that affective computing is beneficial. Bickmore (2003) built a relational agent, that is, a conversational character designed to build and maintain long-term, social-emotional relationships with their users. This agent was tested against a control agent with friendly, conversational features but without the social-emotional skills. Even though the users had doubts about the social-emotional agent having feelings (which it actually had not), they scored this agent higher on likability, trust, respect, feeling it cared for them, and willingness to continue interacting with it compared to the control agent.

2.1.1 Challenges

The idea of computers that can serve us better is great, although there are still many challenges in realizing this. One challenge is correctly recognizing an affective state. This state is very variable, and often hard to describe. I find the weather metaphor of Kagan (1984) very clarifying when trying to describe an affective state:

> "The term *emotion* refers to relations among external incentives, thoughts, and changes in internal feelings, as *weather* is a superordinate term for the changing relations among wind velocity, humidity, temperature, barometric pressure, and form of precipitation. Occasionally, a unique combination of these meteorological qualities creates a storm, a tornado, a blizzard, or a hurricane – events that are analogous to the temporary but intense emotions of fear, joy, excitement, disgust, or anger. But wind, temperature, and humidity vary continually without producing such extreme combinations. Thus meteorologists do not ask what weather means, but determine the relations among the measurable qualities and later name whatever coherences they discover."

Like weather, affect can be described by continuous variables (e.g. activity level), but also by discrete categories (e.g. excitement). The extremes of affect are more easily recognizable and are often described by such discrete categories. For example, the frustrating feeling you have when losing hours of work on your computer because of a power failure. More subtle affective states, like those experienced during normal computer usage, are harder to describe, and perhaps continuous variables are more suitable in those cases. Describing an affective state is made even harder by the fact that people rarely describe experiencing an emotion without also experiencing a similar one (Watson & Clark, 1992). In the example above, the feeling of frustration will probably not be the only feeling experienced: anger and disappointment are affective states that also arise when losing hours of work.

Not only recognizing human affect is a challenge, correctly responding to affect is another serious problem. It is not always appropriate to respond to affect, sometimes we ignore it. For example, an irritated or frustrated person is sometimes better left alone, instead of trying to improve his/her affective state with well intentioned advice which probably makes it worse. How do we decide whether to ignore an affective state or to respond to it? Furthermore, in case a response is desirable, new questions arise on how to respond. What is suitable to the current situation? In any case, the response should appear natural and intuitive. But should the response be supportive, or is influencing of the emotion more appropriate? These questions are difficult to answer for many people, and for computers as well (Picard, 2007).

2.1.2 Example Applications

To give an even better idea of the affective computing domain, some examples of (research towards) applications are presented in this section.

Stress Reduction

Ferreira, Sanches, Höök, and Jaensson (2008) proposed an Affective Health system, which ought to enable users to balance their stress levels. Although the system has not been built (yet), the idea is to provide visualized real-time biofeedback on a mobile phone, which can be interpreted by the users.

Another example of affective computing on stress reduction is the Wigo prototype (Figure 2.2; Alonso, Keyson, & Hummels, 2008). This is a tangible interface to interpret and reduce stress in the office work context. The prototype contains a button that can be rolled from side to side by the thumb (wiggled). The movement frequency, speed, distance, and duration are used to detect stress. When the movement becomes stressful, stress reduction is obtained by forcing the user to slow down by increasing the friction on the rotation.

Figure 2.2: Wigo.

Music

The idea of an affective music player is to create a music player that selects music to influence affect towards a goal state. Characteristics of real world music were investigated by van der Zwaag, Westerink, and van den Broek (in press). Results showed that tempo, mode, and percussiveness modulate affect. Further, an affective music player working in real-time was designed and tested by Janssen, van den Broek, and Westerink (in press).

Learning

Robison, McQuiggan, and Lester (in press) evaluated the consequences of affective feedback in interacting with a virtual agent in a learning environment. The learning environment Crystal Island was used, where users study microbiology and genetics in a narrative context. Users could interact with a pedagogical agent, which provided affective feedback. The research showed that to actually design an affective support system to facilitate learning more effectively, more research is needed to determine how users will react on the feedback.

Art

Mood Swings is an affective interactive art system, which interprets and visualizes affect expressed by a person (Figure 2.3; Bialoskorski, Westerink, & van den Broek, 2009). The system consists of eight luminous orbs that are moved by the user when interacting with the system. These movements contain characteristics that can be used to identify a users affective state. Based on the recognized affective state, Mood Swings displays a color that matches the affective state.

Figure 2.3: A person interacting with Mood Swings.

In short, affective computing focuses on creating systems that are able to correctly handle human affect. This research domain is important as it improves the interaction between humans and computers. Although work has been done in this field (see the examples above), challenges, such as correctly recognizing and responding to affect, still exist.

2.2 Ubiquitous Computing

Affective computing can be used in combination with *ubiquitous computing*. This latter term refers to the idea that intelligent systems are (invisibly) embedded into the world around us. Currently, computing is moving from the Desktop PC to the world around us. Digital devices are placed in physical objects, like mobile phones, wearables, homes, offices, and cars. The goal is to create a world were computers are used without noticing them because they are so embedded, natural, and fitting. Mark Weiser, the founder of ubiquitous computing, stated it as:

> "a new way of thinking about computers, one that takes into account the human world and allows the computers themselves to vanish into the background" (Weiser, 1991).

The concept of ubiquitous computing is (almost) synonymously used to the concept *ambient intelligence*. This term refers to creating electronic environments where the user is central. The systems in that environment should have five characteristics (Aarts & Marzano, 2003), which show great resemblance with the idea of ubiquitous computing. Systems should be embedded (i.e. integrated into many physical objects), context-aware (i.e. able to recognize you and your situational context), personalized (i.e. towards your needs), adaptive (i.e. change in response to you), and anticipatory (i.e. anticipate your desires without conscious mediation).

2.2.1 Challenges

As in affective computing, there are also many challenges in ubiquitous computing. To limit the challenges discussed here, I will focus on the challenges found essential to ubiquitous computing by da Costa, Yamin, and Geyer (2008).

A first challenge is *heterogeneity* of the various embedded systems. These systems will differ in computing and communication (e.g. different user interaction methods, screen resolutions, processing capabilities). Ubiquitous computing should be able to manage the required conversions to overcome these differences (Niemelä & Latvakoski, 2004; Saha & Mukherjee, 2003).

Scalability is another challenge: in the future, countless users will be interacting with ubiquitous systems. Moreover, the number of applications and devices interconnected will grow to a scale never experienced before. Consequently, it will become unmanageable to explicitly create new applications for each device (Niemelä & Latvakoski, 2004; Saha & Mukherjee, 2003; Satyanarayanan, 2001).

The following challenge for ubiquitous computing is *dependability and security*. Failures above an acceptable threshold of frequency and/or severity should be avoided. To achieve this, reliability, availability, and safety of the systems need to be maximized (P. Robinson, Vogt, & Wagealla, 2005).

Privacy and trust are a next challenge. As the scale of computing grows, the amount of information gathered will grow as well (users movements, behavior patterns and habits will be monitored). This will increase the importance to protect personal data against abuse (e.g. spam or black mail). Knowledge about potential bad use might discourage users from using ubiquitous computing. Therefore, a user must be able to trust the computing systems. Moreover, the system needs to know which users to trust and to what degree before responding to requests (P. Robinson et al., 2005; Satyanarayanan, 2001).

Further, *spontaneous interoperation* forms a challenge. When the context of one component changes, all components interacting with the former component need to adjust to those changes. So, components from several devices change constantly according to the circumstances when communicating with other components. To accomplish spontaneous interoperation, components need the ability to change other components without the need of new software or parameters (Niemelä & Latvakoski, 2004; Kindberg & Fox, 2002).

Mobility is another challenge for ubiquitous computing. Users are mobile, and change their position frequently. In a true ubiquitous environment, they should have access to data and applications at any place. Therefore, data and applications should be able to move from one device to another (da Costa et al., 2008).

Context is an important aspect of ubiquitous computing, and also a challenge. The ubiquitous system should perceive the users state and surroundings in order to adjust its actions based on this information. The relationship between computation and the context in which it is embedded needs to be understood (Dourish, 2004). Implementing context-awareness causes complications, like location monitoring, uncertainty modeling, real-time information processing, and merging data from multiple (and disagreeing) sensors. Furthermore, it is important that the context information is accurate, otherwise, the user can experience confusion or intrusion (Saha & Mukherjee, 2003; Satyanarayanan, 2001).

The next challenge is *transparent user interaction.* Interfaces need to be designed that are completely integrated in the environment. Users should be able to interact via these interface intuitively and without any effort, in order to enable them to focus on a task. Instead of continuing the WIMP (window, icon, menu, pointing device) paradigm, interactions should become more like the natural interactions between humans and the physical world. (Yue, Wang, & Wang, 2007).

The final challenge to discuss here is *invisibility.* A main idea of ubiquitous computing is to embed systems into the environment, and make them disappear in the background. This aim can be approximated by reducing the user distraction or intervention to a minimum. The ubiquitous systems should continuously meet the user expectations, so that the user can interact with the system at a very low conscious level (Saha & Mukherjee, 2003; Satyanarayanan, 2001).

2.2.2 Example Applications

Some examples are discussed in this section in order to give a better idea of ubiquitous computing.

iCat

A user-interface robot that can make life easier is the iCat (Figure 2.4; van Breemen et al., 2006). This interactive cat is a domestic companion built to investigate social interaction aspects between users and the iCat. It can generate many different facial expressions, like happy, surprised, angry, sad. Moreover, it has many functions, for example, recognizing objects and faces, performing speech recognition, play sounds and speech, control domestic devices (like lamps, DVD recorder, TV), and obtain information from the Internet. Because of this large range of functions it can be used for various research programs (e.g. game buddy, care of elderly, and truck driver companion).

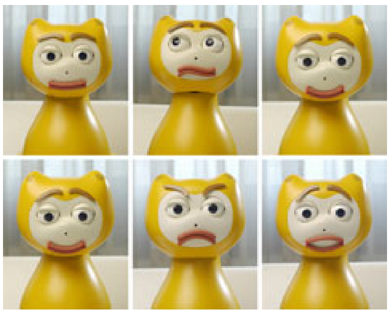

Figure 2.4: Six different facial expressions of the iCat.

SmartBed

Taking care of people while they are asleep, is the basic idea of SmartBed (Brauers, Aubert, Douglas, & Johnen, 2006). The project tries to create a bed that can monitor vital health-care and wellbeing functionalities to help people stay fit, but also in order to increase the quality of life for people with a heart disease. When the user goes to sleep, several parameters are measured automatically. Based on the gathered information, feedback can be provided to try to optimize the quality of sleep and facilitate personal sleep management. Other features are also possible that can be used to great advantage. For example, presence detection in bed can be used to control floor lighting that guides the user when (s)he gets up in the night.

Briefly, ubiquitous computing refers to the embedding of systems into the environment, such that we interact with these systems naturally and unnoticed. Also in this research domain work has been done and challenges exist.

2.3 Combining Affective and Ubiquitous Computing

Both affective and ubiquitous computing can be applied in a domestic environment. Combining these two types of computing seems logical, because it leads to embedded systems that are user oriented (i.e. context-aware) and adaptive, but also social and user friendly. The iCat would have been a nice example if it would be able to recognize human affect and act in an appropriate way. However, it cannot recognize human affect, and, surprisingly, there are currently no known systems that make use of both affective and ubiquitous computing. In affective computing mostly isolated systems are created, while in ubiquitous computing systems are embedded in the environment without functions to use affect.

The domestic environment is an interesting place to start investigating the possibilities to combine ubiquitous and affective computing. For ubiquitous computing the domestic environment is already a major research focus (Brush & Inkpen, 2007). Advancing the development of devices for the domestic environment requires a better understanding of how computing is used at home. Although, the home computer started as an extension of work places, nowadays it is more about relaxing and leisure. Besides the time saving activities, like paying bills or washing dishes/clothes, computing is more and more becoming time using with activities as game playing and entertainment. So, computing at home is pleasurable and playful, but it can be useful as well (Howard, Kjeldskov, & Skov, 2007).

Adding the possibilities of affective computing will create a more intense experience of both time using and time saving activities.

One way to introduce the influencing part of affective computing to a ubiquitous domestic environment is by usage of colored light. Lights are already present in each home. Therefore, colored light is an adequate option. To my knowledge no work has been done on this precise topic. Nevertheless, the possibilities of colored light can be illustrated by some example settings. One example was already given at the beginning of chapter 1: a romantic dinner (or more general a romantic evening) where the surrounding settings in the dining room (or any other room) are adjusted to the users affect. Colored lights can be used to enhance the romance. Another example is a user that is stressed out. By adjusting the environmental light settings, a more relaxed affective state may be obtained. Furthermore, this adaptation of the light settings can be usable feedback for the user indicating that (s)he is too stressed. This kind of stress reduction is not limited to the domestic environment. It can, for example, also be applied in office environments.

To be able to use colored light in an affective and ubiquitous (domestic) environment, the precise effects of colored light on affect need to be known. The experiment conducted here exactly addresses this topic.

Chapter 3

Background of the Experiment

This chapter will provide background information regarding the conducted experiment. It will start with information on affect (definitions, and how to label and measure affect). Thereafter, the characteristics of color will be provided and related literature regarding the influence of color on affect will be discussed.

3.1 Affect

Although emotion is a key part of affective computing, the term is rather ambiguous: there is no consensus about the definition of emotion and it is often mixed up with the terms affect, mood, and feeling. As evidence is growing that distinct neuronal systems mediate emotion and feeling, it seems that these two terms represent separate mechanisms (Dolan, 2002). Therefore, both mechanisms will be addressed in this study, and to prevent any confusion the following definitions will be used.

Emotion is the automatic psychophysiological and behavioral response to an event. Note that this definition differs from its common sense meaning.

Feeling is the subjective counterpart of an emotion.

Affect is the combinations of emotions and feelings.

Mood is a relatively stable, longer-term affective state, and not necessarily tied to specific objects or elicitors. The precise duration of mood is not defined in literature.

3.1.1 Labeling Affect

Different approaches exist on how to label affect. As explained in section 2.1.1 by using a weather metaphor, affect can be described by discrete labels as well as continuous dimensions.

A well-known example of labeling affect with discrete categories is the basic emotions defined by Ekman (1971). Initially, he defined six basic emotions (anger, disgust, fear, happiness, sadness, and surprise). Based on facial expression research, this list is extended to about 15 emotions (Ekman, 1999). In his view, other more complex emotions can be formed by modifying or combining the basic emotions.

Besides the discrete categories, affect can also be labeled by continuous dimensional scales. Some researchers believe that two dimensions suffice to do this. Different terms are used to name these two dimensions, for example, valence and arousal (Russell, 1980; Osgood, Suci, & Tannenbaum, 1957), positive and negative activation (Watson, Wiese, Vaidya, & Tellegen, 1999), tension and energy (Thayer, 1989). Others argue that three dimensions are needed, for instance, valence, arousal, and dominance (Bradley & Lang, 1994), valence, arousal, and dominance-submissiveness (Mehrabian & Russell, 1974), or evaluation, potency, and activity (Osgood, 1969).

In this study, I will use the circumplex model of affect of Russell (1980), which consists of two continuous dimensions (Figure 3.1). According to Posner, Russell, and Peterson (2005) and Posner et al. (2009), all single affective states can be described by combining the valence and arousal dimensions. Fear, for example, is a combination of negative valence and heightened arousal. Other affective states beside fear can also be described by a negative valence and a high arousal (e.g. anger). Nevertheless, the exact place on the continuous scales of these comparable emotions will differ. The definitions of the two dimensions are as follows.

Valence indicates the attractiveness (positive valence) or aversiveness (negative valence) of an event, object, or situation. This dimension ranges from highly unpleasant or negative experiences (e.g. anger) to highly pleasurable or positive experiences (e.g. joy).

Arousal is the (psychophysiological) excitement that comes with the affective experience. This dimension ranges from a very calm or relaxed state to a very excited or activated state.

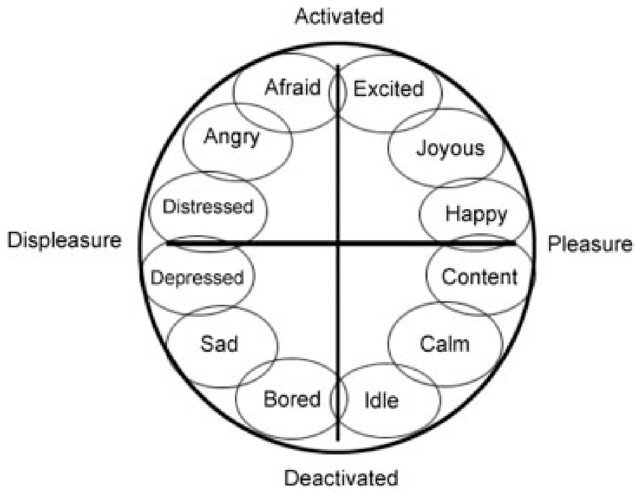

Figure 3.1: A graphical representation of the circumplex model of affect taken from Posner, et al., 2009. The horizontal axis represents the valence dimension, and the vertical axis the arousal dimension. The discreet categories of affect expressed in this model are examples that belong to a quadrant. Furthermore, the circles indicate that the affective states are ambiguous and overlapping categories.

3.1.2 Measuring Affect

Different manners exist to measure ones affective state. To capture the emotion aspect of affect, psychophysiological measurements can be used. Most psychophysiological measures originate in the autonomic nervous system. Commonly used measures of peripheral psychophysiology are based on electrodermal (skin conductance), cardiovascular (heart rate and heart rate variability), and respiratory activity (Boiten, Frijda, & Wientjes, 1994; Larsen & Fredrickson, 1999; Mauss & Robinson, 2009).

Skin conductance (SC) is a typical means of electrodermal activity to assess the arousal caused by a stimulus. Two electrodes are placed on participants fingers, which send a mild electrical current through the skin. The SC reflects changes in electrical conductivity of the skin as a result of activity of the sweat gland (Dawson, Schell, & Filion, 2000). It has been found that SC increases linearly as ratings of arousal increase (Bradley, Codispoti, Cuthbert, & Lang, 2001; Christie & Friedman, 2004; Gomez, Stahel, & Danuser, 2004; Lang, Greenwald, Bradley, & Hamm, 1993).

Other psychophysiological measures for emotion are based on cardiovascular activity. The heart is controlled by both the sympathetic and the parasympathetic branch of the autonomic nervous system. Therefore, changes in the cardiovascular system can be caused by co-activity or independent activity of either branches. Low-intensity stimuli are thought to be mainly mediated by the parasympathetic branch and associated with heart rate (HR) deceleration, while intense stimuli are thought to be mediated by the sympathetic branch and associated with HR acceleration. Consequently, HR acceleration is associated with aversive, unpleasant events, and HR deceleration with pleasant events (Bradley & Lang, 2007). Heart rate variability (HRV) is usually seen as an index of parasympathetic activity (Berntson, Quigley, & Lozano, 2007). HRV is suggested to reflect valence, such that a more negative valence is accompanied by a lower HRV as compared to a more positive valence (Appelhans & Luecken, 2006; van den Broek, Schut, Westerink, & Tuinenbreijer, 2009).

Respiratory activity (RSP) is commonly measured by use of the parameters respiration rate (RR) and depth (RD). RR indicates the number of breaths (respiratory cycles) one takes in a minute, while RD is the volume of air that is inspired or expired during one respiratory cycle. It seems that respiratory changes correspond to level of activation (i.e. arousal; Boiten et al., 1994; Boiten, 1998): an increase of RR and RD indicates excitement (i.e. high arousal), while a decrease of these measures indicates calmness or passiveness (i.e. low arousal).

Skin temperature (ST) is a measure sometimes also taken into account when measuring emotion. Baumgartner, Esslen, and Jäncke (2006) found a decrease of ST for the emotion fear (negative) compared to happiness (positive). This is in line with Krumhansl (1997), who found that happy music increases ST, while sad and fearful music decreases ST. Further, McFarland (1985) found that arousing and negative music decreases ST, and calm and positive music increases ST. A study with contradicting results is that of Lundqvist, Carlsson, Hilmersson, and Juslin (2009). Happy music was found to decrease ST, while sad music increases ST. These authors also took arousal into consideration, and suggested that perhaps this factor influences ST: low arousal causes an increase, and high arousal a decrease of ST. This idea is compatible with the results of McFarland (1985).

To capture the feeling aspect of affect, self-reports of subjective experiences are often provided by the use of questionnaires. A commonly used questionnaire is the Self-Assessment Manikin developed by Lang (1995). This questionnaire consists of three pictorial scales on which participants can evaluate their valence, arousal, and dominance levels. Another possibility is the usage of open questions about people's feelings (e.g. how do/did you feel?).

Using a combination of both subjective evaluations and various (more objective) psychophysiological measures has the advantage of capturing both the feeling and emotion aspect of affect. Therefore, both questionnaires and psychophysiological measurements will be used in this study.

3.2 Color

3.2.1 Color Characteristics

Color is often thought to have an influence on affect. During the last century, multiple experiments have been conducted to address the effect of color on affect. When using color in experimental research, it is important to control all characteristics of color properly. The characteristics of colored light are hue, saturation, and lightness, which are graphically represented in Figure 3.2 and defined as follows.

Hue denotes the color most clearly corresponding to the wavelength of the (reflected) light. It ranges from 0° to 360°.

Saturation indicates the colorfulness, that is how pure a color is. A colored light that is very pure, has little gray in it.

Lightness indicates the level of illumination, and ranges from no (reflected) light to full illumination (i.e. from 0% which appears black to 100% which appears white).

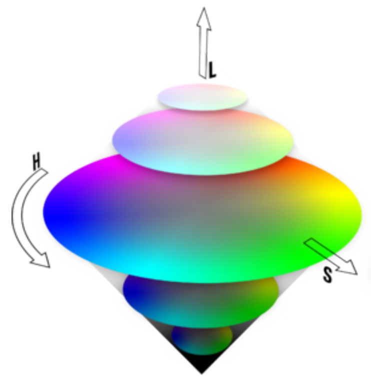

Figure 3.2: A graphical representation of the color characteristics hue, saturation, and lightness.

3.2.2 Influence of Color on Affect

Some research on the influence of color on affect has been done. The focus has been mainly on the arousal dimension of affect, but a few studies also addressed the valence dimension.

Arousal

Hue In earlier days, Gerard (1958) and Wilson (1966) investigated the relation between color and arousal using several psychophysiological measurements. Gerard (1958) found that color causes changes in systolic blood pressure, SC, RSP, eye blink frequency, and subjective measurements, and concluded from these findings that red light is more arousing, while blue light is more calming. Wilson (1966) reported that red cards induced higher arousal than green cards based on SC.

Since the publications of Gerard (1958) and Wilson (1966), several studies on the effect of color on arousal, both psychophysiological and subjective, have been performed. The results are ambiguous. On the one hand, more results have been found indicating that red is the most arousing color: Yoto, Katsuura, Iwanaga, and Shimomura (2007) found red to be more exciting than blue and green on subjective evaluations of colored papers. Further, Jacobs and Hustmyer (1974) presented color plates to participants and concluded on the basis of increases in SC that red causes more arousal than yellow and blue. The HR and EEG results of Küller, Mikellides, and Janssens (2009) indicated that a red painted room is more exciting than a blue painted room.

On the other hand, Valdez and Mehrabian (1994) used colored cards and found on the arousal component of the PAD questionnaire that yellowish green is the most arousing color, followed by bluish green, and that red is the least arousing. Yoto et al. (2007) found blue papers to be more arousing than red papers using EEG[1]. The theory that blue is more arousing than red is strengthened by the finding that blue light increases melatonin suppression more than red light (Thapan, Arendt, & Skene, 2001). This indicates that blue is more activating, as a melatonin increase causes sleepiness.

Alongside, there are also findings that hue effects on arousal are not constant. Yoto et al. (2007) found effects on subjective evaluations and EEG, but no effects on blood pressure. Furthermore, while effects were found on SC by Jacobs and Hustmyer (1974), they found no effects on HR and RSP. Although, Küller et al. (2009) found differences on HR and EEG, unexpectedly none were found on subjective evaluations. Also, Suk (2006) found no effects on subjective evaluations using both digital and surface colors. In addition, Mikellides (1990) found no effects on EEG, SC, and pulse rate using red and blue painted walls. Finally, Gerard (1958) found effects on numerous measurements, but in contrast he found nothing on HR.

Saturation and Lightness A closer look at the experimental procedures of the earlier experiments on arousal shows that the light and color characteristics saturation and/or lightness might not have been controlled for well in these earlier studies. For example, in the experiment of Wilson (1966), 18 of the 20 participants stated that the green card was lighter than the red one, suggesting that the colors were not matched for lightness and/or saturation. Further, Jacobs and Hustmyer (1974) reported that the most saturated color available was

[1] Note the contradiction that Yoto et al. (2007) found red to be more exciting than blue and green on subjective evaluations, while the authors also found blue to be more arousing than red using EEG.

chosen from a database, which of course does not mean that the saturation is equal in all colors. As a consequence, differences in the effects found in some of the earlier experiments might be caused by saturation, lightness, or interactions between hue, saturation, and lightness. An idea also opted by Kaiser (1984), Mikellides (1990), and W. Robinson (2004).

The influence of saturation and lightness on affect was addressed in the study of Suk (2006) by means of a questionnaire. The results showed that higher saturation resulted in higher arousal ratings. Further, both high and low lightness caused lower subjective ratings of arousal than medium lightness levels (i.e. an inverted U-shape). Furthermore, Valdez and Mehrabian (1994) also investigated affective responses to hue, saturation, and lightness. They found that higher arousal is caused by colors with less lightness and more saturation. Moreover, it has been found by using measures like melatonin secretion, body temperature, subjective sleepiness, and EEG that bright light causes more alertness, while dim light causes more sleepiness (Cajochen, 2007; Kubota et al., 2002).

In conclusion, because the existing studies regarding hue are ambiguous, and those regarding saturation and lightness are limited, more and properly controlled research on influences of colored light on arousal is needed.

Valence

Hue A small number of the earlier experiments addressed the valence of hue via subjective evaluations. Both Gerard (1958) and Suk (2006) reported that participants experience blue as more positive than red. Valdez and Mehrabian (1994) also addressed the pleasantness of colors. They found that short wavelength hues (blue and green) are the most pleasant colors, long wavelength hues (yellow-red and red) are a bit less pleasant, and medium wavelength hues (yellow and green-yellow) are the least pleasant colors. Finally, no differences between colors with respect to valence were found in the experiment of Küller et al. (2009). In general, the color blue seems to be judged more positively than red.

Saturation and Lightness Suk (2006) and Valdez and Mehrabian (1994) also addressed the saturation and lightness effects on valence. The former found higher subjective ratings of valence with higher saturation, and lower ratings for high and low lightness compared to medium lightness. The latter found that light and saturated colors are more pleasant. Furthermore, a preference of high lightness over low lightness was found in subjective impressions of comfort, spaciousness, brightness, and saturation evaluation by Manav (2007).

Chapter 4

Experiment

This chapter defines the research question. Thereafter, it describes the experimental design. Finally, the chapter provides predictions on the outcome of the experiment.

4.1 Research Question

As shown in the previous chapter, there is little consensus about the influence of color on affect. However, to enable the use of colored light in a domestic ubiquitous environment to influence affect, the effects of colored light on human affect have to be clarified. An experiment was conducted in order to address this disagreement. The goal of the experiment was to verify whether different characteristics of colored light (saturation, lightness, and hue) can be used to influence a person's affective state. Moreover, the research question of this experiment was defined as *What is the influence of different characteristics of colored light on affect?*

4.2 Experimental Design

As affect consists of two aspects (feeling and emotion), the influence on both aspects was assessed. To find the effect of colored light on the emotional aspects of affect several psychophysiological measures were recorded. To be precise, skin conductance (SC), respiration (RSP), skin temperature (ST), and blood volume pulse (BVP; from which heart rate (HR) and heart rate variability (HRV) were extracted) were measured.

Besides these psychophysiological measurements, the subjective evaluations of the colored light stimuli were gathered by means of a questionnaire in order to address the feeling aspect of affect. As discussed in the previous chapter, most of the earlier studies investigated the effect of color on arousal only. However, an increased arousal, for instance, is not necessarily a positive feeling, but can be an indication of anger, fear, and annoyance as well. On the one hand, the color red, for example, often denotes danger, and therefore negativity. On the other hand, it can also be associated with romance and love, and thus positivity. Both can trigger an increase in arousal. Consequently, not only arousal, but also the attractiveness or aversiveness (i.e. valence) of a color should be investigated to be able to interpret how a particular color influences a person's affective state. Therefore, two questions of the questionnaire on the feelings caused by the colored lights were based on the circumplex model of affect (Russell, 1980) which comprises both the arousal and valence dimensions. Also, a third question on preference was added to the questionnaire to address the opinion about the colored lights regardless of the feelings that the lights evoked.

Furthermore, a color can trigger associations which can differ from person to person and from time to time. These associations may explain why people respond differently to various colors at different occasions. Someone can, for instance, respond positively arousing to red based on an association with romance, while at another time this same person can respond negatively arousing to the same red as result of an association with blood, injuries, and trauma. Disregarding these associations in an experimental design might result in an absence of effects due to distributed associations. In other words, arousal can be triggered by both positive and negative associations, which can average the effects on arousal to zero. In order to investigate whether this is the case participants were primed with affectively loaded pictures to address associations triggered by colors. Priming is the phenomenon that an earlier stimulus (i.e. the prime) often implicitly influences the response to a later stimulus (i.e. the target; Anderson, 1999). Specifically, associative priming was used, where the prime is assumed to make associated information more available. For example, participants who view negatively arousing blue pictures are expected to show negative arousal when watching blue light.

Pictures were chosen as primes because pictures have been found to be affectively evocative in various experiments. Cuthbert, Schupp, Bradley, Birbaumer, and Lang (2000), for example, showed that emotionally arousing pictures create a pronounced late positive brain potential that is greatly reduced or absent for non-affective pictures. Moreover, the potential is more enhanced for pictures that are more emotionally intense. Further, the eye blink response is modulated by the picture valence, as shown by Bradley, Lang, and Cuthbert (1993) and Dichter, Tomarken, and Baucom (2002). In addition, RSP effects have been found due to viewing affective pictures (Gomez et al., 2004). Besides the effects on psychophysiological measurements, pictures were found to differ on the valence and arousal scales (Lang et al., 1993). To measure the affective load of the primes, participants had to fill in an additional questionnaire regarding the subjective valence and arousal of the pictures.

4.3 Predictions

It is expected that if hue, saturation, lightness, and priming have an influence on affect, this will be shown in both the psychophysiological measurements and the subjective evaluations. Based on the related literature, it was further anticipated that saturated colored lights will be more arousing and perceived as more positive than desaturated colored lights. In addition, an increase in lightness was expected to cause an increase of arousal. Because the claimed effects of hue may be caused by associations, it was expected that the priming of pictures will elicit the same effects earlier attributed to hue. Finally, with respect to the psychophysiological measurements, the expectation was that changes in SC and RSP reflect variations in arousal, while valence changes are expected to be projected on HRV.

Chapter 5

Methodology

In this chapter the methodology of the conducted experiment will be described. It will start with a description of the participant characteristics, followed by details about the picture and colored light stimuli. Thereafter, the subjective and psychophysiological measurements are addressed. Then, the experimental procedure will be provided and finally the statistical analysis is described.

5.1 Participants

None of the 40 participants of the experiment had participated in previous light experiments performed at Philips Research. They all had normal or corrected-to-normal vision, and did not show any form of color blindness. The participants were between 21 and 51 years old (mean = 25.5, SD = 4.94), 18 were female and 22 male.

5.2 Materials

5.2.1 Picture Stimuli

Pictures were used to prime an association between color and affective load. The pictures had one dominant color that stood out (red, green, blue, or white). For each dominant color four pictures were selected (in total 16 pictures), which could be further divided into two affective picture loads. The affective load of these pictures was determined in a pilot study in which participants had to rank a large number of pictures per color. The two most positively calming and negatively arousing pictures were selected for this study. Also selecting positively arousing and negatively calming pictures with one dominant color appeared unachievable. A description of each picture is given in Table 5.1, while the picture pairs themselves can be found in Appendix D.

Each participant saw half of the picture pairs (two positively calming and two negatively arousing pairs). Only one pair of each dominant color was present to a participant according to a fully balanced design.

White pictures were used, even though there were no matching colored white light stimuli. The reason to use white pictures is to keep the balance between the amount of negatively arousing and positively calming pictures per participant constant. If only red, green, and blue pictures would have been used, there would have been 2 negatively arousing and 4 positively calming pictures (or vice versa) presented to a participant. This might have resulted in a bias towards the affective load most represented by the pictures.

Table 5.1: A description of the picture pairs used in the experiment split to the dominant colors and affective load.

Dominant Color	Positively Calming Affective Load	Negatively Arousing Affective Load
Red	lots of strawberries a red rose	red ants consuming a larva 2 animals in front of a forest fire
Green	a butterfly 4-leaf clovers	a snake eating a mouse a green spider
Blue	a blue sky jumping dolphins	a shark a destructed town
White	a little polar bear an excited woman	a skull an angry white tiger

5.2.2 Colored Light Stimuli

For the experimental color conditions, light-emitting diode (LED) wall washers were located on the floor such that their light output fully covered the wall with a color. The five wall washers of each 48 LUXEON Rebel DS65 LEDs (16 for each RGB-color) could be managed separately.

The colored light outputs of the wall washers were matched as closely as possible by means of 1976 CIELAB coordinates (L^*, a^*, and b^*) with a reference color temperature of 4300K and a reference luminance of 500 cd/m^2 measured with a PR-680 SpectraDuo Photometer (Photo Research, Inc). Lightness, saturation, and hue were carefully controlled in order to allow comparisons of the effects of different colored light stimuli. For an overview and the details of the colored light stimuli see Table 5.2. Lightness could be directly read from the photometer (L^* of the 1976 CIELAB coordinates), while saturation and hue had to be calculated:

$$Saturation = \frac{\sqrt{(a^*)^2 + (b^*)^2}}{L^*}$$

$$Hue = tan^{-1}(\frac{b^*}{a^*})$$

Table 5.2: Details of the wall washer settings measured with all wall washers on simultaneously.

Lightness	Color	Saturated			Desaturated		
		Lightness	Saturation	Hue	Lightness	Saturation	Hue
High	Red	81.4%	2.32	46°	80.7%	0.79	354°
	Green	81.3%	2.15	154°	81.1%	0.79	169°
	Blue	62.0%	2.36	277°	62.3%	0.77	263°
Low	Red	62.5%	2.40	45°	63.0%	0.75	360°
	Green	63.2%	2.24	154°	63.5%	0.76	172°
	Blue	54.3%	2.22	273°	54.4%	0.77	261°

Due to technical limitations of the wall washers, it was not possible to define red, green and blue colored light stimuli with equal lightness according to a fully balanced design. Not only was the maximal lightness of the blue LEDs lower than those of red and green lights, but also the minimal levels of lightness varied over the three colors. As a consequence, it was not possible to reduce the green and red maximal lightness levels to that of blue light, because in that case, the minimal lightness levels of the red and green LEDs are too high to generate the desired desaturated low-lightness blue light stimulus. In order to deal with this problem, the experimental design has been chosen in such a way that the high-lightness levels of the blue light stimulus matches the low-lightness levels of the red and green light stimuli. In this way, the hue effect of the three colors can be obtained by comparing the data of the blue high-lightness stimuli with the data of the red and green low-lightness stimuli (Figure 5.1).

A neutral light setting was created by illuminating the room with six fluorescent light units integrated in the ceiling (4300K, 500 cd/m^2).

5.3 Measurements

5.3.1 Subjective Evaluations

Questionnaires were used to gather several subjective evaluations. The first questionnaire was designed to evaluate the colored lights and will be referred to as Light Stimuli Questionnaire. It contained an open question on associations, and three pictorial five-point scales. Two of these scales were taken from the validated Self-Assessment-Manikin scales (Lang, 1995) to assess the dimensions arousal and valence. The third scale was created for this study by Roos Rajae-Joordens to assess the dimension preference. Appendix B presents the instructions of Light Stimuli Questionnaire and the questions for one colored light stimulus as an example.

The second questionnaire was designed to gather the subjective ratings of the pictures and is from now on referred to as Picture Load Questionnaire. The pictures were judged on the dimensions arousal and valence with the same pictorial scales as used for the colored lights. Furthermore, the questionnaire contained an open question on the participants thoughts when they first saw the pictures. The instructions of the Picture Load Questionnaire and an example of the questions for one picture stimulus can be found in Appendix C.

All pictorial scales of both questionnaires range from 1 to 5. A score of 1 on the valence, arousal, or preference scale represents, respectively, the most negative, the most calming, or the least preferred rating. Moreover, a score of 3 indicates a neutral subjective evaluation. Finally, a score of 5 represents the most positive, most arousing/activating, or most preferred score on the valence, arousal, or preference scale.

5.3.2 Psychophysiological Measurements

In order to gather several psychophysiological measurements, sensors (NeXus-10, Mind Media BV, the Netherlands) were attached to the participant's body. Two of them were active electrodes, placed on the left index finger and left ring finger to measure SC. The RSP sensor was put around the chest (over the clothes), the BVP sensor was clipped on the middle finger, and the ST sensor taped to the left little finger. All psychophysiological data were stored with BioTrace+ Software version 2008a (Mind Media BV, the Netherlands).

5.4 Experimental Procedure

The experiment was conducted in a room with no incoming daylight and white painted walls and ceiling. A LCD-Wide screen Pixel Plus TV (type 30PF9975) was placed in the room, such that it was out of view when facing the wall on which the lights were projected.

Participants were initially seated at an approximately two meter distance from the television. After filling out a consent form (Appendix A), the sensors were attached and a short oral instruction was given. Next, the BioTrace+ Software (Mind Media BV, the Netherlands) was started and the pictures were shown via a slide show on the television. Each picture was presented for 10 seconds, and the sequence in which the pictures were presented, was repeated twice. Subsequently, the participant was moved, which resulted in him/her facing a white wall at a distance of approximately 3.5 meters. The television was turned off, and the experimenter left the room to prevent any influence on the psychophysiological measurements. The script to manage the lights was started remotely, and simultaneously a marker was placed with BioTrace+ in the psychophysiological signal. Presentation of the light settings started with a three minute neutral light setting to measure a baseline reference. Thereafter, the neutral setting was turned off and each experimental colored light setting was presented for 60 seconds. Between two colored light settings the neutral setting was turned on for 60 seconds. At the end of the light settings sequence the psychophysiological measurements were stopped, and the sensors were removed. Participants were asked to fill in the two questionnaires described in section 5.3.1, while the stimulus to which the current question was related (i.e. a colored light setting or a picture), was presented once again to refresh the participant's memory.

5.5 Data Analysis

The statistical tests were performed using SPSS Statistics 17.0 (SPSS Inc.). The significance level (alpha) was set at 0.05 (Bonferroni corrections were applied in case multiple comparisons were done).

With respect to the colored light stimuli, it is important to keep in mind that not all data gathered could be examined in only one analysis, because of an incomplete design due to technical limitations of the wall washers. Therefore, three different combinations of light stimuli were analyzed, which are visually presented in Figure 5.1. The light stimuli were combined in order to investigate

- the effect of Saturation and Lightness per hue (with either all 4 red, 4 green, or 4 blue stimuli). The individual sets of this type will be referred to by the name of the hue (i.e. *Red-set*, *Green-set*, or *Blue-set*; the overall reference is *OneHue-set*);

– the effect of Saturation, Lightness, and Hue for red and green (all red and all green stimuli, in total 8 stimuli). The data set is called *RG-set*;

– the effect of Saturation and Hue for red, green, and blue (using the red and green low-lightness stimuli, and the blue high-lightness stimuli). This data set is referred to by *RGB-set*.

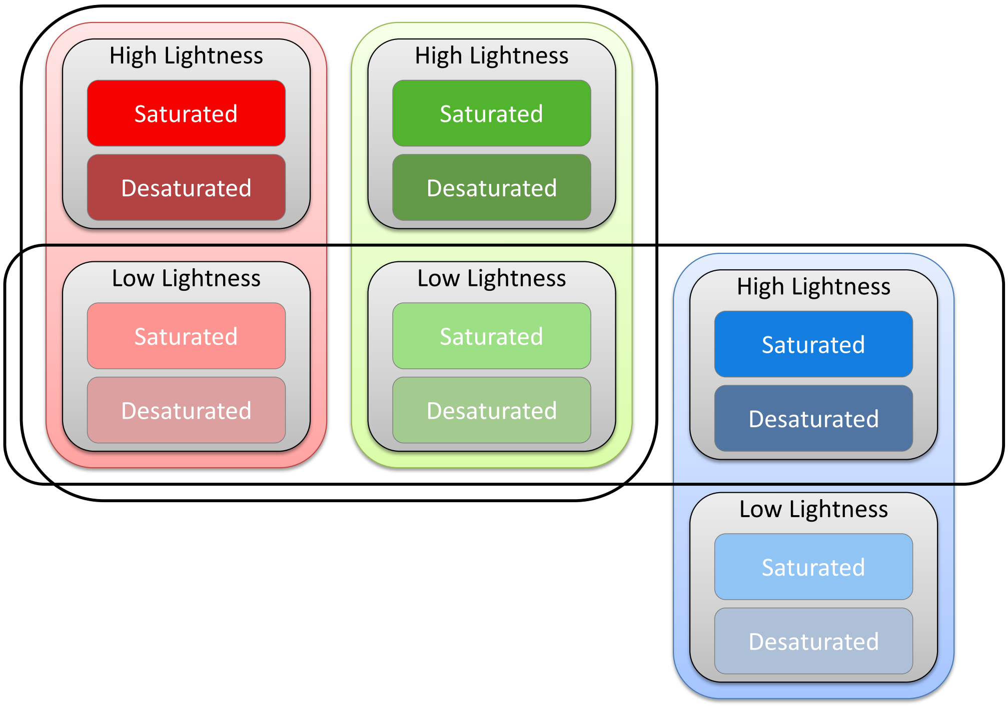

Figure 5.1: A graphical representation of the colored light stimuli used in the analyses split to Hue, Lightness, and Saturation.

Because other studies showed that males and females can experience and report affect differently (Durik et al., 2006), the analysis was started by identifying possible effects of gender for both the picture and colored light stimuli. This was done by means of a multivariate anova on each scale of both questionnaires and on each psychophysiological measurement with Gender (male / female) as between-subject factor. In case gender had an effect on one of the measurements, the factor Gender was added as between-subject factor in further analyses concerning that measurement.

Next, the selected pictures were validated by means of Mann-Whitney U tests on the Picture Load Questionnaire. A non-parametric test was chosen, because the data are not normally distributed. The valence and arousal scores of the red, green, and blue pictures were addressed in six separate analyses with Picture Load (negatively arousing / positively calming) as between-subject factor.

Subsequently, possible effects of the presentation order of the light stimuli were tested. Participants either started with saturated colored lights or with desaturated colored lights. A multivariate anova with Order (started with saturated stimuli / started with desaturated stimuli) as between-subject factor was performed on each scale of the Light Stimuli Questionnaire and on each psychophysiological measurement. In case effects of order were found on one of the measurements, this factor was added as between-subject factor in further analyses concerning that measurement.

Furthermore, during the experiment it already appeared that the participants perceived the valence and preference scale as highly comparable. Therefore the differences between the valence and preference scales of the Light Stimuli Questionnaire were tested by means of a paired t-tests for each colored light stimulus. Based on these tests it was decided whether to continue analyses on the preference scale.

Thereafter, the effects of the affective picture load on the colored light stimuli were tested. Because the effects of for example green pictures on red light stimuli are not meaningful, the effects of the pictures with a certain color (e.g. red pictures) were investigated on the light stimuli with the same color (e.g. red light stimuli). Therefore, each OneHue-set (Red-set, Green-set, Blue-set) was addressed with a separate repeated measures anova with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors and Picture Load (negatively arousing / positively calming) as between-subject factor. Each scale of the Light Stimuli Questionnaire and each psychophysiological measurement was addressed by three analyses (one for each hue). Based on the results of these analyses, it was decided whether to continue analysis with or without the factor Picture Load.

In case clear effects of Picture Load were found, the factor was taken into account in two additional analyses for each scale of the Light Stimuli Questionnaire and each psychophysiological measurement. The first additional analysis was to investigate the effects of Saturation, Lightness, Hue, and Picture Load for the red and green stimuli (RG-set) by means of a repeated measures anova with Saturation (saturated / desaturated), Lightness (high / low), and Hue (red / green) as within-subject factors, and Picture Load (4 levels; negative red & green / positive red & green / negative red & positive green /

positive red & negative green) as between-subject factor. The second additional analysis in case Picture Load shows clear effects was to investigate the effect of Saturation, Hue, and Picture Load for red, green, and blue stimuli (RGB-set). This is done by using a repeated measures anova with Saturation (saturated / desaturated) and Hue (red / green / blue) as within-subject factors, and Picture Load (8 levels; NegRed NegGreen NegBlue / NegRed NegGreen PosBlue / NegRed PosGreen NegBlue / NegRed PosGreen PosBlue / PosRed PosGreen PosBlue / PosRed PosGreen NegBlue / PosRed NegGreen PosBlue / PosRed NegGreen NegBlue) as between-subject factor.

However, when clear effects of Picture Load were absent, the factor Picture Load was excluded, and three more analyses for each scale of the Light Stimuli Questionnaire and each psychophysiological measurement were performed. In this case, the two described above analyses including Picture Load were performed *without* the factor Picture Load. Thus, the first analysis investigated the effects of Saturation, Lightness, and Hue for the RG-set by means of a repeated measures anova with Saturation (saturated / desaturated), Lightness (high / low), and Hue (red / green) as within-subject factors. The second analysis addressed the effects of Saturation and Hue for the RGB-set using a repeated measures anova with Saturation (saturated / desaturated) and Hue (red / green / blue) as within-subject factors. A third additional analysis addressed the effects on the blue colored light stimuli (Blue-set) by means of a repeated measures anova with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors.

Chapter 6

Data Preprocessing

The gathered measurements were preprocessed before they were analyzed. This chapter provides the preprocessing steps for both the subjective evaluations and the psychophysiological measurements.

6.1 Subjective Evaluations

Responses given to both questionnaires provided data for the subjective analysis. Answers to the open questions were minimal. Participants repeatedly stated to have had no thoughts when viewing the stimuli, or they stated not to remember their thoughts. Consequently, the open questions were often left blank, and could therefore not be analyzed.

Furthermore, to validate the use of parametric tests on the scales of the Light Stimuli Questionnaire the data must meet with four assumptions (Field, 2007).

First, the assumption of *independence* states that the data from different participants should be independent. The data does not violate this assumption, as all participants are tested individually.

Second, the assumption of *interval data* states that the distance between points of our scale should be equal at all parts along that scale. The five points on the pictorial Likert-type scale are evenly distributed over the scale, which is often assumed to be interval data.

Third, there is the assumption of *homogeneity of variance* meaning that the variances should be the same throughout the data. Each scale has been tested for this assumption by use of the Levene's test of which the results can be found in Table E.1 in the appendix. All test results are non-significant, which indicates that the difference between the variances is not significantly different from zero. Therefore, the data set fulfills this assumption.

Fourth, the assumption of *normally distributed data* can be tested using a Shapiro-Wilk test. This test showed that the data set is not significantly different from a normal distribution (for the results see Table E.2 in the appendix).

In sum, the data set does not seem to violate any of the assumptions, therefore, I report on parametric tests.

6.2 Psychophysiological Measurements

6.2.1 Raw Data

Raw data gathered during the experiment had to be processed before analysis. A typical example of some of the measurements is given in Figure 6.1. The point in time where the script controlling the colored light settings was started, could be traced back using the markers placed during the experiment. With this point, the correct 60 second period of the psychophysiological signal could be detected for each colored light stimulus.

Processing steps will be described below for HR, HRV, RSP, SC, ST, and RSP-HR coherence (COH). Some signals are processed with an internally developed Philips Biosignal Toolbox (de Waele, 2009). The functions used were mainly developed by Gert-Jan de Vries. For other preprocessing steps the commercially available BioTrace+ Software (version 2008a) was used.

Heart Rate and Heart Rate Variability The inter-beat interval (IBI) was calculated from BVP via the Biosignal Toolbox. For each colored light stimulus the mean IBI was calculated. The formula 60/IBI was applied to obtain the HR in beats per minute (b/min). HRV was also calculated by use of the Biosignal Toolbox in the time domain from the IBI, and averaged for each light stimulus.

Respiration Using the Biosignal Toolbox RSP was filtered and for each colored light stimulus the mean RD and mean RR were calculated.

Skin Conductance The SC signal (in μSiemens) can be divided into two different components. The first is a basic, overall level of skin conductance (SCL). The second component reflects individual skin conductance responses (SCR) related to perceived events, and occurs on top of the SCL. Both components are used for analysis.

By using the Biosignal Toolbox the SC signal was filtered and sampled down. For each

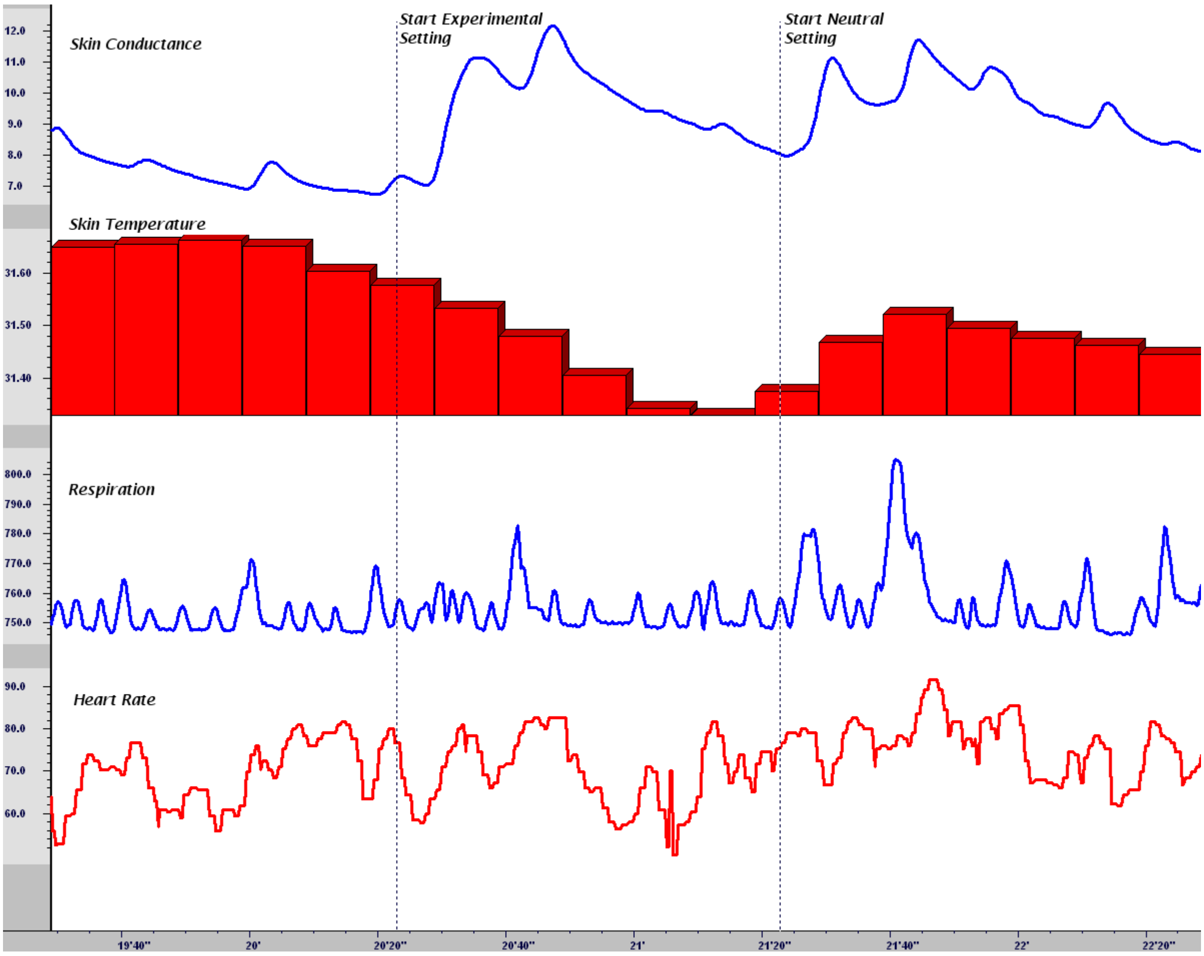

Figure 6.1: A typical example of the psychophysiological measurements monitored with BioTrace+, from top to bottom: SC, ST, RSP, and HR. The first dotted vertical line indicates the start of an experimental light setting, and the second dotted line indicates the end of this light setting (i.e. the start of a neutral light setting).

colored light stimulus the mean SCL was calculated. Further, the toolbox is able to extract several features of SCR based on the SCRGauge method made by Kohlisch (1992). The one used here is the number of skin responses per second (#SCR). Also for this measure means were calculated for each colored light stimulus.

Skin Temperature ST was exported from BioTrace+ in Degrees Celsius. Thereafter, the ST mean ($\overline{x}$ST) and ST slope (∇ST) of each colored light stimulus were calculated via the Biosignal Toolbox.

RSP-HR Coherence Calculation of the coherence between RSP and HR is a function provided by BioTrace+ Software. The coherence is the linear correlation between the two measures calculated using a Pearson product moment. The mean correlations were calculated using the Biosignal Toolbox.

6.2.2 Baseline

The mean baseline values were calculated over the last two minutes of the baseline recordings for each psychophysiological measurement (COH, HR, HRV, RD, RR, SCL, #SCR, $\overline{x}$ST, ∇ST). In order to prevent effects caused by baseline differences, mean baselines of participants exposed to varying positively calming and negatively arousing pictures were compared. In case these baselines differ, a baseline correction had to be performed. In order to determine this, univariate anovas on mean baseline with Red, Green, and Blue Picture Load (negatively arousing / positively calming) as between-subject factors were performed. The results show no significant effects of Picture Load on the baseline (Table F.1 of the appendix). Therefore, there was no need to perform baseline correction on the signals.

Chapter 7

Results

This chapter will describe the results of the subjective evaluations and the psychophysiological measurements. A complete overview of the results can be found in Appendices E and F.

7.1 Subjective Evaluations

7.1.1 Gender

Separate multivariate anovas for each scale of the questionnaires with Gender (male / female) as between-subject factor showed no effect of Gender on the Light Stimuli Questionnaire (valence: $F(12,27) = 2.134$, n.s.; arousal: $F(12,27) = 1.193$, n.s.; preference: $F(12,27) = 1.482$, n.s.), and on the Picture Load Questionnaire (valence: $F(6,33) = 0.704$, n.s.; arousal: $F(6,33) = 1.100$, n.s.). Gender had no influence on the responses to the different scales of both questionnaires. Based on these results, the factor Gender was excluded from further analyses with respect to the subjective evaluations.

7.1.2 Pictures

Mann-Whitney U tests with Picture Load (negatively arousing / positively calming) as between-subject factor were performed on the scales of the Picture Load Questionnaire. Mean ratings of the valence and arousal scales for each picture pair are plotted in Figure 7.1. For the valence scale, a significant effect of Picture Load was found for all three hues (Red: $U = 50$, $p = .000$; Green: $U = 68$, $p = .000$; Blue: $U = 13$, $p = .000$): negatively arousing pictures (Red: 2.61; Green: 2.85; Blue: 2.52) are rated more negatively than the positively calming pictures (Red: 3.95; Green: 3.73; Blue: 4.34).

On the arousal scale, the effect of Picture Load was found significant for all three hues as well (Red: U = 91, p = .003; Green: U = 23.5, p = .000; Blue: U = 116.5, p = .023). Again, the direction of the effect is similar for the different hues: the negatively arousing pictures (Red: 3.53; Green: 3.25; Blue: 3.12) were rated as being more arousing than the positively calming pictures (Red: 2.45; Green: 1.65; Blue: 2.40).

Based on these results, it was assumed that the picture selection is valid. This means that the participants indeed perceived the pictures selected to be negative and arousing as negatively arousing, and those pictures selected to be positive and calming were perceived as positively calming.

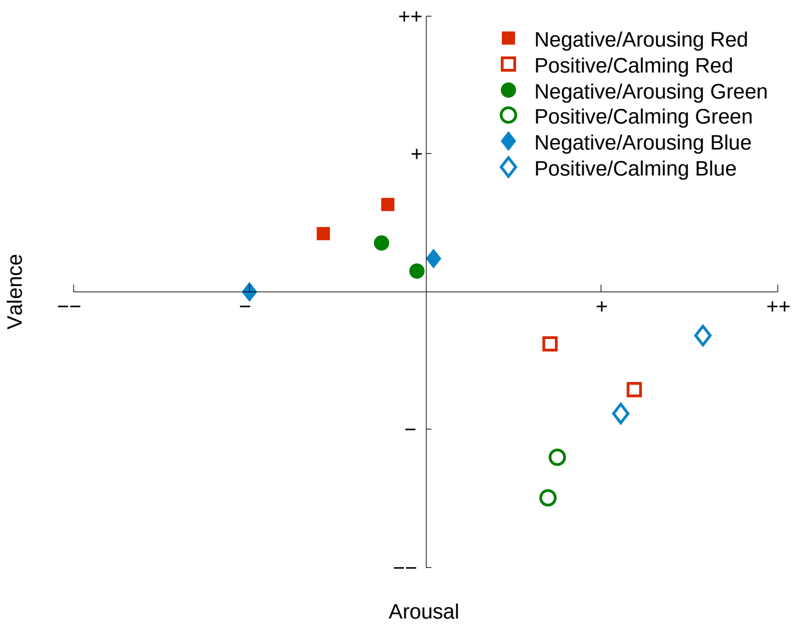

Figure 7.1: A graphical representation of the mean ratings on the valence and arousal scales of the Picture Load Questionnaire.

7.1.3 Colored Lights

Order

Separate multivariate anovas were performed for each scale of the Light Stimuli Questionnaire with Order (started with saturated stimuli / started with desaturated stimuli) as between-subject factor. No effect of Order was found (valence: F(12,27) = 0.821, n.s.;

arousal: F(12,27) = 0.692, n.s.; preference: F(12,27) = 0.857, n.s.) Order had no influence on the responses to the different scales. Therefore, the factor Order was excluded from further analyses with respect to the subjective evaluations.

Valence and Preference Scales

Paired t-tests for each colored light stimulus on the valence and preference scales of the Light Stimuli Questionnaire revealed no significant differences between the ratings on the valence and preference scales. Moreover, correlations for all 12 pairs were significant (all p's = .000) and varied between .60 and .82. Because valence and preference do not differ and are highly correlated, the latter was omitted from further analyses.

Analyses including the factor Picture Load

OneHue-set analyses Separate repeated measures anovas were performed for the different hues (red, green, and blue) with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors, and Picture Load (negatively arousing / positively calming) as between-subject factor. The three OneHue-set analyses were done for the valence and arousal scales of the Light Stimuli Questionnaire separately (six analyses in total). All results can be found in Table E.3 in the appendix.

No main effects of Picture Load on the *valence* scale were found. Only one interaction regarding Picture Load was found, namely Lightness with Picture Load in the Green-set analysis (η_p^2 = .12). Participants who saw positively calming green pictures responded more positively to the green high-lightness stimuli (m = 3.63) than to the low-lightness stimuli (m = 3.23). Those who saw negatively arousing pictures rated high (m = 3.38) and low lightness (m = 3.40) equally.

Only one main effect of Picture Load was found on the *arousal* scale, namely in the analysis of the Green-set (η_p^2 = .10). Participants who saw negatively arousing green pictures (m = 2.40) rated the green stimulus lights as more arousing than the participants who saw positively calming green pictures (m = 1.98). None of the interactions was found significant on arousal.

In summary, only one main effect and one interaction were found. These effects are limited and with moderate strength. Therefore, it was assumed that the picture manipulation did not influence the participants when evaluating the colored light stimuli. As a consequence, the Light Stimuli Questionnaire data were further analyzed without the factor Picture Load.

Analyses without the factor Picture Load

As the factor Picture Load has been left out of further analyses, the research question was now answered by analyzing the Blue-set, RG-set, and RGB-set only. Consequently, the Red-set and Green-set were not analyzed again without the factor Picture Load.

Blue-set analyses Separate repeated measures anovas were performed for the valence and arousal scales of the Light Stimuli Questionnaire with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors. The means are graphically represented in Figure 7.2 and the results can be found in Table E.4 in the appendix.

On the *valence* scale, a significant main effect of Saturation was found ($\eta_p^2 = .17$). Blue saturated light stimuli (m = 3.63) were rated more positively than blue desaturated light stimuli (m = 3.30). There was no effect of Lightness on the valence scale and no significant interaction of Saturation with Lightness.

The *arousal* scale showed only a trend for Saturation ($\eta_p^2 = .10$), indicating that blue saturated light stimuli (m= 1.90) are evaluated more arousing than the desaturated ones (m= 1.71). Furthermore, there was no effect Lightness and the interaction of Saturation with Lightness were not significant.

RG-set analyses Separate repeated measures anovas were performed for the valence and arousal scales of the Light Stimuli Questionnaire with Saturation (saturated / desaturated), Lightness (high / low), and Hue (red / green) as within-subject factors. The results can be found in Table E.4 in the appendix and the means are plotted in Figure 7.3.

On the *valence* scale, a significant effect of Saturation was found ($\eta_p^2 = .14$). Desaturated light stimuli (m = 3.46) were evaluated more positively than saturated light stimuli (m = 3.11). The effect of Lightness was also significant ($\eta_p^2 = .12$). Light stimuli with a high-lightness (m = 3.38) are perceived more positively than those with low-lightness (m = 3.19). The factor Hue did not show a significant effect, although there is a trend ($\eta_p^2 = .09$) towards a more positive evaluation of green (m = 3.41) compared to red (m = 3.16).

Furthermore, the interaction of Saturation with Hue was significant ($\eta_p^2 = .22$). Desaturated red (m = 3.50) is considered to be more positive than saturated red (m = 2.83), while the valence of saturated (m = 3.39) and desaturated (m = 3.43) green are similar. The interactions of Saturation with Lightness and Lightness with Hue were not significant.

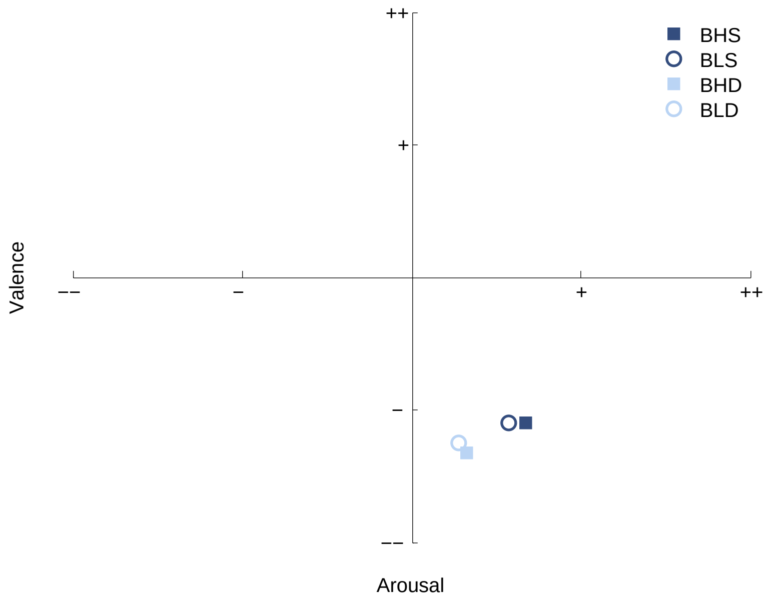

Figure 7.2: Means of the Blue-set analyses for each colored light stimulus on the valence and arousal scales of the Light Stimuli Questionnaire. B indicates the blue stimuli, S the saturated stimuli, D the desaturated stimuli, H high lightness, and L low lightness.

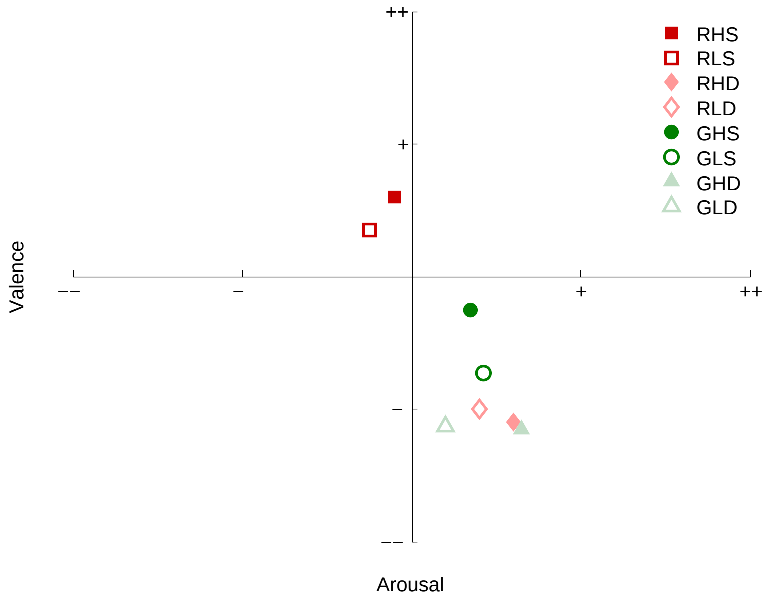

Figure 7.3: Means of the RG-set analyses for each colored light stimulus for the valence and arousal scales of the Light Stimuli Questionnaire. R indicates the red stimuli, G the green ones, S means saturated, D desaturated, H high lightness, and L low lightness.

The *arousal* scale showed a significant effect of Saturation (η_p^2 = .63). Desaturated light stimuli (m = 1.91) are judged to be more calming than saturated light stimuli (m = 2.99). The main effect of Lightness was significant as well (η_p^2 = .11). Light stimuli with high-lightness (m = 2.53) were rated as more arousing than the stimuli with low-lightness (m = 2.38). Hue was also significant (η_p^2 = .50): red (m = 2.71) is evaluated as more arousing than green (m = 2.19).

Also, the interaction of Saturation with Hue was significant (η_p^2 = .52). Saturated red (m = 3.48) is the most arousing, followed by saturated green (m = 2.51), and finally desaturated red (m = 1.95) and green (m = 1.86) which are equally arousing. Furthermore, the interaction of Saturation with Lightness was significant (η_p^2 = .34). Saturated high-lightness (m = 3.18) is more exciting than saturated low-lightness (m = 2.81), while for the desaturated stimuli there is no difference between high (m = 1.88) and low-lightness (m = 1.94). There was no significant interaction of Lightness with Hue.

RGB-set analyses

Separate repeated measures anovas were preformed for the valence and arousal scale with Saturation (saturated / desaturated) and Hue (red / green / blue) as within-subject factors. The results are presented in Table E.4 in the appendix and Figure 7.4.

On the *valence* scale no significant effect of Saturation was found. The effect of Hue was significant (η_p^2 = .16). Pairwise comparisons showed that this effect is due to the fact that blue light (m = 3.50) was rated significantly more positive than red light (m = 3.08).

Furthermore, the interaction of Saturation with Hue was significant (η_p^2 = .41). In case of blue light stimuli, the desaturated stimulus (m = 3.33) was more negatively evaluated than the saturated stimulus (m = 3.68). Red light shows a reverse pattern with desaturated red (m = 3.40) rated more positively than saturated red (m = 2.75). Finally, the green light stimuli are similar in valence (saturated: 3.43; desaturated: 3.20)

On the *arousal* scale a main effect of Saturation was found (η_p^2 = .54). Saturated light stimuli (m = 2.51) are more arousing than desaturated light stimuli (m = 1.85). Also, the main effect of Hue was significant (η_p^2 = .66). The sequence from the most calming to the most arousing is blue (m = 1.79), green (m = 2.08), and red (m = 2.68).

The significant interaction of Saturation with Hue (η_p^2 = .52) showed that the difference between saturated (m = 3.35) and desaturated (m = 2.00) red is larger than the difference for blue (saturated: 1.90; desaturated: 1.68). The difference for green lies in between (saturated: 2.28; desaturated: 1.88).

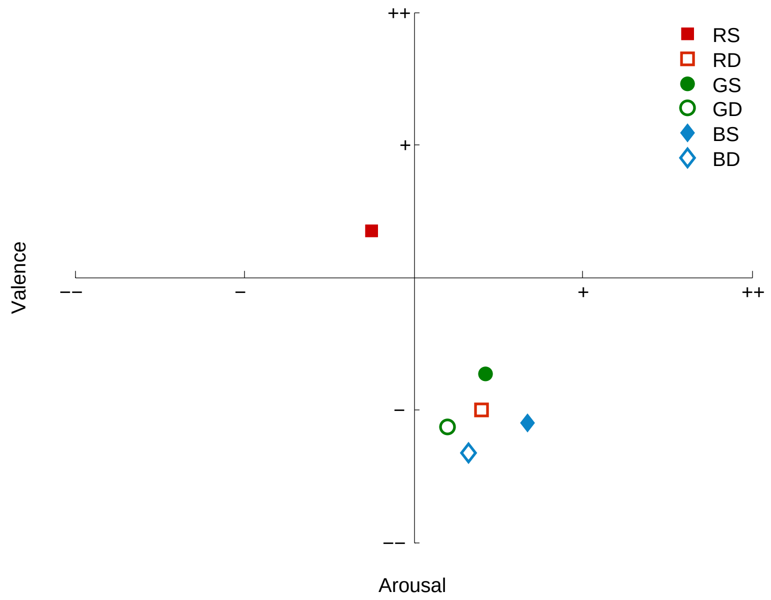

Figure 7.4: Means of the RGB-set analyses for each colored light stimulus for the valence and arousal scales of the Light Stimuli Questionnaire. R indicates the red stimuli, G the green stimuli, B the blue ones, S means saturated, and D desaturated.

7.2 Psychophysiological Measurements

7.2.1 Gender

Separate multivariate anovas for each psychophysiological measurement with Gender (male / female) as between-subject factor showed a significant effect of Gender on HR (F(12,25) = 2.559, p = .023, η_p^2 = .55) and SCL (F(12,26) = 2.365, p = .032, η_p^2 = .52). HR is higher in females (m = 76.59) compared to males (m = 67.47), and SCL is higher in males (m = 7.27) compared to females (m = 6.79). For all other measurements the effect of Gender was non-significant (COH: F(12,27) = 0.303, n.s.; HRV: F(12,24) = 1.015., n.s.; RD: F(12,22) = 0.657, n.s.; RR: F(12,23) = 0.962, n.s.; #SCR: F(12,25) = 0.594, n.s.; $\overline{x}$ST: F(12,27) = 0.836, n.s.; ∇ST: F(12,27) = 1.145, n.s.). Based on these results, the factor Gender was only taken into account for the analyses of HR and SCL, and excluded from all other analyses.

7.2.2 Colored Lights

Order

Separate multivariate anovas were performed for each psychophysiological measurement with Order (started with saturated stimuli / started with desaturated stimuli) as between-subject factor. No measurement showed a significant effect of Order (COH: F(12,27) = 1.700, n.s.; HR: F(12,25) = 1.984, n.s.; HRV: F(12,24) = 1.150, n.s.; RD: F(12,22) = 1.316, n.s.; RR: F(12,23) = 0.585, n.s.; SCL: F(12,26) = 0.774, n.s.; #SCR: F(12,25) = 1.217, n.s.; $\overline{x}$ST: F(12,27) = 0.922, n.s.; ∇ST: F(12,27) = 1.768, n.s.). As a result, the factor Order was not taken into account in any of the analyses regarding the psychophysiological measurements.

Analyses including the factor Picture Load

OneHue-sets analyses Each OneHue-set was analyzed with a repeated measures anova with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors and Picture Load (negatively arousing / positively calming) as between-subject factor. This was done for the means of all nine psychophysiological measurements separately. The between-subject factor Gender (male / female) was only used in the analyses of HR and SCL. Results are presented in Tables F.2, F.3, and F.4 in the appendix.

No main effect of Picture Load was found on HR, HRV, RD, RR, SCL, #SCR, $\overline{x}$ST, and ∇ST in any of the three OneHue-set analyses. Only a main effect of Picture Load was found on COH in the Red-set analysis (η_p^2 = .10). Positively calming red pictures (m = -0.22) caused a higher negative COH than negatively arousing red pictures (m = -0.10).

The Picture Load effects could be masked by the factors Lightness or Saturation. However, the absence of consistent interaction effects indicated that this is not the case: only 4 of the 54 tested interactions including the factor Picture Load were found significant, namely Lightness with Picture Load on RD in the Red-set analysis (η_p^2 = .13) and the Green-set analysis (η_p^2 = .16), and Saturation with Picture Load on COH (η_p^2 = .14) and HRV (η_p^2 = .19) in the Green-set analysis.

Based on the fact that only a few significant effects (with moderate strength) were found, it can be assumed that the picture manipulation did not influence the psychophysiological measurements. This is in line with the results of the subjective evaluations. Therefore, Lightness, Saturation, and Hue were analyzed further without the factor Picture Load.

Analyses without the factor Picture Load

Similar to the subjective evaluations, after leaving out the factor Picture Load, the research question was now answered by analyzing the Blue-set, RG-set and RGB-set only. Therefore, the Red-set and Green-set were not analyzed any further.

Blue-set analyses Separate repeated measures anovas were run on each psychophysiological measurement with Saturation (saturated / desaturated) and Lightness (high / low) as within-subject factors. The HR and SCL analyses were performed with Gender (male / female) as between-subject factor. The results can be found in Table F.5 of the appendix, while means and the standard errors of the means (SEMs) are provided in Table 7.1.

On HR, the effect of Gender was significant ($\eta_p^2 = .25$). Females (m = 76.58) have a higher HR than males (m = 67.62). There were no other significant effects and no significant interactions on HR.

A main effect of Saturation was found significant on #SCR ($\eta_p^2 = .21$). The frequency of skin responses is higher for saturated light stimuli (m = 0.06) than for desaturated light stimuli (m = 0.05). Neither the effect of Lightness nor the interaction of Saturation with Lightness was significant in the analysis of #SCR.

No significant effects were found on COH, HRV, RD, RR, SCL, $\overline{x}$ST, and ∇ST. Only a trend of Saturation was present on SCL ($\eta_p^2 = .08$), suggesting that saturated lights (m = 7.28) cause a higher SCL than desaturated lights (m = 6.55).

RG-set analyses Repeated measures anovas were performed with Saturation (saturated / desaturated), Lightness (high / low), and Hue (red / green) as within-subject factors. Each psychophysiological measurement was addressed in a separate analysis. In the analysis of HR and SCL the between-subject factor Gender was added. The complete overview of results can be found in Table F.6 in the appendix, and means and SEMs are provided in Table 7.2.

For the measures COH, HRV, RD, RR, and $\overline{x}$ST no significant effects were found. Below, the effects of the remaining psychophysiological measures will be described.

A significant effect of Gender was found for HR ($\eta_p^2 = .29$). Females (m = 77.06) have a higher mean HR than males (m = 67.49). Saturation, Lightness and Hue showed no significant effect on HR. There were also no significant interactions.

No effects were found significant for SCL, but a trend was present for Hue ($\eta_p^2 = .10$), suggesting that red light stimuli (m = 7.15) cause a higher SCL than green light stimuli

Table 7.1: Means and SEMs of the psychophysiological measurements for the factors Saturation and Lightness in the Blue-set analyses. In case of HR and SCL, the means and SEMs are also split to Gender, where m and f indicate male and female, respectively.

Measure	Saturation				Lightness			
	Saturated		Desaturated		High		Low	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
COH	-0.166	0.038	-0.161	0.024	-0.157	0.025	-0.169	0.029
HR - m	67.403	1.761	67.845	1.743	67.880	1.761	67.368	1.744
HR - f	76.303	2.003	76.854	1.983	76.977	2.003	76.180	1.984
HRV	2.557	0.425	3.024	0.437	2.549	0.352	3.032	0.519
RD	9.380	0.892	9.461	0.857	9.382	0.924	9.459	0.823
RR	15.841	0.667	15.967	0.590	15.900	0.633	15.907	0.620
SCL - m	7.324	1.182	6.991	1.007	7.376	1.105	6.939	1.059
SCL - f	7.239	1.277	6.110	1.087	6.670	1.194	6.679	1.144
#SCR	0.062	0.008	0.047	0.006	0.053	0.006	0.056	0.008
$\overline{x}$ST	32.436	0.621	32.353	0.684	32.300	0.639	32.489	0.642
∇ST	$4.40 \cdot 10^{-4}$	$5.34 \cdot 10^{-4}$	0.0012	$6.72 \cdot 10^{-4}$	$2.66 \cdot 10^{-4}$	$5.31 \cdot 10^{-4}$	0.0013	$6.58 \cdot 10^{-4}$

(m = 6.84). There were no significant effects of Saturation, Lightness, and Gender. Also, no significant interactions on SCL were found.

For #SCR a significant interaction of Saturation with Hue was found ($\eta_p^2 = .11$). Saturated red light stimuli (m = 0.07) result in more skin responses per minute than desaturated red stimuli (m = 0.06), while saturated (m = 0.06) and desaturated (m = 0.06) green light stimuli do not differ in #SCR. Furthermore, #SCR results showed a trend of Saturation ($\eta_p^2 = .08$). It indicated that saturated stimuli (m = 0.07) tend to have more #SCR than desaturated stimuli (m = 0.06). Also, Lightness showed a trend towards significance ($\eta_p^2 = .08$) suggesting that a lower lightness (m = 0.07) results in more #SCR than a higher lightness (m =0.06). There was no significant effect of Hue, and no significant interactions with Lightness on #SCR.

Finally, ∇ST showed no significant effects, but a trend was found for Lightness ($\eta_p^2 = .10$). A lower lightness (m = 0.001) seems to cause a higher ∇ST than a higher lightness (m = 0.000).

RGB-set analyses A separate repeated measures anova was performed on each psychophysiological measurement with Saturation (saturated / desaturated), and Hue (red / green /

blue) as within-subject factors. The analyses of HR and SCL also included the between-subject factor Gender. The results are presented in Table F.7 in the appendix, and means and SEMs are provided in Table 7.3.

No significant effects were present in the analyses of COH, HRV, RD, RR, $\overline{x}$ST, and ∇ST. The significances found are described below.

HR showed a significant effect of Gender ($\eta_p^2 = .28$): females (m = 76.88) have a higher HR than males (m = 67.49). There were no other significant effects or interactions on HR.

The results of SCL showed no significant effects, but a trend of Saturation was present ($\eta_p^2 = .10$): saturated light stimuli (m = 7.40) seemed to cause a higher SCL compared to desaturated light stimuli (m = 6.67).

For #SCR the effect of Hue was found significant ($\eta_p^2 = .17$). Pairwise comparisons showed that red light stimuli (m = .07) cause more skin responses per minute than blue light stimuli (m = .05). Furthermore, the main effect of Saturation showed a trend towards significance ($\eta_p^2 = .09$) with saturated light stimuli (m = .07) having a higher skin response frequency than desaturated light stimuli (m = .06). The interaction of Saturation with Hue was not significant.

Table 7.2: Means and SEMs of the psychophysiological measurements for the factors Saturation, Lightness, and Hue in the RG-set analyses. In case of HR and SCL, the means and SEMs are also split to Gender, where m and f indicate male and female, respectively.

Measure	Saturation				Lightness				Hue			
	Saturated		Desaturated		High		Low		Red		Green	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
COH	-0.173	0.032	-0.141	0.028	-0.161	0.030	-0.152	0.027	-0.163	0.029	-0.150	0.030
HR - m	67.504	1.658	67.470	1.694	67.405	1.630	67.569	1.704	67.466	1.693	67.508	1.657
HR - f	77.452	1.843	76.664	1.883	77.285	1.812	76.831	1.894	76.730	1.882	77.386	1.841
HRV	2.734	0.280	2.796	0.377	2.733	0.273	2.797	0.379	2.721	0.314	2.809	0.368
RD	9.727	0.975	9.846	0.973	9.573	1.019	10.000	0.944	9.770	0.955	9.803	0.997
RR	15.921	0.645	15.767	0.642	15.803	0.620	15.885	0.669	15.797	0.632	15.891	0.661
SCL - m	7.654	1.126	7.142	1.091	7.198	1.103	7.599	1.083	7.616	1.121	7.181	1.059
SCL - f	6.879	1.217	6.300	1.178	6.692	1.191	6.487	1.170	6.682	1.211	6.497	1.143
#SCR	0.067	0.007	0.058	0.008	0.060	0.007	0.065	0.008	0.064	0.008	0.061	0.007
$\overline{x}$ST	32.312	0.626	32.522	0.651	32.323	0.636	32.512	0.625	32.428	0.618	32.406	0.631
∇ST	$3.48 \cdot 10^{-4}$	$4.87 \cdot 10^{-4}$	$6.91 \cdot 10^{-4}$	$4.73 \cdot 10^{-4}$	$-1.40 \cdot 10^{-4}$	$3.69 \cdot 10^{-4}$	0.0012	$5.20 \cdot 10^{-4}$	$5.62 \cdot 10^{-4}$	$4.11 \cdot 10^{-4}$	$4.77 \cdot 10^{-4}$	$4.56 \cdot 10^{-4}$

Table 7.3: Means and SEMs of the psychophysiological measurements for the factors Saturation and Hue in the RGB-set analyses. In case of HR and SCL, the means and SEMs are also split to Gender, where m and f indicate male and female, respectively.

Measure	Saturation				Hue					
	Saturated		Desaturated		Red		Green		Blue	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
COH	-0.153	0.033	-0.155	0.025	-0.156	0.030	-0.149	0.033	-0.157	0.025
HR - m	67.354	1.684	67.623	1.675	67.319	1.734	67.267	1.626	67.880	1.761
HR - f	77.059	1.915	76.700	1.906	76.098	1.973	77.564	1.850	76.977	2.003
HRV	2.746	0.334	2.491	0.309	2.506	0.334	2.989	0.510	2.360	0.304
RD	9.832	0.975	9.756	0.904	9.918	0.930	10.083	0.997	9.382	0.924
RR	15.884	0.675	15.896	0.659	15.798	0.660	15.972	0.725	15.900	0.633
SCL - m	7.781	1.160	7.267	1.053	7.710	1.129	7.487	1.057	7.376	1.105
SCL - f	7.018	1.253	6.078	1.138	6.516	1.219	6.458	1.142	6.670	1.194
#SCR	0.066	0.008	0.056	0.007	0.068	0.009	0.063	0.008	0.053	0.006
$\overline{x}$ST	32.420	0.618	32.462	0.664	32.596	0.617	32.428	0.637	32.300	0.639
∇ST	$5.35 \cdot 10^{-4}$	$6.34 \cdot 10^{-4}$	0.0012	$5.82 \cdot 10^{-4}$	$9.72 \cdot 10^{-4}$	$6.29 \cdot 10^{-4}$	0.0014	$8.07 \cdot 10^{-4}$	$2.66 \cdot 10^{-4}$	$5.31 \cdot 10^{-4}$

7.3 Summary

Gender was taken into account in the analyses of both HR and SCL. Main effects of Gender were only found on HR, which represent a linear shift in heart rate between males and females that has nothing to do with the presentation of the light stimuli. Furthermore, no additional value was found for the order of the light stimuli, the affective picture loads, and the preference scale. Therefore, these factors were omitted from further analyses.

The remaining analyses revealed, on the one hand, considerable significant effects of the colored light characteristics on the subjective evaluations. On the other hand, skin conductance is the only psychophysiological measurement where effects were found, but these were not very strong. The relevant significant effects are presented in table 7.4 and will be discussed in chapter 8.

Table 7.4: An overview of the relevant significant effects. The directions of the main effects are shown in small font size, where s stands for saturated, d for desaturated, h for high-lightness, l for low-lightness, r for red, g for green, and b for blue. Main effects presented in a gray background are significant, while those in a white background are trends towards significance.

	Blue analysis		RG analysis		RGB analysis	
Saturation	Arousal $_{s>d}$	$\eta^2_p = .10$	Arousal $_{s>d}$	$\eta^2_p = .63$	Arousal $_{s>d}$	$\eta^2_p = .54$
	Valence $_{s>d}$	$\eta^2_p = .17$	Valence $_{d>s}$	$\eta^2_p = .14$		
	#SCR $_{s>d}$	$\eta^2_p = .21$	#SCR $_{s>d}$	$\eta^2_p = .08$	#SCR $_{s>d}$	$\eta^2_p = .09$
	SCL $_{s>d}$	$\eta^2_p = .08$			SCL $_{s>d}$	$\eta^2_p = .10$
Lightness			Valence $_{h>l}$	$\eta^2_p = .12$	*Not tested*	
			Arousal $_{h>l}$	$\eta^2_p = .11$		
			∇ ST $_{h<l}$	$\eta^2_p = .10$		
			#SCR $_{h<l}$	$\eta^2_p = .08$		
Hue	*Not tested*		Arousal $_{r>g}$	$\eta^2_p = .50$	Arousal $_{r>g>b}$	$\eta^2_p = .66$
			SCL $_{r>g}$	$\eta^2_p = .10$	#SCR $_{r>b}$	$\eta^2_p = .17$
			Valence $_{g>r}$	$\eta^2_p = .09$	Valence $_{b>r}$	$\eta^2_p = .16$
Saturation x Lightness			Arousal	$\eta^2_p = .34$	*Not tested*	
Saturation x Hue	*Not tested*		Arousal	$\eta^2_p = .52$	Arousal	$\eta^2_p = .52$
			Valence	$\eta^2_p = .22$	Valence	$\eta^2_p = .41$
			#SCR	$\eta^2_p = .11$		

Chapter 8

Discussion

This chapter will start with a section that discusses the results of the experiment. First, the absence of priming effects of the pictures will be addressed, thereafter the effects of the colored lights, and finally conclusions will be provided. The final section will discuss the implications of the results in affective and ubiquitous computing.

8.1 Influence of colored light on affect

The current study was designed to address the influence of colored light on affect. Hue, saturation, and lightness were controlled, and psychophysiological measurements and subjective evaluations were gathered. Participants were primed with affectively loaded pictures in order to associate the colored light stimuli with an affective load. For example, negatively arousing blue pictures were supposed to elicit a negative and arousing affect when blue light was shown, while positively calming blue pictures were selected to cause a positive and calming affect when watching blue light.

The results showed that the picture load did not seem to have impact on either the psychophysiological measurements or the subjective evaluations of the light stimuli. It appears to be more difficult to cause a priming effect with affectively loaded pictures. It might be that using pictures evaluated as being positive and calm or negative and arousing does not guarantee a strong enough affective load to serve as a prime. Maybe stimuli with a stronger affective load are needed. Another explanation may be the fact that both negatively arousing and positively calming pictures were presented to each participant. The affective loads might have caused interference, such that they canceled each other out resulting in an overall neutral affective picture load. In this case, only pictures with one affective load should be presented to each participant.

The psychophysiological measurements were not affected by the colored lights, with the exception of the number of skin conductance responses (#SCR). In contrast with the psychophysiological measurements, the subjective evaluations showed several influences of the three colored light characteristics lightness, saturation, and hue.

The lightness of a colored light has no influence on #SCR. Furthermore, it has only a small impact on the valence and arousal: the results are limited and of moderate strength. The lightness manipulation might probably have been not powerful enough to cause large effects. The perceptual difference between high and low lightness was relatively small[1]. However, the fact that some (subjective) effects were found indicates that lightness might influence affect.

As expected, the saturated colored lights are more arousing according to the arousal dimension of the questionnaire, while the desaturated colored lights are more calming for all hues. This was also found in the preliminary results of Rajae-Joordens (to be submitted). The size of the difference between saturated and desaturated colored lights depends on the hue. This differentiation between saturation levels was also found on #SCR, which may suggest that #SCR and arousal are related. To the contrary, the impact on valence is not as clear as that on arousal and #SCR: whether the saturated or desaturated lights are rated to be more pleasant depends highly on the hue.

The hue effects found on #SCR suggest an effect of hue on emotion. Red lights caused more skin conductance responses compared to blue lights. Furthermore, arousal is influenced strongly by hue: The red lights are the most arousing, followed by green, and finally blue. These effects of subjective arousal are similar to results Yoto et al. (2007), Wilson (1966), Gerard (1958), and the preliminary results of Rajae-Joordens (to be submitted). Valence is also influenced by hue. Blue seems to cause a more positive feeling than red, which is comparable to Valdez and Mehrabian (1994), Gerard (1958), and Suk (2006), and the preliminary results of Rajae-Joordens (to be submitted). A closer look at the data revealed, however, that the hue effects seem to be caused mainly by the saturated red lights (see for example Figures 7.3 and 7.4). Consequently, it is reasonable to question whether it is hue that causes the effect. Even though the stimuli were matched, according to the participants the saturation level of saturated red was perceived differently from the saturated green and blue. A possible explanation might be related to the model that was used to match the colored light characteristics. The white point that was used as reference

[1] Choosing other lightness levels to increase the difference between the lightness levels was not possible due to technical limitations

for the measurements of the 1976 CIELAB coordinates was equal to the neutral setting presented in between the stimulus presentations. Because this neutral setting was chosen such that the light was neither very pleasant or unpleasant, this white point was more reddish than bluish. This might be the reason that participants mentioned that saturated red was perceived as more saturated compared to saturated blue in this study. So, the found hue effects are likely to be saturation effects due to the white point weakness in the model used for matching the colored light stimuli. This learns us that it is extremely difficult to design an irrefutable experiment in which very saturated stimuli are presented in a further dark room without a white reference point.

Despite of the fact that it is not clear whether the results should only be attributed to saturation, the results suggest a discrepancy between psychophysiological measurements and subjective evaluations with respect to hue. These two measures can be linked with the separate definitions for the two parts of affect. Feelings represent the subjective component of affect, while emotions refer to the psychophysiological and behavioral component of affect. When examining this discrepancy, one can argue that feelings are indeed affected by colored light, but emotions only very slightly. The emotional effects might be too small and undetectable.

In the light of the theory of Lazarus (1982) one can question whether affect is actually influenced by color. He states that "cognition and affect should be regarded .. as fused and highly interdependent" and that "thought and feelings are simultaneous". He believes that feeling and emotion are both required to create affect. The current results, then, are not a reflection of affect, as clear effects on emotion are absent. In this case, it might be that the subjective evaluations of the colored lights are based on interpretations driven by personal experience of how a particular color may affect feelings, without experiencing any affect at the time that the lights were presented. In other words, subjective ratings would be given from a spectator point of view instead of a participant point of view.

Concluding, based on these results, it is difficult to provide a definite conclusion on whether colored light has an influence on affect. For lightness the influence is still unclear, while saturation does influence affect. With respect to hue, it might, on the one hand, be concluded that there is an effect which is reflected in different subjective evaluations, but that is undetectable in the psychophysiological measurements. On the other hand, the differentiation of the subjective evaluations might simply be due to the fact that people are able to label the affective load of colored lights from a spectator view. In any case, the results of the present study clearly indicate that it is very difficult to derive the affective impact of light stimuli from psychophysiological measurements and questionnaires. Moreover, this study also learned us how difficult it is to design a very well controlled experiment.

8.2 Affective and Ubiquitous Computing

Colored light is, intuitively, thought to be an adequate medium to influence affect. The existing literature, however, on the influence of color on affect is ambiguous. The current experiment was designed to address the influence of colored light characteristics on affect in order to enable the use of colored light in a ubiquitous and affective environment.

With respect to the colored light characteristic lightness, the current manipulation seemed to be too small to cause clear effects on either the subjective evaluations or the psychophysiological measurements. However, lightness is not to be disregarded as a possible influencing variable of colored light in affective and ubiquitous computing. On the contrary, lightness needs more attention in order to find the actual potential of this characteristic of colored light.

Also, effects of hue were found in the experiment. However, it was questioned above whether these are actual hue effects. The effects were caused by the perceived saturation level of the saturated red stimuli, and can therefore be saturation effects. In affective and ubiquitous computing it seems still to be difficult to use the hue characteristic of colored light.

Furthermore, saturation was found to influence valence, arousal, and #SCR. Therefore, it seems that saturation is the only colored light characteristics that can currently be used in affective and ubiquitous computing: when one needs to be calmed down the colored lights can be tuned to a more desaturated setting, while in case one needs to be activated the colored light setting should be more saturated.

Because the effects on the psychophysiological measurements are rather limited, it appeared that the emotion part of affect is not heavily influenced or that the effects are not (easily) detectable. Additionally, it was questioned whether the effects on feelings were actually based on feelings experienced during the presentation of the lights or rather based on judgments of the affective load of the lights without the experiences of accompanying feelings. Both these considerations confirm that the correct recognition of affect is indeed incredibly difficult, as already mentioned in section 2.1. This has also consequences for the possible usage of saturation as an influence on affect. Even though saturation may be usable, currently the affective and ubiquitous system can not be a closed loop system:

for now, it can not be doubtlessly determined how someone reacts to changes in the light settings.

In conclusion, the influences of colored light on affect are not as clear as hoped for. Consequently, for now, colored light seems not to be very useful in affective and ubiquitous computing. However, it might be possible that extended exposure to colored light gradually influences the longer-term mood of a person without a clear detectable short-term effect on affect. More research is needed to investigate the effects of colored light on mood, ways to determine possible effects and how this knowledge might be applied to create affective and ubiquitous closed loop systems in the future.

Chapter 9

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Appendix A

Consent Form

Name of Participant: ....

Concerns: Colored light experiment with pictures

This experiment is to study the effect of various aspects of colored light on several physiological and psychological measures. These measures will be collected during the experiment, which consists of three parts. During the first part, some pictures will be presented to which you have to pay attention. During the second part, different light settings will be shown. It is important that you pay attention and keep your eyes open when the light settings are presented. The third part consists of several questions about the pictures and the light settings shown in the first two part of the experiment.
All information and data collection will remain confidential and will only be seen by the experimenters for analysis.

I confirm that I understand and accept these explanations.

I have been informed that if I have any complaints about the experiment or the experimenter I can direct them to the head of the department or the in-house Doctor.

I also understand that I can decide to stop the test without given reason at any time during the test.

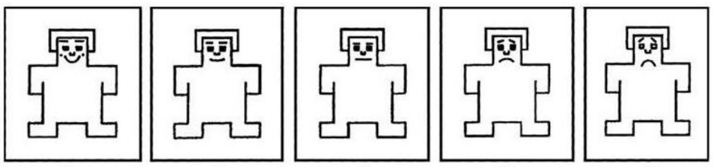
Date: ....   Signature of Participant: ....

Appendix **B**

Light Stimuli Questionnaire

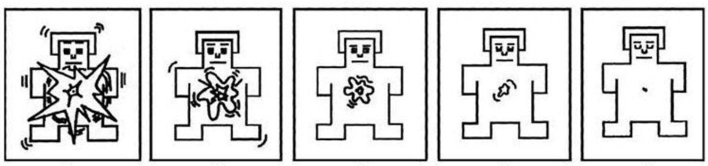
B.1 Instructions

Instructions to fill in the questionnaire



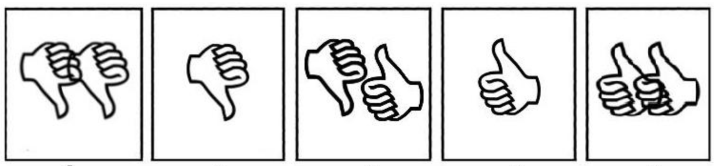
0 0 0 0 0

On the first line of each figure you can indicate what your mood was during the light exposure (from positive to negative).



0 0 0 0 0

On the second line you can indicate your level of arousal during the light exposure (from exciting to calm).



0 0 0 0 0

On the third line, you can indicate how much you liked the light exposure (from not at all to very much).

B.2 Example

1: RED-HL-SAT

When I saw this light, I thought about

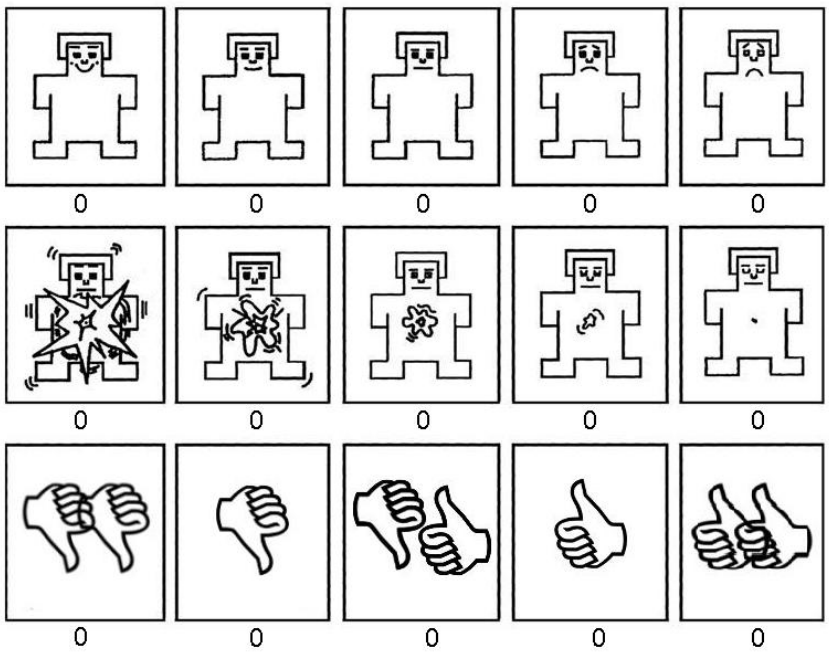
…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

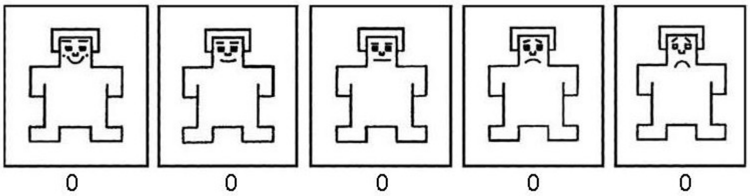


Appendix C

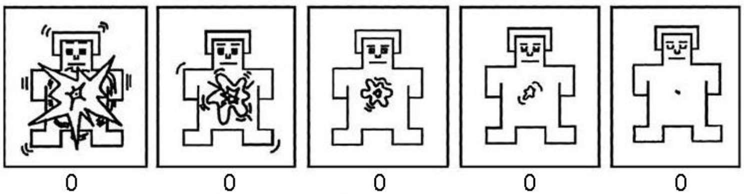
Picture Load Questionnaire

C.1 Instructions

Instructions to fill in the questionnaire



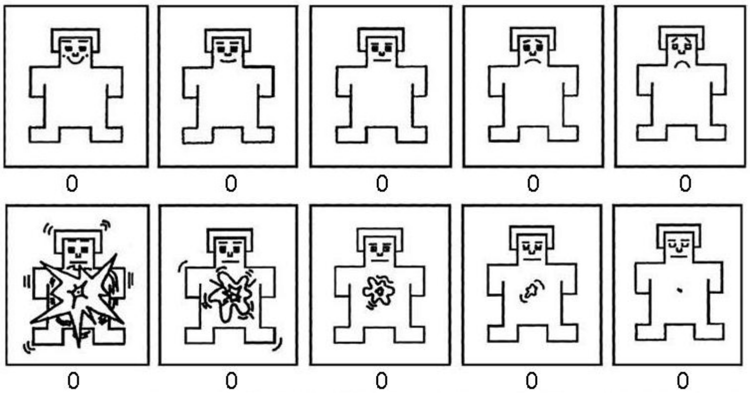
On the first line of each figure you can indicate what your mood is when you see the picture (from positive to negative).



On the second line you can indicate your level of arousal when you see the picture (from exciting to calm).

On the lines you can write down your thoughts when you see this picture.

C.2 Example



Appendix D

Experimental Pictures

D.1 Red Pictures

Figure D.1: The red picture stimuli used in the experiment. Above the two positively calming pictures, and below the negatively arousing ones.

D.2 Green Pictures

Figure D.2: The green picture stimuli used in the experiment. Above the two positively calming pictures, and below the negatively arousing ones.

D.3 Blue Pictures

Figure D.3: The blue picture stimuli used in the experiment. Above the two positively calming pictures, and below the negatively arousing ones.

D.4 White Pictures

Figure D.4: The white picture stimuli used in the experiment. Above the two positively calming pictures, and below the negatively arousing ones.

Appendix E

Subjective Evaluation Result Tables

E.1 Homogeneity

Table E.1: Subjective evaluation results of Levene's homogeneity tests on the colored light settings questionnaire, split to the different scales and the different Picture Load variables.

Picture Color	Scale		
	Valence	Arousal	Preference
Red	F(1,38) = 1.713, p = .199	F(1,38) = 0.401, p = .531	F(1,38) = 1.389, p = .246
Green	F(1,38) = 2.041, p = .161	F(1,38) = 1.993, p = .166	F(1,38) = 0.874, p = .356
Blue	F(1,38) = 2.558, p = .118	F(1,38) = 0.538, p = .468	F(1,38) = 0.075, p = .785

E.2 Normal Distribution

Table E.2: Subjective evaluation results of the Shapiro-Wilk tests for normal distribution on the colored light settings questionnaire, split to the different scales and the different Picture Load variables. Positively calming pictures are indicated with pos/calm, and negatively arousing pictures are denoted with neg/ar.

Picture Color	Picture Load	Scale		
		Valence	Arousal	Preference
Red	neg/ar	D(19) = 0.924, p = .132	D(19) = 0.949, p = .382	D(19) = 0.970, p = .779
	pos/calm	D(21) = 0.988, p = .993	D(21) = 0.946, p = .284	D(21) = 0.986, p = .982
Green	neg/ar	D(20) = 0.964, p = .629	D(20) = 0.972, p = .787	D(20) = 0.924, p = .119
	pos/calm	D(20) = 0.968, p = .711	D(20) = 0.960, p = .546	D(20) = 0.971, p = .775
Blue	neg/ar	D(21) = 0.985, p = .980	D(21) = 0.958, p = .474	D(21) = 0.970, p = .725
	pos/calm	D(19) = 0.949, p = .382	D(19) = 0.954, p = .458	D(19) = 0.935, p = .211

E.3 Analyses with Picture Load

Table E.3: Subjective evaluation results of the OneHue-set analyses including the factor Picture Load. P-values smaller than 0.05 are marked with *.

Red-set analysis	Valence	Arousal
Saturation	F(1,38) = 13.516; p = .001*	F(1,38) = 90.322; p = .000*
Lightness	F(1,38) = 3.799; p = .059	F(1,38) = 0.564; p = .457
Picture Load[a]	F(1,38) = 0.504; p = .482	F(1,38) = 0.009; p = .926
Saturation x Lightness	F(1,38) = 0.073; p = .789	F(1,38) = 4.184; p = .048*
Saturation x Picture Load[a]	F(1,38) = 0.410; p = .526	F(1,38) = 1.983; p = .167
Lightness x Picture Load[a]	F(1,38) = 0.416; p = .523	F(1,38) = 0.230; p = .634
Green-set analysis	Valence	Arousal
Saturation	F(1,38) = 0.052; p = .821	F(1,38) = 22.376; p = .000*
Lightness	F(1,38) = 4.099; p = .050	F(1,38) = 8.794; p = .005*
Picture Load[a]	F(1,38) = 0.038; p = .846	F(1,38) = 4.418; p = .042*
Saturation x Lightness	F(1,38) = 7.305; p = .010*	F(1,38) = 10.000; p = .003*
Saturation x Picture Load[a]	F(1,38) = 0.006; p = .940	F(1,38) = 0.530; p = .471
Lightness x Picture Load[a]	F(1,38) = 5.265; p = .027*	F(1,38) = 0.977; p = .329
Blue-set analysis	Valence	Arousal
Saturation	F(1,38) = 7.746; p = .008*	F(1,38) = 3.915; p = .055
Lightness	F(1,38) = 0.646; p = .427	F(1,38) = 0.419; p = .521
Picture Load[a]	F(1,38) = 0.994; p = .325	F(1,38) = 0.037; p = .848
Saturation x Lightness	F(1,38) = 0.152; p = .698	F(1,38) = 0.362; p = .551
Saturation x Picture Load[a]	F(1,38) = 0.317; p = .577	F(1,38) = 0.325; p = .572
Lightness x Picture Load[a]	F(1,38) = 0.002; p = .968	F(1,38) = 1.910; p = .175

[a]Different Picture Load factors were used for the different analyses: the affective load of the red pictures in case of the Red-set analysis, the affective load of the green pictures for the Green-set analysis, and the affective load of the blue pictures for the Blue-set analysis.

E.4 Analysis without Picture Load

Table E.4: Subjective evaluation results of the Blue-set, RG-set, and RGB-set analyses without the factor Picture Load. P-values smaller than 0.05 are marked with *.

Blue-set analysis	Valence	Arousal
Saturation	F(1,39) = 7.745; p = .008*	F(1,39) = 4.110; p = .050
Lightness	F(1,39) = 0.661; p = .421	F(1,39) = 0.328; p = .570
Saturation x Lightness	F(1,39) = 0.085; p = .772	F(1,39) = 0.285; p = .596
RG-set analysis	Valence	Arousal
Hue	F(1,39) = 4.063; p = .051	F(1,39) = 38.305; p = .000*
Saturation	F(1,39) = 6.364; p = .016*	F(1,39) = 66.619; p = .000*
Lightness	F(1,39) = 5.191; p = .028*	F(1,39) = 4.776; p = .035*
Saturation x Hue	F(1,39) = 10.656; p = .002*	F(1,39) = 42.093; p = .000*
Saturation x Lightness	F(1,39) = 3.354; p = .075	F(1,39) = 20.456; p = .000*
Lightness x Hue	F(1,39) = 0.015; p = .902	F(1,39) = 2.053; p = .160
RGB-set analysis	Valence	Arousal
Hue	F(2,38) = 3.683; p = .035*	F(2,38) = 37.364; p = .000*
Pairwise Comparisons[a]		
Red-Green	p = .300	p = .000*
Red-Blue	p = .027*	p = .000*
Green-Blue	p = .471	p = .003*
Saturation	F(1,39) = 0.056; p = .814	F(1,39) = 45.760; p = .000*
Saturation x Hue	F(2,38) = 13.232; p = .000*	F(2,38) = 20.719; p = .000*

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[a]Corrected for multiple comparisons with Bonferroni.

Appendix F

Psychophysiological Measurement Result Tables

F.1 Baseline analysis

Table F.1: Psychophysiological measurement results for the two minute baselines with the factor Picture Load.

	Red Picture Load	Green Picture Load	Blue Picture Load
COH	F(1,36) = 0.383, p = .540	F(1,36) = 0.192, p = .664	F(1,36) = 0.223, p = .640
HR	F(1,35) = 0.099, p = .754	F(1,35) = 0.125, p = .726	F(1,35) = 0.059, p = .809
HRV	F(1,35) = 0.518, p = .477	F(1,35) = 0.009, p = .923	F(1,35) = 0.038, p = .847
RD	F(1,31) = 0.293, p = .592	F(1,31) = 0.083, p = .775	F(1,31) = 0.039, p = .844
RR	F(1,32) = 0.731, p = .399	F(1,32) = 0.149, p = .702	F(1,32) = 0.150, p = .701
SCL	F(1,36) = 0.360, p = .552	F(1,36) = 0.022, p = .882	F(1,36) = 0.297, p = .589
#SCR	F(1,34) = 0.373, p = .546	F(1,34) = 1.798, p = .189	F(1,34) = 0.238, p = .629
$\overline{x}$ST	F(1,36) = 0.441, p = .511	F(1,36) = 0.462, p = .501	F(1,36) = 0.180, p = .674
∇ST	F(1,36) = 0.011, p = .919	F(1,36) = 0.979, p = .329	F(1,36) = 0.313, p = .580

F.2 Red-set analyses with Picture Load

Table F.2: Psychophysiological measurement results for the Red-set analyses including the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Lightness	Red Picture Load
COH	F(1,38) = 0.610, p = .440	F(1,38) = 0.291, p = .593	F(1,38) = 4.370, p = .043*
HR	F(1,35) = 0.654, p = .424	F(1,35) = 0.984, p = .328	F(1,35) = 1.103, p = .301
HRV	F(1,37) = 0.047, p = .830	F(1,37) = 1.175, p = .285	F(1,37) = 0.869, p = .357
RD	F(1,33) = 0.895, p = .351	F(1,33) = 0.602, p = .444	F(1,33) = 0.259, p = .614
RR	F(1,34) = 0.150, p = .701	F(1,34) = 0.000, p = .992	F(1,34) = 1.126, p = .296
SCL	F(1,36) = 2.025, p = .163	F(1,36) = 0.017, p = .898	F(1,36) = 0.046, p = .832
#SCR	F(1,36) = 5.634, p = .023*	F(1,36) = 2.080, p = .158	F(1,36) = 0.144, p = .706
$\overline{x}$ST	F(1,38) = 0.914, p = .345	F(1,38) = 2.486, p = .123	F(1,38) = 0.514, p = .478
∇ST	F(1,38) = 0.154, p = .697	F(1,38) = 1.152, p = .290	F(1,38) = 1.212, p = .278

	Saturation x Lightness	Saturation x Red Picture Load	Lightness x Red Picture Load
COH	F(1,38) = 0.001, p = .974	F(1,38) = 0.336, p = .566	F(1,38) = 0.067, p = .797
HR	F(1,35) = 0.097, p = .757	F(1,35) = 0.967, p = .332	F(1,35) = 0.038, p = .846
HRV	F(1,37) = 2.174, p = .149	F(1,37) = 0.009, p = .926	F(1,37) = 0.693, p = .410
RD	F(1,33) = 0.846, p = .364	F(1,33) = 0.726, p = .400	F(1,33) = 4.860, p = .035*
RR	F(1,34) = 0.021, p = .885	F(1,34) = 0.863, p = .360	F(1,34) = 0.002, p = .961
SCL	F(1,36) = 1.113, p = .298	F(1,36) = 1.750, p = .194	F(1,36) = 0.032, p = .859
#SCR	F(1,36) = 0.000, p = .995	F(1,36) = 0.250, p = .620	F(1,36) = 0.740, p = .395
$\overline{x}$ST	F(1,38) = 1.506, p = .227	F(1,38) = 0.280, p = .600	F(1,38) = 0.114, p = .738
∇ST	F(1,38) = 3.675, p = .063	F(1,38) = 0.008, p = .929	F(1,38) = 0.975, p = .330

	Gender	Saturation x Gender	Lightness x Gender
HR	F(1,35) = 15.241, p = .000*	F(1,35) = 3.906, p = .056	F(1,35) = 3.384, p = .074
SCL	F(1,36) = 0.206, p = .653	F(1,36) = 0.631, p = .432	F(1,36) = 0.998, p = .324

F.3 Green-set analyses with Picture Load

Table F.3: Psychophysiological measurement results for the Green-set analyses including the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Lightness	Green Picture Load
COH	F(1,38) = 1.640, p = .208	F(1,38) = 0.012, p = .912	F(1,38) = 3.130, p = .085
HR	F(1,34) = 4.350, p = .045*	F(1,34) = 0.527, p = .473	F(1,34) = 0.525, p = .474
HRV	F(1,35) = 0.006, p = .938	F(1,35) = 1.106, p = .300	F(1,35) = 0.088, p = .768
RD	F(1,33) = 0.082, p = .777	F(1,33) = 1.794, p = .190	F(1,33) = 0.100, p = .754
RR	F(1,34) = 0.463, p = .501	F(1,34) = 0.213, p = .647	F(1,34) = 0.363, p = .551
SCL	F(1,35) = 1.190, p = .283	F(1,35) = 0.765, p = .388	F(1,35) = 0.186, p = .669
#SCR	F(1,36) = 0.248, p = .621	F(1,36) = 0.556, p = .461	F(1,36) = 2.395, p = .130
$\overline{x}$ST	F(1,38) = 0.278, p = .601	F(1,38) = 0.038, p = .847	F(1,38) = 0.186, p = .669
∇ST	F(1,38) = 0.120, p = .730	F(1,38) = 3.354, p = .075	F(1,38) = 0.699, p = .408
	Saturation x Lightness	Saturation x Green Picture Load	Lightness x Green Picture Load
COH	F(1,38) = 1.551, p = .221	F(1,38) = 5.944, p = .020*	F(1,38) = 1.300, p = .261
HR	F(1,34) = 0.330, p = .569	F(1,34) = 1.000, p = .324	F(1,34) = 0.299, p = .588
HRV	F(1,35) = 1.470, p = .233	F(1,35) = 8.227, p = .007*	F(1,35) = 0.827, p = .369
RD	F(1,33) = 0.038, p = .847	F(1,33) = 0.148, p = .703	F(1,33) = 6.390, p = .016*
RR	F(1,34) = 0.063, p = .803	F(1,34) = 0.050, p = .825	F(1,34) = 2.213, p = .146
SCL	F(1,35) = 0.144, p = .707	F(1,35) = 0.182, p = .672	F(1,35) = 0.079, p = .781
#SCR	F(1,36) = 0.283, p = .598	F(1,36) = 1.012, p = .321	F(1,36) = 0.302, p = .586
$\overline{x}$ST	F(1,38) = 0.244, p = .624	F(1,38) = 0.139, p = .711	F(1,38) = 0.256, p = .616
∇ST	F(1,38) = 1.157, p = .289	F(1,38) = 0.288, p = .595	F(1,38) = 0.002, p = .967
	Gender	Saturation x Gender	Lightness x Gender
HR	F(1,34) = 15.964, p = 000*	F(1,34) = 0.036, p = .851	F(1,34) = 0.004, p = .949
SCL	F(1,35) = 0.274, p = .604	F(1,35) = 1.400, p = .245	F(1,35) = 2.251, p = .143

F.4 Blue-set analyses with Picture Load

Table F.4: Psychophysiological measurement results for the Blue-set analyses including the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Lightness	Blue Picture Load
COH	F(1,38) = 0.004, p = .947	F(1,38) = 0.244, p = .624	F(1,38) = 2.270, p = .140
HR	F(1,35) = 0.466, p = .500	F(1,35) = 0.996, p = .325	F(1,35) = 0.069, p = .794
HRV	F(1,37) = 2.423, p = .128	F(1,37) = 1.734, p = .196	F(1,37) = 0.104, p = .749
RD	F(1,33) = 0.122, p = .729	F(1,33) = 0.017, p = .896	F(1,33) = 0.000, p = .990
RR	F(1,34) = 0.050, p = .824	F(1,34) = 0.018, p = .893	F(1,34) = 2.184, p = .149
SCL	F(1,35) = 4.012, p = .053	F(1,35) = 0.522, p = .475	F(1,35) = 0.596, p = .445
#SCR	F(1,36) = 9.904, p = .003*	F(1,36) = 0.398, p = .532	F(1,36) = 0.387, p = .538
$\overline{x}$ST	F(1,38) = 0.078, p = .781	F(1,38) = 0.908, p = .347	F(1,38) = 0.091, p = .765
∇ST	F(1,38) = 0.887, p = .352	F(1,38) = 1.586, p = .216	F(1,38) = 0.126, p = .724

	Saturation x Lightness	Saturation x Blue Picture Load	Lightness x Blue Picture Load
COH	F(1,38) = 3.891, p = .056	F(1,38) = 1.876, p = .179	F(1,38) = 0.324, p = .573
HR	F(1,35) = 0.078, p = .781	F(1,35) = 0.166, p = .686	F(1,35) = 4.008, p = .053
HRV	F(1,37) = 0.468, p = .498	F(1,37) = 0.080, p = .779	F(1,37) = 0.448, p = .507
RD	F(1,33) = 0.098, p = .757	F(1,33) = 1.949, p = .172	F(1,33) = 0.877, p = .356
RR	F(1,34) = 0.680, p = .415	F(1,34) = 2.554, p = .119	F(1,34) = 0.976, p = .330
SCL	F(1,35) = 2.394, p = .131	F(1,35) = 0.280, p = .600	F(1,35) = 2.685, p = .110
#SCR	F(1,36) = 0.030, p = .864	F(1,36) = 0.419, p = .521	F(1,36) = 0.119, p = .732
$\overline{x}$ST	F(1,38) = 1.180, p = .284	F(1,38) = 0.404, p = .529	F(1,38) = 0.400, p = .531
∇ST	F(1,38) = 0.106, p = .746	F(1,38) = 2.668, p = .111	F(1,38) = 0.316, p = .578

	Gender	Saturation x Gender	Lightness x Gender
HR	F(1,35) = 12.304, p = .001*	F(1,35) = 0.004, p = .948	F(1,35) = 0.055, p = .815
SCL	F(1,35) = 0.020, p = .888	F(1,35) = 1.480, p = .232	F(1,35) = 0.516, p = .478

F.5 Blue-set analyses without Picture Load

Table F.5: Psychophysiological measurement results for the Blue-set analyses without the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Lightness	Saturation x Lightness
COH	F(1,39) = 0.018, p = .894	F(1,39) = 0.221, p = .641	F(1.39) = 4.033, p = .052
HR	F(1,37) = 0.497, p = .485	F(1,37) = 0.855, p = .361	F(1,37) = 0.051, p = .823
HRV	F(1,38) = 2.508, p = .122	F(1,38) = 1.807, p = .187	F(1,38) = 0.474, p = .495
RD	F(1,34) = 0.052, p = .821	F(1,34) = 0.045, p = .833	F(1,34) = 0.217, p = .644
RR	F(1,35) = 0.156, p = .695	F(1,35) = 0.001, p = .980	F(1,35) = 1.116, p = .298
SCL	F(1,37) = 3.381, p = .074	F(1,37) = 0.552, p = .462	F(1,37) = 2.673, p = .111
#SCR	F(1,37) = 9.873, p = .003*	F(1,37) = 0.432, p = .515	F(1,37) = 0.064, p = .801
$\overline{x}$ST	F(1,39) = 0.063, p = .804	F(1,39) = 0.864, p = .358	F(1,39) = 1.037, p = .315
∇ST	F(1,39) = 0.711, p = .404	F(1,39) = 1.691, p = .201	F(1,39) = 0.155, p = .696

	Gender	Saturation x Gender	Lightness x Gender
HR	F(1,37) = 12.254, p = .001*	F(1,37) = 0.006, p = .938	F(1,37) = 0.041, p = .842
SCL	F(1,37) = 0.095, p = .759	F(1,37) = 1.005, p = .323	F(1,37) = 0.598, p = .444

F.6 RG-set analyses without Picture Load

Table F.6: Psychophysiological measurement results for the RG-set analyses without the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Lightness	Hue
COH	F(1,39) = 1.331, p = .256	F(1,39) = 0.165, p = .687	F(1,39) = 0.279, p = .600
HR	F(1,36) = 1.179, p = .285	F(1,36) = 0.273, p = .604	F(1,36) = 0.899, p = .349
HRV	F(1,36) = 0.053, p = .820	F(1,36) = 0.061, p = .806	F(1,36) = 0.077, p = .783
RD	F(1,34) = 0.165, p = .687	F(1,34) = 1.251, p = .271	F(1,34) = 0.011, p = .916
RR	F(1,35) = 0.415, p = .524	F(1,35) = 0.105, p = .748	F(1,35) = 0.123, p = .727
SCL	F(1,37) = 2.654, p = .112	F(1,37) = 0.245, p = .623	F(1,37) = 3.898, p = .056
#SCR	F(1,37) = 3.318, p = .077	F(1,37) = 3.181, p = .083	F(1,37) = 0.953, p = .335
$\overline{x}$ST	F(1,39) = 0.561, p = .458	F(1,39) = 0.918, p = .344	F(1,39) = 0.063, p = .803
∇ST	F(1,39) = 0.220, p = .642	F(1,39) = 4.101, p = .050	F(1,39) = 0.020, p = .888
	Saturation x Hue	Lightness x Hue	Saturation x Lightness
COH	F(1,39) = 0.284, p = .597	F(1,39) = 0.182, p = .672	F(1,39) = 0.709, p = .405
HR	F(1,36) = 3.896, p = .056	F(1,36) = 2.293, p = .139	F(1,36) = 0.020, p = .889
HRV	F(1,36) = 0.044, p = .835	F(1,36) = 2.392, p = .131	F(1,36) = 3.152, p = .084
RD	F(1,34) = 0.623, p = .435	F(1,34) = 0.482, p = .492	F(1,34) = 0.318, p = .577
RR	F(1,35) = 0.036, p = .851	F(1,35) = 0.165, p = .687	F(1,35) = 0.002, p = .969
SCL	F(1,37) = 1.460, p = .235	F(1,37) = 1.600, p = .214	F(1,37) = 0.125, p = .726
#SCR	F(1,37) = 4.441, p = .042*	F(1,37) = 0.299, p = .588	F(1,37) = 0.119, p = .732
$\overline{x}$ST	F(1,39) = 0.411, p = .525	F(1,39) = 3.046, p = .089	F(1,39) = 0.838, p = .366
∇ST	F(1,39) = 0.001, p = .981	F(1,39) = 0.777, p = .384	F(1,39) = 0.061, p = .807
	Gender		
HR	F(1,36) = 14.925, p = .000*		
SCL	F(1,37) = 0.256, p = .616		
	Saturation x Gender	Lightness x Gender	Hue x Gender
HR	F(1,36) = 0.993, p = .326	F(1,36) = 1.232, p = .274	F(1,36) = 0.696, p = .410
SCL	F(1,37) = 0.010, p = .920	F(1,37) = 2.350, p = .134	F(1,37) = 0.632, p = .432

F.7 RGB-set analyses without Picture Load

Table F.7: Psychophysiological measurement results for RGB-set analyses without the factor Picture Load. P-values smaller than 0.05 are marked with *.

	Saturation	Hue	Saturation x Lightness
COH	F(1,39) = 0.006, p = .941	F(2,38) = 0.040, p = .961	F(2,38) = 0.540, p = .587
HR	F(1,37) = 0.011, p = .919	F(2,36) = 1.446, p = .249	F(2,36) = 2.336, p = .111
HRV	F(1,37) = 1.021, p = .319	F(2,36) = 0.759, p = .475	F(2,36) = 0.262, p = .771
RD	F(1,34) = 0.036, p = .852	F(2,33) = 1.201, p = .314	F(2,33) = 0.004, p = .996
RR	F(1,35) = 0.001, p = .971	F(2,34) = 0.119, p = .888	F(2,34) = 1.449, p = .249
SCL	F(1,37) = 4.068, p = .051	F(2,36) = 0.199, p = .820	F(2,36) = 1.114, p = .339
#SCR	F(1,37) = 3.554, p = .067	F(2,36) = 3.740, p = .033*	F(2,36) = 1.879, p = .167
Pairwise	-	Red-Green: p = .909	-
Comparison[a]	-	Red-Blue: p = .031*	-
	-	Green-Blue: p = .209	-
$\overline{x}$ST	F(1,39) = 0.019, p = .890	F(2,38) = 1.688, p = .199	F(2,38) = 0.185, p = .832
∇ST	F(1,39) = 0.504, p = .482	F(2,38) = 0.737, p = .485	F(2,38) = 0.795, p = .459

	Gender	Saturation x Gender	Hue x Gender
HR	F(1,37) = 14.049, p = .001*	F(1,37) = 0.510, p = .480	F(2,36) = 1.485, p = .240
SCL	F(1,37) = 0.377, p = .543	F(1,37) = 0.350, p = .558	F(2,36) = 0.410, p = .667

[a]Corrected for multiple comparisons with Bonferroni.