The experience of colour

This chapter is presented in the Thesis of Iris Bakker and is realised with co-author Jan de Boon

Abstract

The experience of colour is a complex phenomenon that it is difficult to define and to measure the influences on people. In the current paint industry three indicators are used to define the qualities of colour: hue, saturation and intensity (HSI) (Castleman, 1998). Colour studies use these terms to define colour qualities. However, it appears that these three colour qualities are too limited to describe colour experience in its totality. The research findings show large differences. People experience their environment, including colour, at different processing levels: physiological, affective and cognitive. A framework with these perspectives is used to learn about the background of colour. Humans experience the coloured environment with all their senses as the human sensory information system is the only system that is responsible for transporting data concerning the connection between the outer environment and the inner human. Each sense focuses on a specific colour characteristic as it appears in nature. As these colour characteristics represent themselves as polarities such as warmth and coldness, harmony and disharmony and light and darkness, they appeal to specific colour contrasts. In their turn these colour contrasts appeal to specified senses. For example, the sense of temperature is sensitive for the warmth-coldness contrast. The connection between twelve natural phenomena, twelve senses and twelve colour contrasts explain the colour experience in its totality. This view shows that the HSI method is too limited, since it only uses three types of colour contrasts. Relying solely on the HSI method may be one of the causes why colour research shows ambiguous results.

6.1 Introduction

Previous research described in the chapters 4 and 5 shows the difficulties of establishing effects of colour on productivity. Colour appears to be a complex and versatile phenomenon that influences people via physiological, affective and cognitive processes and thereby may affect productivity. The goal of the present research is to examine how colour influences people and their productivity and to specify the optimal physical conditions for enhancing productivity. For this reason, an exploration is carried out within three knowledge areas to be able to define the total colour experience. The following questions have been a guide for this search:

1. Physiological level: Which evolutionary developed systems and physiological mechanisms in the eye can be traced determining the way how we see and experience colours?
2. Affective level: Does colour influence emotional and motivational processes and feelings?
3. Cognitive level: How does colour influence the mind and how we think about colour. Can we learn about the mechanism by looking at ancient cultures and applied languages on colour?

As the focus is purely on seeing and experiencing colours, no attention will be paid to the capacities of recognizing of movement and changes, although this is a fundamental functionality of the human eye. Also colour is a dynamic phenomenon in nature and the human eye is a perfect instrument of vision with the focus on differences. The eye is extremely focused on signal movements. Even in stable situations without any changes in the environment, the eye is searching with so-called cascades for movements. In this chapter we focus on the influences of colour, although it is realised that vision concerns integrated functionalities. In fact colour analysis and coding cannot be isolated from analysis and coding of attributes such as form and motion (Gegenfurtner and Kiper, 2003). In addition, the eye is not developed to observe monochromatic colours, but is always searching for changes and variations in colour.

Due to the complex and elusive character of colour, in addition to experimental research, also other views will be examined to understand the influences of colour. The focus is on the influence of colours through the eye. It could be possible that in addition colours have effects through the human skin, although this has not been demonstrated by experimental research. Cojochen et al (2006) showed there was no acute elevation of body temperature or suppression of melatonin when light was administered to the skin in the popliteal area (Cajochen et al, 2005). In addition, Foster et al (1991), Eastman et al (2000), Lindblom et al (2000) and Wright and Czeisler (2002) showed no effects when bright light is lit behind the knee. In contrast, Campbell and Murphy (1998) found this effect.

As the environment influences people in their development, behaviour, their ways of thinking, also colour influences our behaviour, since colour is an integrated part of the environment. To understand how colour influences people, it is important to understand how colour is experienced. Colour research makes use of the HSI system, with Hue, Saturation and Intensity as features to define the exact colour. The HSI- system is often used in the paint industry (Castleman, 1998) and provides users practical information on what the colour looks like. Other systems used are physical and focus on wavelengths and number of quanta (Van Beek, 1983) or physiological with a focus on the number of red, blue and green photons as the receptors in the human eye are sensitive for these colours (Conway, 2009). The choice of system used in research determines the output. The system used to watch determines the results. In this paper the assumption is that when colour research is based on the three HSI-factors, significant facts can be found related to these factors (Tedford et al, 1977, Valdez and Mehrabian, 1994, Mahnke, 1996, Camgoz et al, 2003). If the HSI-factors are *not* the only indicators for human experience, conflicting results could be found in colour research and this is exactly the case: colour researches show in many cases conflicting results (Bakker, 2013b, 2013c).

People experience their environment on an unconscious level (Dijksterhuis, 2007). People generally focus on the activities they are doing and not on details in the environment. This is due to the efficient energy system of the human brain: the neurological processes are efficiently organised to minimize the need for energy consumption (Niven and Laughlin, 2008). Although the brain only accounts for 2% of the human bodyweight, it accounts for 20% of the resting metabolism (Attwell and Laughlin, 2001) with a relative high demand for the visual cortex (Wong-Riley, 2010). To minimize this need for energy, the human vision system has developed high efficiency methods to transport and manipulate visual data. James Grimes (1996) demonstrated that the eye registers far less details when subjects are showed nearly the same pictures. This example stresses the dominant role of mental representations in perception (in Gregory, 1998). Another efficiency measure is that looking at areas with the same brightness, the eye mainly focuses on boundaries of those areas and not on the areas themselves (Fortner and Meyer, 1997; Gregory, 1998). The blind spot test, used by Gerritsen (1972), shows that the human eye completes images without testing exactly all details. The blind spot test shows not only the existence of the blind spot, but also that the human eye completes images which actually do not exist. Gerritsen used as background for the blind spot test a checkered pattern and it can be observed that exactly at the blind spot, the checkered pattern emerges and the eye completes the checkered pattern, which in fact the eye could not see.

People experience colour depending on context and their expectations. Detailed environmental information appears on a conscious level only in situations in which the environment does not fit to our expectations, or if we pay specific attention to it for other reasons. If a tree has violet colours, people are aware of this strange phenomenon because it differs from their expectations of a green tree that they are accustomed to (Vonk, 2003). People consciously pay attention to the violet tree because it is abnormal to their expectations. In hospitals for instance the colour white is often applied to hospital walls. If a wall is pink coloured in a hospital, it will be more striking than if found in a trendy clothing store where striking colours are often applied (Vonk, 2003). The representations stored in the human memory, are connected with contextual information.

The main question

The main question is whether any mechanism exists that more accurately defines the human experience of colour and how people physiologically, affectively and cognitively are influenced.

Related to the physiological processes, insight is needed on how the human eye functions (Figure 1). First, the evolutionary development of the human eye could be useful in understanding the working principles and learning more about colour experience. Next, it could be useful to learn about physiological insights. Related to the affective processes, insight is needed on how people psychologically experience and react on colour. Thirdly, related to the cognitive processes, cultural developments and etymological information about the development of colour words and original meanings are interesting.

The next guide will be followed to find the way how colour influences people (see Figure 1):

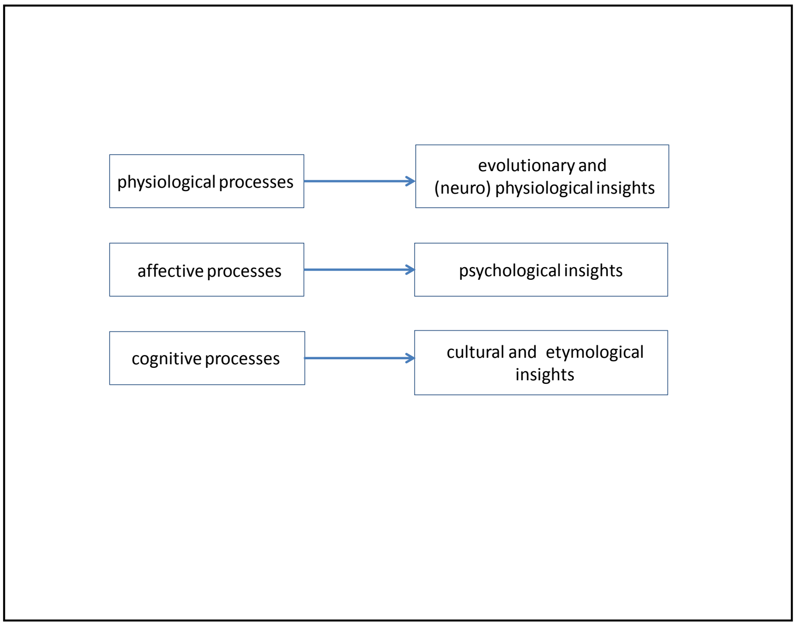

Figure 1: The view on colour: physiological, affective and cognitive view

In the next paragraphs the experience of colour will be discussed separately for the three mentioned views. Each paragraph begins with a question and ends with a conclusion. Lastly, a view is presented to define the human colour experience in a more appropriate way.

6.2 What is the influence of colour on physiological processes?

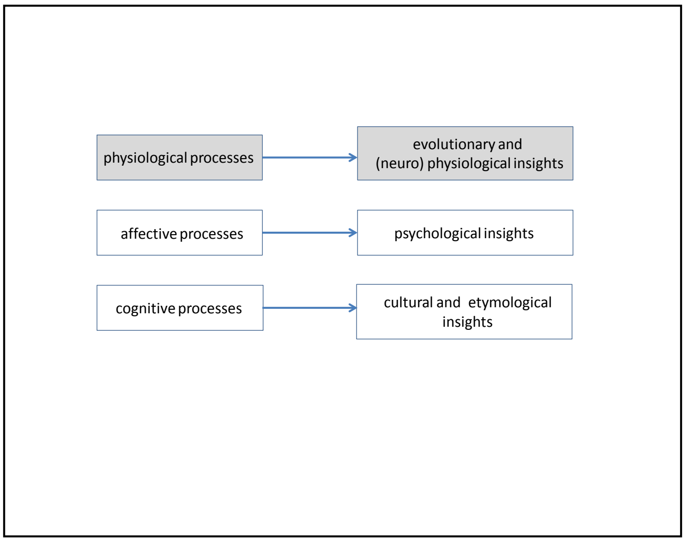

Figure 2: The view on physiological processes

The research question with respect to the physiological processes is: which evolutionary developed systems or (physiological mechanisms in the eye determine the way how we see and experience colours?

6.2.1 Colour vision and evolution

Are there any evolutionary developed systems in the human eye which physically influences colour experience?

More than 600 million years ago (Mya period) early organisms evolved with photoreceptors with a light sensitivity (Conway, 2009). These types of vision had purely a cardian and/or shadow detecting function (Lamb et al, 2007). Since they have only one type of photoreceptor these early organisms could not discern any colour. After a development of sensitivity for the yellow (middle waves) and the blue light (short waves) and a long period of dichromatic vision, about thirty million years ago, the trichromatic colour vision of today developed (Nathans, 1999). During this period a gen duplication and modification took place. After this gen duplication and modification, a comparison of the middle and long waves was possible thereby providing the early ancestors of people the ability to see the colour red (Conway, 2009). Scientists in the nineteenth century developed the hypothesis that the gen duplication is a co-evolutionary development connected with the appearance of yellow or orange coloured fruit of tropical trees. More recent ecological evidence shows that these trees such as several members of the family Sapotaceae, are exclusively dispersed by monkeys, with the same colour vision system of trichromacy (Mollon, 1995). The development of trichromacy and the ability to see the colour red was induced by the existence of ripe fruit. Evolutionary, the only reason to see colours is the ability to discern objects when the background is multi-coloured and vary in forms and lightness and to see in complex environments which elements belong together (Mollon, 1995). The early existence of being able to see the middle wavelengths (yellow) is probably due to the fact that these wavelengths had the lowest attenuation through saltwater (Conway, 2013). We hypothesize that the early existence of seeing blue is caused by the need for polarity of seeing yellow, due to the fact that all sensory systems are based on polarities in order to see and experience the world as a totality (Schneider,1987; Goethe, 1981; Bortoft, 2010; Bohm, 1985).

Conclusion
The human eye is not developed as an instrument to observe colours but to discern objects.

6.2.2 Physiology of the human eye

Which mechanisms in the eye determine the way how we see and experience colours?
All processes are strongly connected to each other and all the organs in the human body cooperate together, therefore it is difficult to separate them. The reason we focus on colour vision by means of different mechanisms and data streams, is to bring some clarity to the different functionalities and the way how mechanisms operate together. As Darwin states '*the eye, with all its inimitable contrivances... could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree...*' (Lamb et al, 2007), it is impossible to describe all details of the human eye in a respectful way. Many excellent researchers as Hering, Helmholtz, Land, Maxwell and Young have made enormous progress giving insight in how people observe colours. However, there are still many questions. After analysing data and mechanisms on the human eye (realizing that the functionality of the human will be simplified), it appears that for the experience of colours two mechanisms are fundamental in observing and experiencing colours. The first mechanism concerns discerning and recognizing objects by means of colour contrast and colour constancy respectively. Colour contrast enables people to discern objects and colour constancy contributes to the ability of recognition. The second mechanism concerns the cooperation between physiological, affective and cognitive processes and forms an intelligent exchange system of visual information located in the central part of the brain (Milner, 1974; Gegenfurtner and Kiper, 2003; Sarter et al, 2006).

Colour contrasts and colour constancy: *making comparisons*
In the process of seeing colours the ability of seeing distinction is based on detecting contrasts. The eye is extremely focused on detecting different types of contrasts. Even the basic organisation for transformation of information to the brain by neurons is a complex network of thousands or millions connections with other neurons, enabling the ability to discern contrasts. The communication between neurons happens by on and off cells, the so called excitatory and inhibitory cells: if signals of information are too small or too large, an inhibitory process begins, however if the signals are appropriate, excitatory processes forward the information (Hubel, 1990; Kandel et al, 2000). The human eye observes incoming wavelengths not as isolated signals, but observes data in their totality related to their spatial and temporal context (Grossberg, 1994; Grossberg et al, 1997; Conway, 2009). Complex networks of opponent cells, double opponent cells, bipolar cells and horizontal cells all contribute to find these contrasts related to context (Stockman and Brainard, 2010; Conway, 2009). In the retina and in the visual cortex processes of comparison take place of the cone activities to compute these colour contrasts (Conway, 2009). This theme of comparison is recognizable by observing colour in two ways. First, comparisons are made between objects and their context and background by making use of colour contrasts to discern objects. Different types of colour contrast exist, such as: dark-light contrast, colour contrast, warm-cold contrast, complementary contrast, simultaneous contrast, successive contrast, quality contrast and quantity contrast. It appears that these types of contrast enable us to see the nuances in colour. Secondly, the comparisons between new objects and objects in our memory, make use of colour constancy to facilitate recognition.

Colour constancy is achieved by local comparison of light reflections coming from the object and adjacent areas (Hurlbert and, Wolf, 2004; Danilova and Mollon, 2006). The result is that we observe well known coloured objects as the same colour while in reality the colours are different due to different illumination conditions. For example, while looking at a white paper under a tree with greenish light reflections through the green leaves, we just see a white paper. However, a camera makes use of the factual existence of middle wavelengths and registers a greenish coloured image. Under different light conditions objects appear the same and facilitate recognition. Factors, such as memory and learning are the critical and determining factors that contribute to colour constancy. Scientists have long searched for the mechanisms of colour constancy: Helmholtz (1867) wrote about human judgement of colours through the undefined process of the '*unconscious interference*'. Hering (1877) emphasized the importance of memory (Zeki and Marini, 1998) and Land and McCann (1971) formulated his retinex theory. Zeki and Marini (1998) indicated the involvement of higher cognitive functions and the predominant role of the cerebral cortex. Recently computations with algorithms define how the primary visual cortex arranges colour constancy (Barnard et al, 2002; Finlayson and Trezzi, 2004; Van de Weijer et al, 2007).

Intelligent exchange of visual information connects physiological, affective and cognitive processes .
The colour information sent from the retina is translated into understandable images and is not transported through one simple stream of factual colour information directly to the visual cortex for decoding, but encounters mediating systems before reaching the visual cortex (Das et al, 2005; Sarter et al, 2006). Two basic pathways transport visual data and transform data into perceptual information: the optical pathway and the energetic pathway.

The optical pathway
In 1860 Helmholtz already argued '*it may often be rather hard to say how much of our perceptions (Anschauungen) as derived by the sense of sight is due directly to sensation, and how much of them, on the other hand, is due to experience and training'* (Pollen, 1999). With the terms 'Vorstellung' or 'Idea' he meant all visual images people have in their mind without any present sensory impression and he applied the term 'Perzeption' for an awareness of a direct sensation (Pollen, 1999). Helmholtz believed in the existence of processes that permanently mix the ideas in our memory and present sensory impression. Neurological evidence research has found how neurological networks combine new sensory information with cognitive recognitions (Pollen, 1999). This combination solves the 'stability-plasticity-dilemma': new sensory data is compared to stable memories and learnt expectations but the brain remains flexible enough to process new sensory input (Pollen, 1999). To blend new sensory data with our memory and expectations, brain feedback loops exist between the different portions of the visual brain (V1 till V5 i.e. parts of the visual cortex) and the LGN (Lateral Geniculate Nucleus i.e. the centre relaying visual information from the retina to the visual cortex) in the thalamus (Milner, 1974) which functions as the primary relay centre for visual information (Figure 3).

In 1969 Gerald Schneider assumed an optical system with a separation in the brain of the localization of a stimulus (the 'where' pathway) and the identification of a stimulus (the 'what'- pathway). This assumption appeared to be true. The 'where' pathway appeared to be the so called dorsal pathway (Milner and Goodale, 1995) which sends retinal information concerning localization of a stimulus and goes from the tractus opticus, through the superior colliculus located in the mid brain to the posterior parterial cortex. It is interesting to understand perception and how we experience colour through the 'what-pathway'. The 'what' pathway appeared to be the ventral pathway (Milner and Goodale, 1995) which sends most of the retinal information through the tractus opticus and then through the lateral geniculate nucleus (dorsal part) (LGNd) - which is located in the thalamus - to the inferior temporal cortex (Mishkin et al, 1983; Goodale and Milner, 1992; Gegenfurtner and Kiper, 2003). This ventral pathway sends information concerning presentation, identification, recognition and perception inclusive. Due to our mental representations, objective colour characteristics such as data concerning wavelengths are transformed into labelled colour information. This information system unconsciously influences the psychological and physiological state of people. The centre of the psychological processes is the amygdala (Morris et al, 1996). The thalamus – in which the LGN is located- is directly connected to the amygdala (Das, 2005) and the reticular activating system (Sarter et al, 2006). In the thalamus an exchange of colour information takes place, and actually physiological, affective and cognitive processes cannot be entangled but work strongly together (Figure 3). Also in his book 'Descartes' Error: Emotion, Reason, and the Human Brain' Damasio (1994) indicates this strong connection between physiological, affective and cognitive processes.

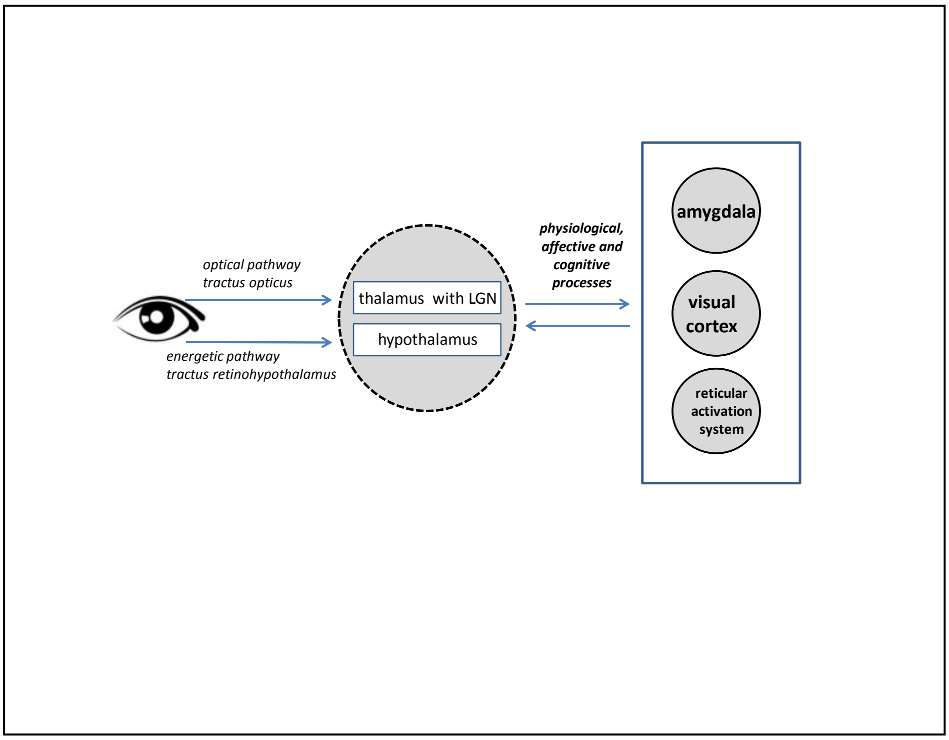

Figure 3: illustration of the way in which colour characteristics are translated into labelled information, from wavelength into recognition of colours.

The energetic pathway

In order to process retinal information very quickly, there is a second path, i.e. the energetic pathway that is stimulated by light. This second pathway was recently discovered in 1990s by researchers as Berson et al (2002, 2003), Foster (2005) and Hankins and Lucas (2002). It appeared that about 1 % of the retinal ganglion cells have a specific light sensitivity. This system is not only responsible for the regulation of sleep and circadian rhythms, but in addition sends information, colour information inclusive, through the Reticular Formation- the most influential component of the Ras-system-, located in the brainstem to the ascending arousal system that is responsible for cortical arousal (Garcia-Rill, 2002; Saper et al, 2005; Walusinki, 2006). This rather small part of retinal information directly influences the physiological processes through the hypothalamus and the pituitary gland (Figure 3).

There is a maximum sensitivity for the blue part of the spectrum (420-480 nm) (Foster, 2005; Cajochen et al, 2005). Hankins and Lucas (2002) measured activities at the 576 nm wavelength, and also larger wavelengths that resulted in increased light response to the condition that the wavelengths are bright enough (Berson, 2013). Human unconscious responses to light (pupillary, circadian or neuroendocrine, etc.) are largely mediated by the ganglion-cell photoreceptors. These ganglion cells also draw information from the other photoreceptor types by way of indirect synaptic circuits. This means that these "reflexive" or "non-image-forming" visual responses are actually quite broad in their spectral (colour) tuning (Berson, 2013). Through the energetic pathway humans unconsciously experience colour characteristics.

Through the optical pathway and the energetic pathway objective retinal information is processed through loops encountering our memories – colour memories inclusive- and is transformed into labelled colour information. Due to our memory, objective colour information is transformed into labelled colour information. People do not experience colour in an objective way.

Conclusion:

Seeing colours helps people to discern and recognize objects by means of colour contrast and colour constancy. Neurological systems transform objective colour information into colour qualities, a process located in the visual cortex with strong interference of the amygdala and the reticular activating system. Intern loops blend colour information perceived by the ganglia in the eye with physical, cognitive and emotional memories into colour labels. Seeing and experiencing colours is a result in which physiological, affective and cognitive processes are *closely intertwined. Due to our personal characteristics and memories, it is possible that personal reactions on colour stimuli differ.*

6.3 Colour and the affective processes

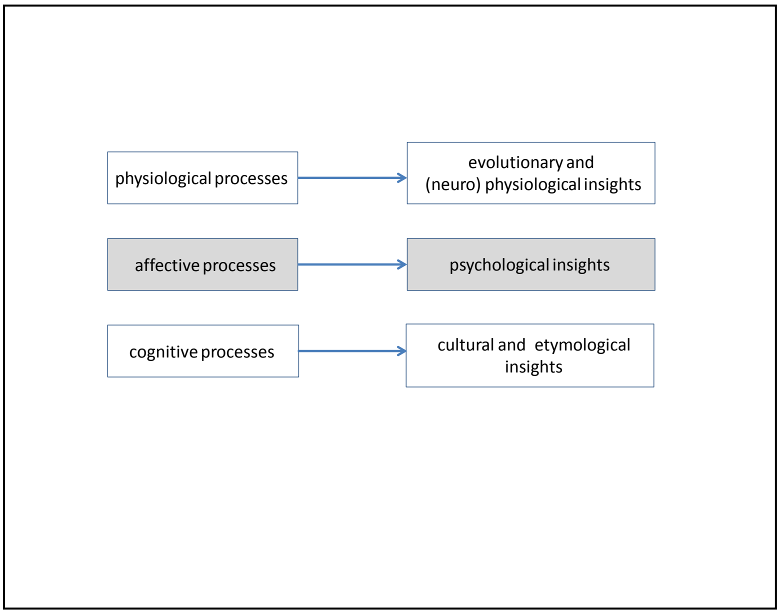

Figure 4: the view on affective processes

The research question with respect to affective processes: What are the effects of colour on affective processes?

Our brain probably encodes the external world by means of symbolic representations of things, creatures and events (Ramachandran, 2006) and therefor the world of colour seems to be extremely difficult to understand. Is it true that our own nature determines which story a colour will tell? Goethe (1810) indicated the central role of the soul in the phenomenological observation when the subjective colour feelings and objective colour quality meet; it is the soul that translates the language of colour. Steiner (1914) mentioned that '*Colour is the language of the soul of the universe'*. Also Kandinsky relates the effects of colour directly to the soul. Albers (2006) indicated the fact that colour continuously deceives. Albers wrote: '*First, it should be learned that one and the same colour evokes innumerable readings. And experience teaches that in visual perception there is a discrepancy between physical fact and psychic effect. In visual perception a colour is almost never seen as it* *really is – as it physically is. This fact makes colour the most relative medium in art'*. Birren (1982) writes '*Uniform illumination and uniform brightness in the field of vision may be ideal from an academic standpoint, but they are inconsistent with the natural properties and capabilities of human beings'*. Itten (1961) distinguishes the real value of colour and the subjective colour quality as two different phenomena.

Colour directly influences the psyche as colour influences mood and affect (Goethe, 1810; Rosenstein, 1985; Kwallek et al, 1988; Küller et al, 2006, 2009). People do not observe the environment as a collection of objective facts, but rather experience spaces, climate aspects, things and colours subjectively depending on personal experiences, characteristics, mood and constitution. The so called mental representations, a mix of objective factual information and subjective personal interpretations determines our affect (Goethe, 1810; Zeylmans van Emmichoven, 1923; Scheuerle, 1984; Bendin, 2008; Vonk, 2003). Learnt associations and memories contribute to these subjective interpretations. The colour red for instance is associated with energy and blue is associated with calmness. Due to these learnt associations, red feels energetic and blue suggests calm.

Memories determine the way in which we perceive colour (Bendin, 2008). For instance, a person whose parents had a yellow carpet in the bedroom and as a young child the parents provided feelings of safety in the bedroom, the young child may have developed a learnt preference for the same colour of yellow as the carpet because that colour represents feelings of safety. So, mental representations permanently influence consciously or unconsciously the way how we perceive the environment, colours inclusive. This also exists during pre-conscious observation, the so-called subliminal observation - when a stimulus is shown in such a short period, that the observer hasn't been aware of the presentation- the information is being interpreted and judged and has an influence on the affect. When a phobia exists, such as being afraid of snakes and a person observes a picture of a snake subliminally, (i.e. the presentation of the image is so brief as to not see the snake on conscious level), the skin conductance of the person increases (Goleman, 1996). In addition, this happens, even when we say that we are not afraid of a snake. Cognition –the snake is recognized by means of mental representations - influences the physiological processes while actually not being aware of any snake. In addition, when people experience colours on conscious level or on unconscious level, mental representations have influence how they experience colours. These mental representations can be genetically based mechanisms or innate learning systems. It is interesting to ask to what extent the intrinsic colour quality expresses itself in these mental representations.

Conclusion
Both at a conscious level and on an unconscious level the perception and experience of colour is modulated by psychological processes, both at an affective and cognitive level.

6.4 Colour and the cognitive processes: Ancient cultures and applied language on colours

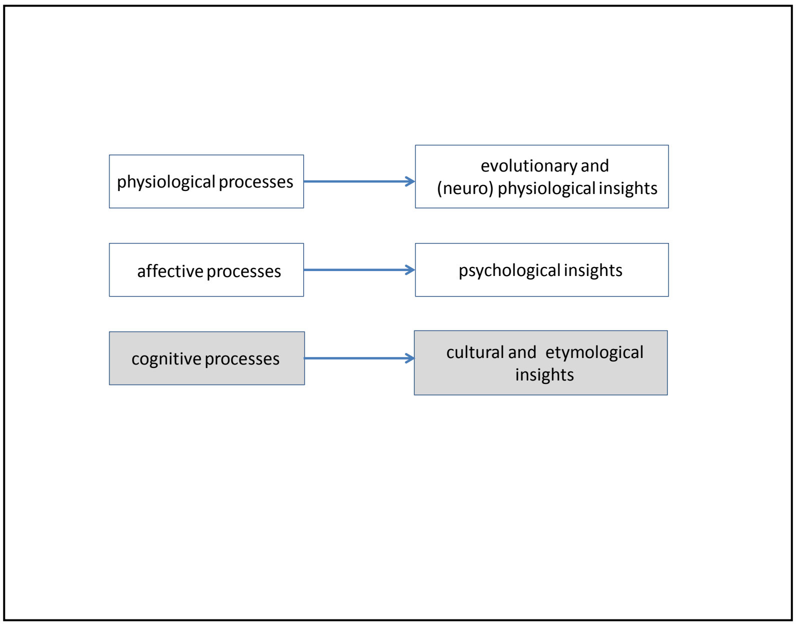

Figure 5: The view on cognitive processes

The research question concerning the cognitive processes is: How does colour influence cognitive processes and what can we learn by looking at ancient cultures and applied language on colour?

In 1836 Emerson wrote: '*Nature always wears the colours of the spirit'.* Maxwell (1872) searched on an approach for the world of colour. He wrote: '*If the sensation which we call colour has any laws it must be something in our own nature that determines the form of these laws….The science of colour must therefore regarded as essentially a mental science'* (in Zeki and Marini, 1998). Both a poet and a mathematical physicist indicate the role of the spirit and the mind in the relationship to colour. To learn about this role, a focus on the ancient cultures and the applied language is practical, because cultures and applied languages enfold information about mental development.

For ancient cultures, such as Ancient Greece or Mesopotamia, there was no separation between the inner world of thoughts and the outer worldly experience. The inner and outer worlds were combined and inner and environmental experience embraced each other. During the beginning of the 5th century A.D, the period of Saint Augustine, a modulation of thoughts appeared: people needed physical evidence for beliefs by seeing something in reality in the outer world. Inner and outer world became separated areas (Sennett, 1992). Additionally, in language the development of separatism developed: in the ancient Hebrew language the verb has the leading role with the accents on connection and the process. In modern languages the noun is accentuated which underlines the separatism between things (Bohm, 1985).

These characteristics of the old cultures show the two ways people looked at colour. In the old culture colour was not seen as a separated and standalone phenomenon, but was perceived as a broader description taking the process into account. For example, in ancient Egyptian the word 'green' (wadj) described the processes of growing, flourishing, or being fresh, unspoilt, raw, young or healthy. One word expresses different colours. The word 'red' (desjer) meant intense red (as blood) and yellow red as barley (Loose, 2010). Also in the ancient Greek time these processes were not described as separated aspects. The word 'chloros' for instance used in ancient Greek documents that modern Greek colour theorists translate as 'green', did not exactly define a colour but was used as connotations that can be related to green. In the Ilias honey is 'chloros', in de Odyssey a nightingale is 'chloros'. Pindaros mentioned 'chloros' as dew and Euripides used 'chloros' to represent tears and blood. 'Chloros' was a term not used to define the colour green, but rather to describe conditions as fresh, wet and live and as such this term was used to describe processes. In Old Testament biblical or ancient traditional literature colour was not conceived as a standalone phenomenon. Often, the information given is not about a specific colour but the degrees of lightness and darkness (MacLaury, 2005). Only white, red and green are distinguished by name, whereas yellow and blue terms are wanting (see jewish encyclopedia). In primitive cultures colours were not accentuated with specific colour names, but related to the things and materials that represented the colour such as soil, bile or rendeer buck (MacLaury, 2005). Etymology shows this relationship such as the colour 'brown' coms from 'bheros' that means 'dark animal' or the Greek word 'phrynos' that also means brown animal.

In old cultures, people observed a colour not as a separated characteristic, but experienced the quality of the colour within their intense connection between the inner and outer world (Zajonc, 1993). In history the meeting between the inner human light and the outer light is a central theme. The Bhagavad-Gita, Homer, Empedocles, Plato and the evangelist Matthew, all speak about the meeting of the two lights as a mediating process between the inner world and the outer world (Zajonc, 1993). In ancient cultures light is a central issue that is expressed by the polarity of yellow and blue. It is intriguing how the colours yellow and blue are used in the ancient cultures. In the Odyssey Homer mentions the copper coloured sky and the sea coloured as wine. In the countless descriptions of Homer of the sky and the sea, linguists never found the name of the colour blue, but only found the iron or copper coloured sky and a black, white, grey, purple or wine coloured sea. The Greek word 'kyanos' is associated with the blue colour of lapis lazuli, but is only used to describe darkness. The Greek conceived blue as a quality of darkness (Zajonc, 1993). This is recognized in etymological data. Blue, induced from the Germanic word 'blao' is possibly related to the Latin 'flavus' that means yellow. The Old Saksich word for blue, blao, meant not only blue, but also yellow. In addition, 'blao' is connected to the old Greek word 'mélas' that means black. The old Norwegian word for blue 'blãr' means both blue and black (Van der Sijs, 2010). It appears that in the ancient times the colour blue was not considered as this colour is today, but merely the colour of darkness. In addition, the appearance of blue being connected to the appearance of yellow indicates the importance of the polarity yellow - blue and as such light- darkness. This phenomenon is mentioned by Gage (1995) who indicates that colour-usage is not always understood by colour science. He mentions that the old French word 'bloi' both meant blue and yellow, and the term 'sinople' used in the Middle Ages, both meant red and green. Gage also describes that in non-European languages white has assimilated to black. The polarities of the usage of colour terms play an important role.

Bortoft (2010) speaks about 'the organizing idea' how we actually observe and as mentioned before, Helmholtz used the term 'perzeption'. It is not purely the physical qualities that determine the impressions of personal images, but it is the organizing idea that determines what is seen. This organizing idea is dependent on time and space. Concerning the influence of time, Graves developed the model of Spiral Dynamics described by Beck and Cowan. The bio psychological Spiral Dynamics model connects time through history with specific types of drives, thinking methods, structures and processes (Beck and Cowan, 2004). Beck and Cowan developed the so called v-memes, (value attracting meta memes) that are units of cultural information (Fiandt et al, 2003). These v-memes can be conceived as psycho cultural DNA that influences our ways of thinking. These ideas are comparable with the ideas of Rupert Sheldrake concerning the morphogenetic fields: these fields contain genetic information for the development of form, behaviour and instinct (Bos, 2009). Time and culture influence the 'idea' that determines the inner world and forms the key factors of how humans experience colour. In its turn this 'idea' determines the mental representations that influence the way how people experience colour.

Conclusion

Ancient cultures did not discern colours by using specified colour names. In many cultures no specified colour names are found in the applied language. Ancient cultures perceived the intrinsic quality of colour relating to their connection between inner- and outer world and descriptions are mainly used to define the differences of darkness and lightness levels. In modern culture inner and outer world are separated. In addition, in modern culture colour is conceived as a separated cue. At present, mental representation determine the way how people experience colour.

6.5 Intermezzo: Intriguing blue, what is its secret?

The early ancestors of the hominids possessed dichromatic vision and saw some colour due to two types of cones with peak sensitivities in the yellow (middle wavelength) and the blue (short wave length) spectrum (Conway, 2009). The ability of seeing the colour blue is an intriguing phenomenon. To avoid the possibilities of oxidative damage due to chemical reactions induced by short wavelength illumination with the free radical cells, the eye had developed different protection methods to attenuate the short wave lengths (Lamb, 2013). The lens (Stockman et al, 1999; Margrain et al, 2004) attenuates the short wave lengths and near and on the fovea, an area of the retina is covered with macular pigment that also attenuates short wavelengths (Conway, 2009). It appears that human eye systems were developed to detect the colour blue in an appropriate way avoiding the risk of oxidative damage caused by the high energy of short wavelengths.
In addition, the percentage of the blue cones is low, 8%- 10% of all cones, compared to the percentages of the red and green cones (Stockman and Sharpe, 1999). In the fovea, the centre part in the eye with high acuity, the number of the blue cones amounts only 3 % (Mollon, 1995) and in the foveola, the middle centre in the fovea with the highest acuity, there are no blue cones at all (Mollon, 1995; Stockman and Sharpe, 1999; Conway, 2009). So, with the part of our eye that enables us to see sharply, the blue cones do not contribute much. The pigment rhodopsin however enables the blue cone to discern the blue light appropriately: rhodopsin is very sensitive for blue light (Fortner and Meyer, 1997). Additionally, the short wave cones play a limited role in perceiving luminance (Stockman and Sharpe, 1999; Fortner and Meyer, 1997) and the short wave cones only relate, in a limited way, visual data to their spatial and temporal context to judge the totality (Stockman and Sharpe, 1999). As such, the functionality of the blue cones is remarkable as they play a minor role in observing totality and context. In addition, the short wave cones have genetically a different structure (Nathans and Hogness, 1986).

In the period of dichromaticy the yellows and the blues could be discerned. These yellows and blues are interesting colours. In contrast to Newton who stated that colours can be conceived as separated parts of the light, Goethe was convinced that colours appear in the dynamic process between the polarities light and darkness. This polarity of light and darkness is the central theme in his colour theory. Darkness is not conceived as a passive phenomenon of nonexistence of light, but as an influencing polarity of light. There must be both light and darkness as absolute preconditions for the existence of colour. Aristotle mentioned the phenomenon that colours are created by the 'blends of light and darkness' (Birren, 1969). In 1810, Goethe wrote: '*Yellow is a light which has been dampened by darkness; blue is a darkness weakened by light*'. This basic colour effect can easily be observed during the day. When sunrays enter a room through cut glass edges and shine on the walls, one can discern the yellow and blue lines showing the edges of the glass. The same effect can be observed in a swimming pool with daylight with a white bottom and painted black lines. Looking down at the black lines, one sees at the white-black boundary blue lines and at the black-white boundary the colour yellow while physically at the bottom of the swimming pool no yellow or blue coloured lines exist. Looking from the opposite direction, both blue and yellow colours will change depending on the direction of looking at the dark lines.

Due to the fact that the blue cones genetically are differently structured and differently located in the retina than the red and the green cones, and that blue cones don't play any role to relate spatial and temporal context to judge the totality, it could be hypothesised that the blue cones only exist as a polarity to the yellow ones to balance the polarity of light and darkness. Etymologically, in ancient languages, the colour blue plays a minor role and blue is often used as a description of darkness. The focus of attention was the amount of light and even etymologically the original words for blue meant 'yellow' as yellow stood for light. Polarity is a basic phenomenon in the human sensory information system, for example one feels something as hard versus soft, warm versus cool, dynamic versus static. This is comparable with the on and off functionalities in the neuronal systems. The need for polarity may be the cause why people can see the colour blue. However, this is only a hypothesis.

6.6 Intrinsic colour quality

Is it the colour itself and as such its intrinsic colour quality that influences people?

People are unconsciously influenced by the intrinsic colour quality that we cannot influence (Goethe, 1810; Steiner, 1909). Physiological, affective and cognitive processes are closely intertwined and may be mental representations predominate how people react on colour. To what extent are people directly influenced by the intrinsic colour quality and what mental representations are constructed by the intrinsic colour quality? For instance, it can be questioned as to whether the activating effect of red or the calming effect of blue are intrinsic colour qualities themselves or purely learnt mental representations.

Natural themes: twelve polarities

To answer this question, a move to the direction of the colour world itself and how humans experience this world is in order. This colour world cannot be quantitatively measured. After collecting knowledge on colour from different perspectives, it appears that it is fundamental to conceive colour as a natural phenomenon, a view that is mentioned among others by Goethe (1810), Frieling and Auer (1961), Müller and Spillmann (1987) and Goldbeck-Löwe (2011). The intrinsic colour quality can be defined by carefully observing how colour expresses itself in nature, because the origins of the colour world begin with nature. By taking a closer look at nature, twelve natural phenomena with their polarities can be observed, realizing that this approach has a hypothetical character:

1. Colour appears or vanishes depending on light conditions. In the black of the night, colour disappears but colour also disappears when light is very intensive. People recognize this process as seen in under- and overexposed photographs. In living creatures a total lack of light is recognizable in the appearance of the colour white as can be seen in roots of plants or bulbs as the onion and the tulip, or in the skeletons which do not receive direct light. Appearance and disappearance concerns the polarity of to be or not to be.
2. Colour is a sign of life that can be recognised in the saturation of colours. No saturation of colour shows only black and white tones. For the life processes both light and warmth is necessary, however, not too little and not too much. Is there no light or warmth, but also is there an abundance of light or warmth, no life is possible. When there is no warmth at all, but only coldness, we recognize white in snow and ice. But also at the highest temperature, iron for instance will turn into a white coloured mass. The colour of death is black, as carbon existing out of dead materials is black. Only when life begins, colour reveals itself. As soon as springtime arrives, colour reveals itself very gently, more saturated in summer

and burning in autumn, before fading away in wintertime. Living humans are connected with colour. When people do not feel well, one speaks of "off-colour" and when people die, colour disappears and the dead body grows pale. These phenomena show the polarity of growing and deceasing.

3. Colour is a dynamic phenomenon. Some colours in nature draw near, while others draw back. A field of yellow sunflowers or red roses seems closer and more defined than a field of violet lavender. The furthest row in a row of mountains appears more blue and atmospheric in the open landscape. This phenomenon is known as the colour perspective, a phenomenon that is strengthened by the functionality of the human eye (i.e. chromatic aberration [3]. Colour perspective concerns a polarity between approaching and retreating.
4. The appearance of colours in plants is often accompanied by its complementary colours. A fresh green bud of a leaf often shows the complementary colour purple (Kadam, 1974; Goethe, 1981; Pavek et al, 1992; Jarret et al, 1993; Winthrop and Simon, 2000). In the spring, many yellow flowers appear, the daffodil, celandine and the crocus, but also violet flowers appear as the crocus and the violet. Another phenomenon is the coloured shadows, as we see the complementary colour of a light source. In addition we see the complementary colour in the so called afterimages, after looking at a certain colour for some time. Colour and its complementary colour are shown as polarities in the colour circle.
5. Colour in nature shows the status of the cradle to grave process and reveals the status of this process such as young, light green grass in the spring, green to dark green grass in the summer, dry, yellow grass in the autumn. We see green, then yellow, then red strawberries that turn brown when overripe. This polarity shows the conditions from fresh to decay.
6. Nature shows large amounts of striking and showy colour combinations and different harmonies. The most well-known colour natural phenomenon is the rainbow which like other atmospheric phenomena, shows colour in its natural brightness. Some colour combinations are more harmonious than others. This phenomenon is known as The Law of Müller, based on the natural brightness of colours. Aemilius Müller, professor at the Academy of Winterthur in Switzerland, discovered a universal colour preference based on the natural brightness of colours. The opposite phenomenon that colours do not correspond with their natural brightness is known as 'inversion'.The phenomenon that colour presents itself in a wide variety of colour combinations shows the polarity harmony and disharmony.
7. Colour is a phenomenon which appears in the interaction between light, darkness, material and the human eye. Goethe wrote: *'Yellow is a light which has been dampened by darkness; Blue is a darkness weakened by light'* (Goethe, 1810; Zajonc, 1976; Ribe, 1985; Goldbeck-Löwe, 2011). Every colour has its own typical brightness: the highest level of brightness is shown in citron yellow, the lowest in blue violet (Gerritsen, 1972). This phenomenon concerns the polarity of light and darkness.
8. Colour can be experienced as warm or cool colours. The red and yellow colours are generally experienced as warm colours. The blue and bluish green colours are perceived as cool colours (Birren, 1950; Sivik, 1973; Jacobs and Suess, 1975; Bellizi et al, 1983; Mahnke, 1996; Stone and English, 1998; Tofle, 2004; Kaya and Epps, 2004). This concerns the polarity of warmth and coldness.
9. Colour shows order. Colour appears in daylight, in minerals and metals and living creatures in a natural order. Sulfur for instance is white when cold, but at 21 degrees it changes to the colour yellow, and at higher temperatures it turns to red (Frieling and Auer, 1961). Also the process of tempering steel shows white, yellow, gold-yellow, red, purple, violet, dark blue, blue, light blue, then grey. In the growing process of plants this sequence of colours is observed: in the dark earth, the seed and the roots are white, when receiving some light, the young plant turns yellow, then to yellow green. With more sunlight the plant colours change to green (Frieling and Auer, 1961; Frieling, 1968). This process, the intensification of colours (Steigerung), is first mentioned by Goethe and is found in his colour circle

(Goethe, 1810; Goldbeck-Löwe, 2011) characterised by order and the appearance of intervals. Here the polarity of intensification is observed.

10. Colours appear with their own unique character. One colour is more elementary than another one, but all colours show their own typical hue. All together they create the so called colour space (Frieling and Auer, 1961; Hardin, 1988; Heller, 1990). Colour shows the polarity from distinction to non-identification by means of the hue.
11. Colours have symbolic meaning for different cultures in the world (Frieling, 1968; Gage, 1995; Mahnke, 1996) which in general seems to be comparable. Goethe (1810) tried to describe the sensual – moral aspects of colour, trying to find the objective inner quality. Later on other colour scientists used different colour systems such as the systems of Itten, Hering, Young, Munsell and Frieling to express the human colour experience basics (Birren, 1969) . All colour systems search for the intrinsic colour quality. Looking at applied systems, etymologically how colour words have developed, and philosophically some central issues can be discerned: yellow is the sign of light as blue is the sign of darkness. Green is the sign of the living world of plants as red is the sign of the living world of animals and people. Violet is a combination of red and blue, combining human life with darkness, causing mystic experience. Light green a combination of yellow as sign of light with green as sign of the world of the plants shows itself in the young leafs. All these signs show the deeper sense of colour. Colour shows the polarity from the deeper sense to showing no sense at all.
12. Colour immediately communicates with the adjacent colours. In nature colour is never experienced as a separated colour with separated colour qualities, but we experience colour relative to other colours. Colours interact and influence each other in their appearance (Chevreul, 1855). As such colour can never be experienced as an isolated phenomenon but only in context. This is recognizable in the polarity between separated identity and placement in context.

As people are part of nature, nature and a natural environment consequently has positive influence on people (Ulrich, 1981; Hartig et al, 1991; Ulrich et al, 1991; Kaplan, 1993, 1995, 2001; Frumkin, 2001; Van den Berg et al, 2003; Groenewegen et al, 2006; Van den Berg et al, 2007; Berman et al, 2008). It can be hypothesized that naturally applied colours with aforementioned the twelve characteristics, attribute to the most optimal conditions for people and in addition the optimal productive work environment. During a long period of millions of years, people and their ancestors are exposed to the twelve characteristics of colour in nature. There seems to be a general and universal trend on how colour influences the human psyche (Goethe, 1810; Adams and Osgood, 1973; Heller, 1990; Crozier, 1999; Ou et al, 2004). This universal trend shows stable connections between colour categories and meanings. In addition, trends can be observed in the development of applied colour words in language. Berlin and Kay (1969) formulated a hypothesis regarding the existence of semantic universals in colour lexicons and a constrained order in evolutionary development of basis colour vocabularies. Research has shown that applied colour names in languages follow an evolutionary pattern. The terms 'black' and 'white' are present in all languages. If a language shows three colour terms, the third one is 'red'. Languages with four colour terms always show either green or yellow and with five colour terms show both green and yellow. If six terms are used, the sixth term is blue and if seven terms the seventh term is brown. If more than seven colour terms are found, different orders of terms are observed for other colours such as pink, purple, orange and grey. In their search for causes Berlin and Kay supposed the existence of biological systems such as response patterns of non-opponent and opponent cells in the LGN providing information concerning hue, brightness and saturation (Kay et al, 1991). In addition, in epigenetic research learnt facts about stimuli belonging to the environment can be shown at least two generations later. Dias and Ressler (2013) recently showed that odour fear conditioning with mice can be inherited for two sequent

generations at behavioural, neuroanatomical and epigenetic levels. This phenomenon covered by epigenetics, could possibly result in culturally learnt patterns concerning colour.
Preferences for colours show patterns that can be related to among other things culture, age, sex, education and human characteristics such as being emotional or being technical (Bakker et al, 2013c). Regarding culture, evidence exists that environmental conditions physiologically influence how people see colour. In 1973 Bornstein showed that people living in the regions concentrated near the equator had more yellow macular pigmentation than people living close to the poles. More macular pigmentation causes a decrease of the amount of short wavelengths reaching the retina. These people are less sensitive to blue and less able to distinguish blue from green (Hardin, 1988). It is possible that the effect of colour on people shows a certain order, due to the existing patterns in comparable semantic values of colours among different cultures, the application in languages and colour preferences. This order is originated in the colour itself and its intrinsic colour quality. The way colour influences the human psyche can be found in the twelve characteristics of colour. It seems to be that the intrinsic colour quality forms a large share of the human mental representations. The differences in the representations are due to local, cultural and temporal factors and individual differences such as personal characteristics and memories.

.

The existence of genetically based preferences" and/or "innate learning mechanisms is discussed in some colour research studies (Hurlbert and Ling, 2007). Hurlbert and Ling argue that the development of trichromacy caused a stronger colour preference for red in females rather than males as females were in accordance with the hunter-gather-theory supposed to gather ripe red coloured fruit. Indeed, for language and speech, evidence is found for the genetic influence by the gen FOXP2 (Fisher and Scharff, 2009), however language and speech are cognitive functions which is not purely the case for experiencing colours. Moreover, we cannot make simple linkages between researches on colour or on language or speech, as normal adults require more time to mention the name of a colour than to read the names of that colours presented in words (Mayfield Ligon, 1930. Moreover, Taylor et al (2012) showed evidence that the theory of Hurlbert and Ling is not consistent. Also colour associations can vary depending on culture (Madden et al, 2000). In addition, Block (2003) does not exclude the possibility of innate behavioural differences between the experience of different colours, although he asks questions about the existence of well-known associations. No genetic influence is found related to colour experience until now.

6.7 In search for a method to define the influence of the intrinsic colour quality.

6.7.1 A short view on colour research

Does colour research result in valid and reliable data?
To understand the exact influence of colour on people, valuable colour research is conducted and a large amount of interesting findings are available. However, the findings on colour frequently show conflicting results due to the complex environmental conditions, the complex test processes, human interactions, and the complexity of colour itself. In these studies two ways are generally followed to learn about the influences of colour: at the one hand subjects are asked about the influences and at the other hand effects on people's performances and physiological effects are measured. In the case of asking subjects about the influences of colour it is unclear whether the answers to questions (often mentioned in questionnaires) have anything to do with the intrinsic colour quality itself. Bakker et al, 2013(a) conducted research in a real-life setting during regular meetings and showed that the answers given do not concern factual information on the applied

colour(s) but primarily address the personal, social and environmental contextual situation (see Chapter 7). Psychological phenomena such as social desirability, cognitive dissonance and a lack of exactness, muddle the truth on colour (Foddy, 1993; Vonk, 2003; Bakker et al, 2013b).
It appears that the second option to measure facts is more fruitful to tell something about the effects of colour. In colour research two topics are measured: different type of performances and physiological values. Measuring performances is complicated and difficult to define and to compare, not only due to the type of performances but also due to different contextual factors. Although the research shows trends with patterns based on larger number of subjects (Mikellides, 1990; Elliot et al, 2007; Küller et al, 2009), physiological measurements appear to be a more valid method for colour research due to factual and objective physiological data. The measurements in physiological colour research show quantitative data that at first glance seem to be comparable. A large amount of indicators is used such as different types of brainwaves (alpha to theta), galvanic skin conduction, blood pressure and heartbeat. A closer look on this research reveals weaknesses such as an unclear relationship between colour and physiological reaction, unclear and/or unknown physiological values, a weak explanation of physiological measurements, weaknesses in the measurement and an artificial, not natural application of light colours such as shining light beams with high frequency into the eye (Wilson, 1966; Ali, 1972; Jacobs and Hustmeyer, 1974; Noguchi and Sakaguchi, 1999; Kim, 2004; Yoto, 2007; Küller et al, 2009: Rajae-Joordens, 2011; Steer-Reeh, 2012; Kim et al, 2012; Yamashita et al, 2012). An extensive overview of the research applying physiological measurements is found in attachment A. It appears the quantitative data derived from physiological measurements does not provide clear information on the relationship of colour and physiological reaction. Some examples of physiological research on colour that does raise questions:

- *Physiological measurements are used which not clearly indicate the relation between colour and colour effect*. Kim (2004) indicates changes in beta and gamma waves and Küller et al (2009) in delta waves, as evidence of attention or arousal caused by colours, whereas beta waves primarily indicate intrinsic motivation related to motoric activity (Lal and Craig, 2001), gamma waves primarily are connected to very short stimuli (Hoogenboom, 2006) and delta waves primarily show activity in the auditory cortex (McGee et al, 1993; Lakatos et al, 2005). Further research and study is needed to develop a clear relationship between the effects of colour and a physiological reaction showing changes in brainwaves.
- *Measurements are applied that (at this moment) cannot be clearly interpreted.* Ali (1972) and Yoto (2007) used the AAC value. The AAC Value in general is an indicator of attention. However, what this AAC value exactly means in relation to the colour effects is not yet clear.
- *Unknown measurements are* used as the COH Value (coherence, i.e. correlation between respiration and heart rate; Rajae, 2011) while the general known RSA (Respiratory sinus arrhythmia) is not applied.
- *Explanations concerning physiological reactions are unclear*. Küller et al (2009) explains why subjects show a decrease of their heartbeat while seeing red as a reaction of such an excited state that this causes a paradoxical slowing heartbeat. However, physiologically a decrease of the heart beat always goes together with a decrease of arousal.
- *Unclear measurements* and weaknesses exist such as no or unclear categorisation of alpha waves, lacking data concerning the localization of electrodes, uncontrolled light and/or colour conditions, low numbers of subjects and combining methods as heartbeat, brainwaves and GSR with different reaction times.

It is questionable if completing questionnaires in psychological research or measuring physiological processes tell the truth about the effects of colours

6.7.2 Twelve characteristics of colour and the twelve senses

Colour, context, test method and a diversity of measurements complicate the interpretation of findings. Perhaps, the twelve characteristics of colour which form the intrinsic colour quality in nature can function as a better guide for understanding a clearer relationship between colour and colour effects. According to Steiner (1909, 1910, 1911) people have twelve senses: four bodily senses (focusing on what), four senses which provide information about the environment (focusing on how) and four mental senses (focusing on why). Humans experience the environment with these twelve senses. Schneider (1987) translated what information is provided by which sense concerning the built environment. Each sense can be conceived as a lurch between two polarities. Depending on the features of the stimulus there is movement between the two polarities i.e. movement between warmth and coldness, form and motion and light and darkness. An overview of the twelve senses with their primary targets is shown in Table 1. It has to be mentioned that the concept of the twelve senses is an hypothetical approach to understand the sensory information system although evidence such as modern neurological research (Dijksterhuis, 2007) is growing on this concept.

Table 1: The twelve senses as mentioned by Steiner and Schneider and primary targets

All twelve senses provide colour information as colour forms a part of the environment. Colour primarily is observed by the sense of sight as we see colour through the eyes. However, colour feeds the other senses which can be recognized through language and expressions such as warm colours (sense of temperature), soft colours (sense of touch) and sweet colours (sense of taste) (Soesman, 2005). Because people experience the outer world, colour inclusive, by means of the twelve senses, which all measure polarities, this could be a solution to understand the intrinsic colour quality in its totality. As a hypothesis, a model can be developed showing the connection between the twelve characteristics of the intrinsic colour quality such as these appear in nature and which are mentioned before (see paragraph 6.6) and the twelve senses with their polarity (see Table 2).

Table 2 : *Relation between the twelve characteristics of the intrinsic colour quality as viewed in nature and the twelve senses with their character (This table is based on detailed information on the senses and asks for a short explanation: Senses are mainly sensitive for one specified stimulus and provide information about the status between two polarities. The sense of touch primarily provides sensory information about the existence of the outer world, providing additionally evidence of the own existence. The sense of life learns about someone's constitution. The sense of movement provides*

information about the situation between standstill and movement. The sense of balance helps to find balance. The sense of smell learns about the quality of the situation in the process and provides information about value what is healthy and good. The sense of taste is sensitive for modulation and harmony which can be found in nature. The sense of sight primarily focus on the differences between light and darkness. The sense of temperature indicates on warmth to coldness differences. The sense of proportion provides information on the level of order. The sense of gestalt focuses on unities which are recognizable due to learning processes. The sense of symbol provides background information about original meanings and symbols and explains about the sense. The sense of identity explains about the existence of other individuals and learns about one's own uniqueness. See for further explanation Bakker and de Boon, 2012).

A connection is made between the mentioned colour characteristics and the human senses with their polarities. Humans experience the environment by means of their senses and each sense is sensitive for a specified polarity: for example the sense of sight is sensitive for the polarity light and dark. A mechanism to define colour experience in its totality could make use of this sensory information and their sensory polarities inclusive.

In paragraph 6.6 the twelve colour characteristics are shown accompanied by their colour polarities. It is generally accepted that colour shows itself by means of contrasts such as well-known and often used complementary contrast, warm-cool contrast and quality contrast. Colour contrasts are equivalent to polarities. Because senses all are sensitive for polarities, they are sensitive for contrasts. As such a match is possible between the twelve senses and colour contrasts. The sensory information system can be applied as mechanism to define the total colour quality (Table 3).

Table 3 : *Relationship between the twelve characteristics of intrinsic colour quality as viewed in nature, the twelve senses and the twelve colour contrasts. (Explanation on contrast types: The sense of touch provides insight in existence/non-existence and mentions whether there is colour or no colour. Life reveals itself by showing colours by means of the level of saturation. When life vanishes, colours are growing pale and become unsaturated. The sense of life focus on the level of saturation. The sense of movement is linked to the motion contrast and the sense of balance shows itself by means of colours and their complementary colours finding balance in the opposite colours of the colour wheel. The sense of smell show the quality contrast and the polarity between pure and murky colours. The sense of taste is sensitive for harmony and as such for the harmony contrast. The sense of sight is sensitive for the light-darkness contrast as primary function of the eye. The sense of temperature reacts on the warm coldness contrast. The sense of proportion focus on the different tension between colours. The sense of gestalt is sensitive for unity and recognition and focuses on hue contrast. The sense of symbol provides information of the meaning and as such the sense itself, focusing on the contrast sense-no sense. The sense of identity shows the connection to adjacent colours that shows itself by means of the simultaneous contrast.*

This mechanism with the twelve colour contrasts could provide a possibility to analyse and define in a more detailed way how colour influences people. This detailed way generates not only information about HSI-values (hue being information provided by the sense of gestalt, saturation being information provided by the sense of life and intensity being information provided by the sense of sight) but in addition takes the information of the other nine senses into account. By using all twelve senses people working in science such as researchers or in companies such as the paint industry are able to define colour in its totality and as such they are able to define colour experience in its totality. For architects, designers, employees in home decoration stores, shops for interior design or paint shops, this can be helpful for communication with customers such as residents and users of buildings such as offices and hospitals. People in general speak about sweet colours when they for instance want to decorate a nursery room or they speak about warm colours want they like to create a warmer atmosphere in their homes. It would be practical to support this communication supporting the way people in general speak about colours. Because the HSI-factors don't provide any information on qualities such as sweetness or warmth, a method would be practical that not only informs about the qualities, but in addition all sensory information. The twelve colour contrasts (Figure 6 and 7) provide this information and it is possible to create new colour cards and colour fans that can be applied in contacts between suppliers and users to select colours. This facilitates the communication and supports understanding what users and customers prefer.

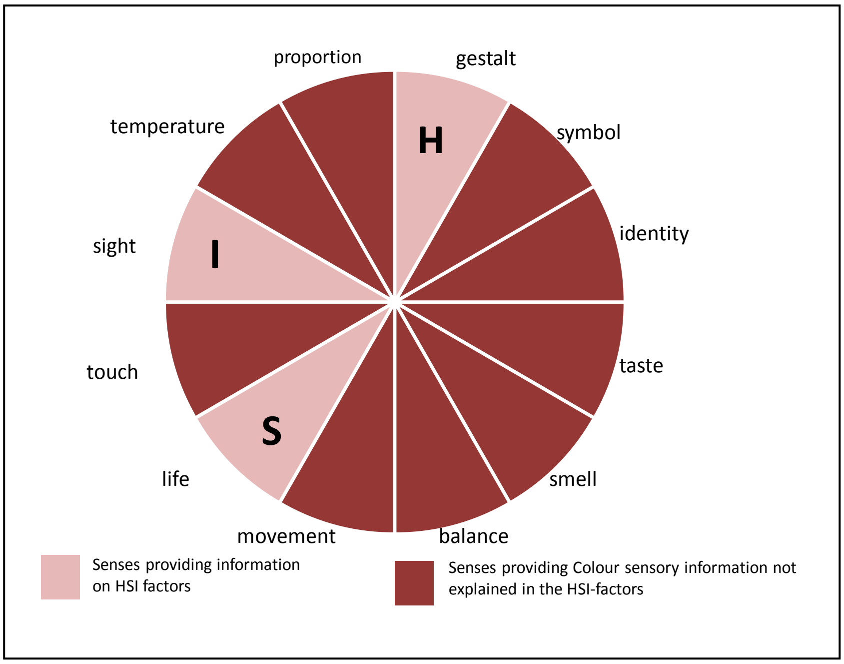

Figure 6: HSI factors only provide sensory information collected by the sense of gestalt, sense of life and the sense of sight. There is missing data concerning the other nine senses

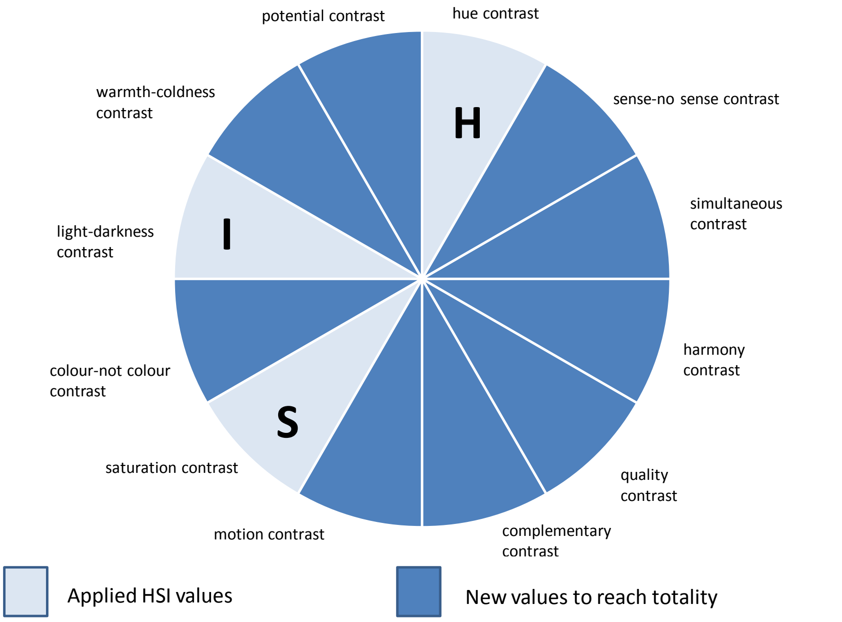

Figure 7: HSI factors only focus on the three colour contrasts and the other nine colour contrasts are missing

Research on colour shows many conflicting results. The method using all sensory information of the twelve senses, is a possible solution to understanding the influence of colour in its totality. It can be concluded that the present method to define the colour by means of the HSI-values should broadened to include the twelve indicators based on the twelve senses developed by Rudolf Steiner (see Figure 8 and 9). It is recommended to introduce a colour system focusing on all twelve colour contrasts. These colour contrasts are directly connected with the appearance of colours in nature (see Figure 8).

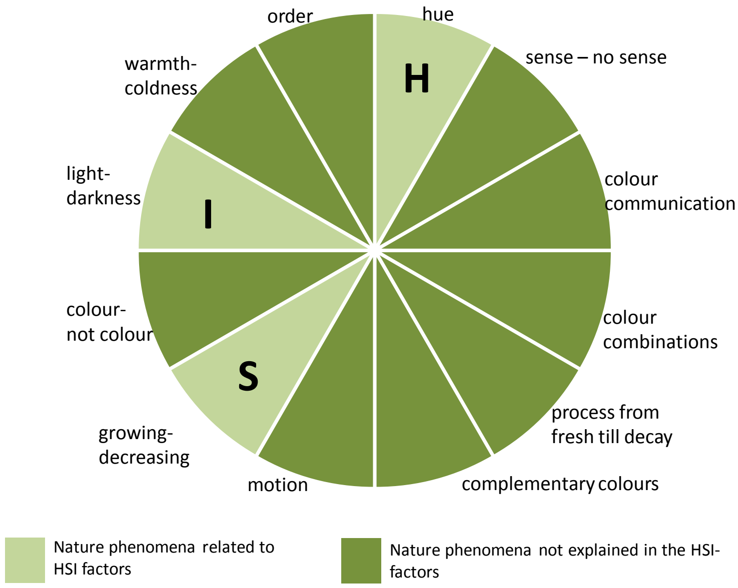

Figure 8: HSI factors related to natural phenomena (see chapter 4.5)

6.8 Conclusion

The main question of this analysis on colour was whether any mechanism exists that accurately defines the human experience of colour and how physiological, affective and cognitive processes are influenced. Next, it is examined whether this analysis provides a practical guideline for applying colours in the physical environment that contribute to productivity.

In an evolutionary perspective seeing colours is developed as an instrument to discern objects and not primarily to see colours. On both a conscious and unconscious level mental representations of colour permanently influence how people experience colour. Also time and culture influence the character of the mental representations which determine how people experience colours. As thinking in modern times is such an important activity, these mental representations are determining how people experience colour. Because people primarily focus on the activities they are doing, they experience the physical environment most often unconsciously. At this level, the intrinsic colour quality has an influence on people and their productivity. This intrinsic colour quality presents itself in nature by means of twelve themes. It appears that the way colour shows itself in nature creates the optimal circumstances for the productive environment.

Colour is a natural phenomenon that presents itself by means of twelve themes as they appear in nature, that are in accordance with twelve polarities and twelve colour contrasts. These colour contrasts are observed by the twelve senses (Figure 11). These twelve senses appear to be a mechanism to express colour experience in its totality. The current view to define colour by means of the three factors hue, saturation and intensity (HSI-system) is too limited as it only describes three colour contrasts. Using the sensory information mechanism including the twelve senses, can be a helpful mechanism that provides information how colour influences physiological, affective and cognitive processes.

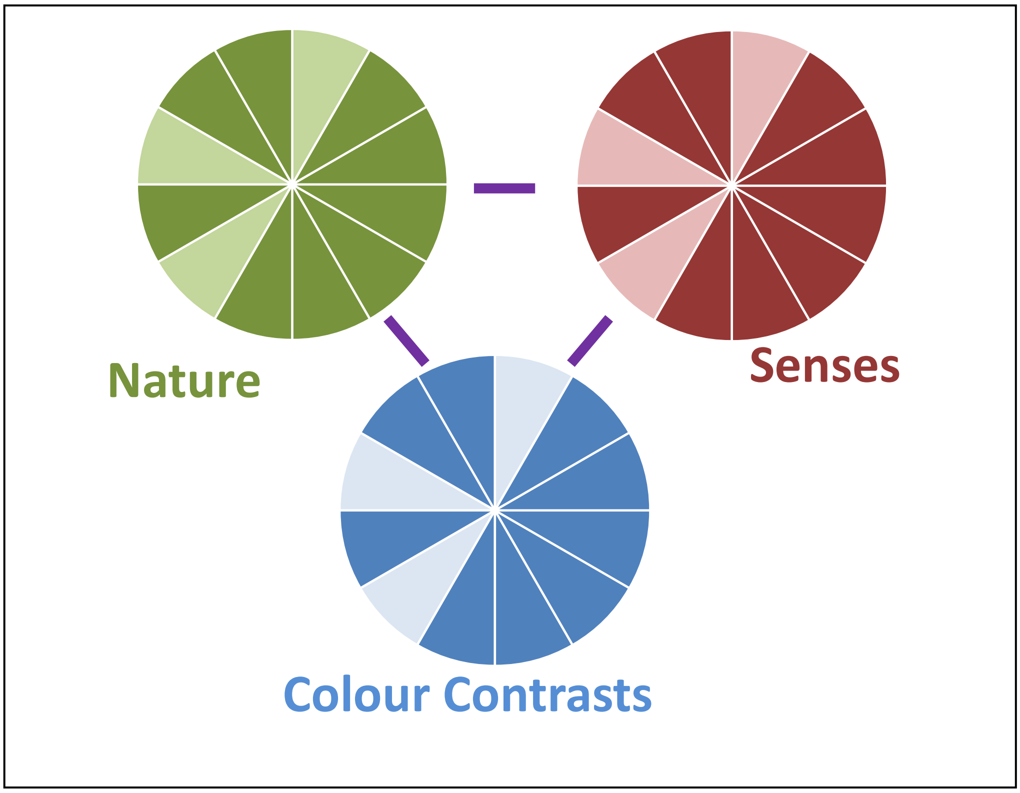

Figure 11: HSI (Hue, Saturation and Intensity) factors related to natural phenomena , senses and colour contrasts

Finally a small remark to show some modesty concerning the versatile and complex topic colour. It seems to be that the little man in our head telling us 'Hi there, that is magenta' or 'Hi there, that is the magenta of your grandma's hat' is an intriguing creature, and even a creature without any exactly located residence. (Ramachandran 2006).

6.9 Back to productivity

In order to understand the experience of colour from a broad perspective, this chapter mainly focused on the experience of colour in general and not particular on the effects of colour on productivity. Looking back at this analysis and the other chapters the next conclusions can be made about the relationship between colour and productivity:

1. No significant effects of colour could be found on perceived productivity, cohesion and wellbeing in the real life setting test of chapter 4. Most subjects mentioned that they did not have any preference concerning the red, the blue or the reference room and most subjects (65%) had the opinion that colour was not of importance for productivity. In the study on colour preferences (chapter 5) the colour 'white' is the most preferred colour: 41% of the participants chose white for the office and 30%

chose white for the meeting room. Many participants stated that they had no colour preference: concerning the office 16% and concerning the meeting room 22% of the participants.

2. After selecting studies about the effects of colour on productivity with the selection criteria application of colour on walls in rooms without light manipulations and without other applications such as pictures, studies show the next results. Küller et al (2008) carried out three experiments focussing on a coloured versus grey condition and a red versus blue condition. No significant effects were found on clerical and creativity tasks. In addition, Ainsworth et al (1993) did not find any significant relationships of three colour conditions red, blue/green and white on typing performance. Analysing the effects of nine monochromatic colours in offices (1996) Kwallek found no significant differences between the effects of the colours. Only, in the white condition significantly more errors were made. In addition, in 1990 Kwallek et al found significant differences concerning a proofreading task in a white, red and green coloured room: in the white condition significantly more errors were made than in the red condition. In her other studies (1997 and 2007) Kwallek found differences between high and low screeners but no significant differences between the effects of the colours red, blue/green and white. It is interesting that Küller et al (2008) found significant differences between subjects with a positive or negative mood.
3. In chapter 6 indications are found that physiological measurements do not give clear insights how colour influences can be related to the different measured values such as heart beat, pulse rate and brainwaves.

The studies show only in a limited way that environmental colours significantly influence productivity. Many people are not convinced of the importance of the applied environmental colours regarding the influence on productivity and more than half of the participants in the test on colour preferences choose for white or the option 'no colour preference' concerning their colour preferences for the office and the meeting room. However, in many circumstances people experience the physical environment unconsciously (Dijksterhuis, 2007). Since they are not or hardly aware of the effects they often do not express clear colour preferences and think that colours are not important. Since colour influences mood (Goethe, 1810; Rosenstein, 1985; Kwallek et al, 1988; Kwallek et al, 1997; Kuller, 1981; Küller et al, 2006, 2009), this effect may in turn influence productivity (Van der Voordt, 2010). In chapter 2 it is mentioned that four moods namely contemplation, awareness, collectiveness and social observation contribute to productivity. Due to the fact that colour significantly influences mood, it can be assumed that colour in addition influences productivity.

We live in a society in which we want to find quick solutions for everything without too much thinking or time for reflexion. The world of colour is different. There seems to be no one to one relationship between productivity and colour – this relationship is to the best of our knowledge never found- and there is no simple short term solution to know which colours should be applied in practice. For optimising knowledge productivity it might be worthwhile to explore if a harmonious environment with a balance between structure and variety, in which people feel psychologically safe and are nurtured in their identity leads to optimising productivity.

Special thanks to Eelke Spaak Msc, PhD Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, The Netherlands, prof.dr. J.C.N. de Geus, Department of Biological Psychology, FPP, Vrije Universiteit, Amsterdam, prod dr A.W.K. Gaillard (emeritus), University Tilburg and Conne Mara Bazley, MA, CHFP, JimConna, Inc Colorado, USA.

6.10 References

http://www.jewishencyclopedia.com. dd. 30 july 2013

Adams, F.M., Osgood, Ch.E., (1973), A Cross-Cultural Study of the Affective Meanings of Colour, *Journal of Cross-Cultural Psychology*, Vol. 4(2), 135-156.

Albers, J. (2006), *Interaction of Colour*, Yale University, New Haven, Connecticut.

Ali, M.R. (1972), Pattern of EEG recovery under photic stimulation by light of different colours. *Electroencephalography and Clinical Neurophysiology,* 33, 332-335.

Attwell, D., Laughlin, S.B. (2001), An Energy Budget for Signaling in the Grey Matter of the Brain *Journal of Cerebral Blood Flow and Metabolism,* Vol 21, 1133–1145.

Bakker, I.C., De Boon, J, (2012), *Zorg voor mens en omgeving, Het zintuig als maatstaf*, Aedes-Actiz kenniscentrum Wonen - Zorg, Wilco Amersfoort.

Bakker, I.C., Van der Voordt, D.J.M., De Boon, J., Vink, P., (2013a), Red or blue meeting rooms: does it matter?: The impact of colour on perceived productivity, social cohesion and wellbeing, *Facilities*, Vol. 31(1/2).68 – 83.

Bakker, I.C., Van der Voordt, D.J.M., Vink, P., De Boon, J. (2013b), The use of questionnaires in colour research in real-life settings: in search of validity and methodological pitfalls, *Theoretical Issues in Ergonomics Science*, 1-13.

Bakker, I.C., Van der Voordt, D.J.M., Vink, P., De Boon, J., Bazley, C. (2013c). Colour preferences for different topics in connection to personal characteristics. *Colour Research & Application.* Online version.

Barnard, K., Cardei, V., Funt, B. (2002), A Comparison of Computational Colour Constancy Algorithms—Part I: Methodology and Experiments With Synthesized Data, *IEEE Transactions on Image Processing*, Vol 11(9), 972-983.

Beck, D.E., Cowan, Ch. C. (2004), *Spiral Dynamics, Waarden, leiderschap en veranderingen in een dynamisch model.* Altamira-Becht Haarlem.

Bellizi, J.A., Crowley, A.E. , Hasty, R.W. (1983), The effects of colour in store design, *Journal of Retailing,* Vol. 59(1), 21-45.

Bendin, E. (2008), Individuelle Stereotypen-Beobachtungen zur Präferenzfrage. III, Internazionales Dresdner Architektursymposium “Lehren, Gestalten, Lernen”. Dresden.

Berlin, B., Kay, P.(1969), *Basic Colour Terms,* Berkeley and Los Angeles: University of California Press.

Berman, M. G., Jonides, J., Kaplan, S. (2008), The cognitive benefits of interacting with nature. *Psychological science,* 19(12), 1207-1212.

Berson, D.M., Dunn, F.A., Takao, M. (2002), Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock*, Science* Vol 295, 1070-1073.

Berson, D.M. (2003), Strange vision: ganglion cells as circadian photoreceptors, *TRENDS in Neuroscience,* Vol 26(6), 314-320.

Berson, D.M.(2013), personal email contact 11 November 2013.

Birren, F. (1950), *Colour Psychology and Colour Therapy*. McGraw-Hill Book Co.

Birren, F.(1982), *Light colour & environment*, Van Nostrand Reinhold Company, New York.

Birren, F.(1969), *Principles of colour,* Van Nostrand Reinhold Company, New York.

Block, N. (2003), *Mental paint*, In Reflections and Replies: Essays on the Philosophy of Tyler Burge edited by Martin Hahn and Bjorn Ramberg, MIT Press, 1-34.

Bohm, D. (1985*), Heelheid en de impliciete orde*, Lemniscaat Rotterdam.

Bornstein, M.H. (1973), Colour vision and Colour naming, in Hardin, C.L. (1988), *Colour for Philosophers, Unweaving the Rainbow*, Hackett Publishing Company, Indianapolis/Cambridge.

Bortoft, H. (2010), *The Wholeness of Nature,* Lindisfarne Press and Floris Books, Edingburgh.

Bos, A. (2009), *Hoe de stof de geest kreeg, De evolutie van het ik*, Uitgeverij Christofoor, Zeist.

Campbell, S.S. and Murphy, P.J. (1998) Extraocular circadian phototransduction in humans. Science 279, 396–399.

Cajochen, Ch, Münch, M., Kobialka, S., Kräuchi, K., Steiner, R., Oelhafen, P., Orgül, S., Wirz-Justice, A.(2005), High Sensitivity of Human Melatonin, Alertness,Thermoregulation, and Heart Rate to Short Wavelength Light, *The Journal of Clinical Endocrinology & Metabolism,* 90(3):1311–1316.

Camgöz, N., Yener, C., Guvenc, D. (2003), Effects of hue, saturation, and brightness: Part 2. *Color Research and Application*, 29, 20–28.

Castleman, K. R. (1998), Concepts in imaging and microscopy: color image processing for microscopy. *Biological Bulletin*, 100-107.

Chevreul, M.E. (1855), *The Principles of Harmony and Contrast of Colours, and Their Applications to the Arts* (2 ed.). London: Longman, Brown, Green, and Longmans. (English translation)

Conway, B.R.(2009), Colour Vision, Cones, and Colour-Coding in the Cortex. *The Neuroscientist,* Vol 15(3), 274-290.

Conway, B.(2013), personal email contact 21 august 2013.

Crozier, W.R. (1999),The meanings of colour: preferences among hues, *Pigment & Resin Technology,* Vol. 28 (1),6 – 14.

Damasio, A.R. (1994), *Descartes' Error: Emotion, Reason, and the Human Brain,* AVON BOOKS, Putnam Berkley Group, Inc., New York.

Danilova, M.V., Mollon, J.D. (2006), The comparison of spatially separated colours, *Vision Res* 46(6–7), 823–36 in Conway, B.R.(2009), Colour Vision, Cones, and Colour-Coding in the Cortex. *The Neuroscientist,* Vol 15(3), 274-290.

Das, P., Kemp, A.H., Liddell, B.J., Brown, K.J., Olivieri, G., Peduto, A., Gordon, E., Williams, L.M.(2005), Pathways for fear perception: Modulation of amygdala activity by thalamo-cortical systems, *NeuroImage* 26, 141 – 148.

Dias, B.G., Ressler, K.J.(2013), Parental olfactory experience influences behavior and neural structure in subsequent generations, *Nature Neuroscience,* doi:10.1038/nn.3594.

Dijksterhuis, A. (2007), *Het slimme onderbewuste, denken met gevoel.* Amsterdam: Uitgeverij Bert Bakker, 33, 53, 74–79, 95, 102.

Eastman, C.I. et al. (2000), Failure of extraocular light to facilitate circadian rhythm reentrainment in humans. *Chronobiol. Int.* 17, 807–826.

Elliot, A.J., Moller, A.C., Friedman, R., Maier, M.A. and Meinhardt, J. (2007), Color and psychological functioning: the effect of red on performance attainment , *Journal of Experimental Psychology,* Vol 136 (1), 154-68.

Emerson, R.W. (1836), website http://oregonstate.edu/instruct/phl302/texts/emerson/nature-emerson-a.html viewed at 19072013.

Frumkin, H. (2001). Beyond toxicity: human health and the natural environment. *American journal of preventive medicine*, 20(3), 234-240.

Fiandt, K., Forman, J., Erickson Megel, M., Pakieser, R.A., Burge,S. (2003), Integral Nursing: An Emerging Framework for Engaging the Evolution of the Profession, *Nursing Outlook*, Vol 51(3), 130- 137.

Finlayson, G.D. Trezzi, E.(2004), Shades of Gray and Colour Constancy, Colour and Imaging Conference, 12th Colour and Imaging Conference Final Program and Proceedings, 37-41(5).

Fisher, S.E., Scharff, C (2009), FOXP2 as a molecular window into speech and language, *Trends in Genetics*, Vol 25(4), 166-177.

Foddy, W. (1993), *Constructing Questions for Interviews and Questionnaires: Theory and Practice in Social Research*, 2–6. William; Cambridge University Press.

Fortner, B., Meyer, Th.E. (1997), *Number y Colours, A guide To Using Colour To Understand Technical Data*, Springer-Verlag New York, Inc.

Foster, R.G.(2005), Neurobiology: Bright blue times, *Nature* 433, 698-699.

Foster, R. G., Provencio, I., Hudson, D., Fiske, S., De Grip, W., Menaker, M. (1991), Circadian photoreception in the retinally degenerate mouse (rd/rd). *Journal of Comparative Physiology* A, 169(1), 39-50.

Frieling, H.(1968), *Das Gesetz der Farbe,* Musterschmidt-Verlag, Göttingen, Zürich, Berlin, Frankfurt.

Frieling, H., Auer, X. (1961), *Mensch-Farbe-Raum, Angewandte Farbenpsychologie*, Verlag Georg D.W. Callwey Münschen, dritte verbesserte und engänzte Auflage.

Gage, J.(1995), Colour and Culture,in Lamb, T., Bourriau, J. (1995), *Colour, Art and Science*, Cambridge University Press, Cambridge.

Garcia-Rill, E.(2002), Chapter 4, Mechanisms of Sleep and Wakefulness, in Lee-Chiong, T.L., Sateia, M.J., Carskadan, M.A. (2002), Sleep Medicine, published by Hanley & Belfus Inc Philadelhia, 31-39.

Gegenfurtner, K.R., Kiper, D.C. (2003), Colour Vision, *Annu.Rev. Neurosci,* 28, 181-206.

Gerritsen, F. (1972), *Het fenomeen kleur, de nieuwe kleurenleer gebaseerd op wetmatigheden van kleurperceptie,* Cantecleer bv, de bilt.

Goldbeck-Löwe, H. (2011), Der Farbenstreit Goethe-Newton, in Wolfschmidt, G.(Hg.),(2011), *Farben in Kulturgeschichte und Naturwissenschaft, Beiträge zur Geschichte der Naturwissenschaften,* Hamburg.

Goleman, D. (1996), *Emotionele intelligentie;* Uitgeverij Contact, Amsterdam/Antwerpen.

Goodale, M.A., Milner, A.D.(1992), Separate visual pathways for perception and action, *T.I.N.S.*, Vol 15(1), 20-25.

Gregory, R.L. (1998), *Eye and Brain*, Oxford University Press, Oxford.

Groenewegen, P. P., Van den Berg, A. E., De Vries, S., Verheij, R. A. (2006), Vitamin G: effects of green space on health, well-being, and social safety. *BMC public health*, 6(1), 149.

Grossberg, S. (1994), 3-D vision and figure–ground separation by visual cortex. *Percept Psychophys* 55:48–120 in Pollen, D.A. (1999), On the Neural Correlates of Visual Perception, *Cerebral Cortex*, Vol 9(1), 4-19.

Grossberg, S., Mingolla,E., Ross, W.D. (1997), Visual brain and visual perception: how does the cortex do perceptual grouping? *Trends in Neurosciences,* Vol 20(30), 106-111.

Hankins, M.W., Lucas, R.J.(2002), The Primary Visual Pathway in Humans Is Regulated According to Long-Term Light Exposure through the Action of a Nonclassical Photopigment, *Current Biology,* Vol 12(3), 191-198.

Hardin, C.L., (1988), *Colour for Philosophers, Unweaving the Rainbow*, Hackett Publishing Company, Indianapolis/Cambridge.

Hartig, T., Mang, M., Evans, G. W. (1991), Restorative effects of natural environment experiences. Environment and behavior, 23(1), 3-26.

Heller, E. (1990), *Kleur, Symboliek, Psychologie, Toepassing* (1990), Inleiding en Hoofdstuk 5, Het Spectum, Utrecht, 13-2- and 83-103.

Hoogenboom, N., Schoffelen, J. M., Oostenveld, R., Parkes, L. M., Fries, P. (2006), Localizing human visual gamma-band activity in frequency, time and space. *Neuroimage*, 29(3), 764-773.

Hubel, D. H.(1990), *Visuele informatie, Schakelingen in onze hersenen*. Valkenburg Offset BV, Ect, original title: Eye, Brain and Vision, The Scientific American Library, United States.

Hurlbert, A, Wolf K.(2004), Colour contrast: a contributory mechanism to colour constancy. *Progress in Brain Research* 144:147–60 in Conway, B.R.(2009), Colour Vision, Cones, and Colour-Coding in the Cortex. *The Neuroscientist,* Vol 15(3), 274-290.

Hurlbert, A.C., Ling, Y. (2007), Biological components of sex differences in colour preference, Current Biology, Vol 17 (16), 623-625.

Itten, J. (1961), *Kunst der Farbe*, Seemanverlag Leipzig, 23.

Jarret, R.L., Vuylsteke, D.R, Gawel, N.J., Pimentel, R.B., Dunbar, L.J.(1993), Detecting genetic diversity in diploid bananas using PCR and primers from a highly repetitive DNA sequence, Euphytica, Vol 68(1-2), 69-76.

Jacobs, K.W. Hustmeyer, F.E. (1974), Effects of four psychological primary colours on GSR, Heartrate and respiration rate, *Perceptual and Motor Skills,* 38, 763-766.

Jacobs, K. W. and Suess, J. F. (1975), Effects of Four Psychological Colours on Anxiety States. *Perceptual and Motor Skills*, Vol. 41, 201-210.

Kadam, B.S. (1974), *Patterns of Anthocyanin Inheritance in Rice V. Purple Plant, Indian Journal of Genetics and Plant Breeding,* Vol 34 (1), 100-117.

Kandel, E.R., Schwartz, J.H., Jessell, Th.M. (2000), Principles of Neural Science, Fourth Edition, McGraw-Hill Companies, United States.

Kaplan, R. (1993), The role of nature in the context of the workplace. *Landscape and urban planning,* 26(1), 193-201.

Kaplan, S. (1995), The restorative benefits of nature: Toward an integrative framework. *Journal of environmental psychology,* 15(3), 169-182.

Kaplan, R. (2001), The nature of the view from home psychological benefits. *Environment and Behavior,* 33(4), 507-542.

Kay, P., Berlin, B., Merrifield, W,(1991), Bio cultural Implications of Systems of Colour Naming, *Journal of Linguistic Anthropology,* Vol 1(1), 12-25.

Kaya, N., Epps, H.H. (2004), Relationship between colour and emotion, a study of college students, *College Student Journal,* 396-405.

Kim, J.Y. (2004), Interior Colour Design Using Psychophysiological Responses Towards User Oriented Smart Environments, Thesis Yonsei University, South Korea.

Kim, T.H., Song, J.K., Jeong, G.W, (2012), Neural Responses to the Human colour Preference for Assessment of eco-friendliness: A functional Magnetic Resonance Imaging Study, *Int. J. Environ. Res*., 6(4):953-960.

Küller, R., Mikellides, B, Janssens, J.(2009), Colour, Arousal, and Performance, A Comparison of Three Experiments, *COLOUR Research and application*, Vol 34 (2), 141-152.

Küller, R.,Ballal, S., Laikea, T., Mikellides, B., Tonellod, G. (2006), The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments, *Ergonomics*, Vol 49(14), 1496-1507.

Kwallek, N., Lewis, C.M., Robiens, A.S. (1988), Effects of Office Interior Colour on Worker' Mood and Productivity, *Perceptual and Motor Skills,* Vol.66 (1) 123-128.

Lakatos, P., Shah, A. S., Knuth, K. H., Ulbert, I., Karmos, G., Schroeder, C. E. (2005). An oscillatory hierarchy controlling neuronal excitability and stimulus processing in the auditory cortex. *Journal of neurophysiology,* 94(3), 1904-1911.

Lal, S. K., and Craig, A. (2001), A critical review of the psychophysiology of driver fatigue. *Biological psychology,* 55(3), 173-194.

Lamb, T., Bourriau, J. (1995), Colour, Art and Science, Cambridge university Press, Cambridge.

Lamb, T.D., Collin, S.P., Pugh, E.N.(2007), Evolution of the vertebrate eye: opsins, photoreceptors, retina and eye cup. Nature Reviews, *NeuroScience*, Vol 8, 960-975.

Lamb, T.D. (2013), personal email contact 20 July 2013.

Land, E. H.,McCann, J. (1971), Lightness and retinex theory. *JOSA*, 61(1), 1-11.

Lindblom, N., Heiskala, H., Hätönen, T., Mustanoja, S., Alfthan, H., Alila-Johansson, A., Laakso, M. L. (2000), No evidence for extraocular light induced phase shifting of human melatonin, cortisol and thyrotropin rhythms. *Neuroreport*, 11(4), 713-717.

Loose, J. (2010), personal email contact 4 nov. 2010.

MacLaury, R.E. (2005), So-Called Brightness in Colour Ethnography: Potentials for LCD Technology in Fieldwork and Categorization Research, *Cross-Cultural Research*, 39, 205-227.

Madden, T. J., Hewett, K., Roth, M. S. (2000), Managing images in different cultures: A cross-national study of color meanings and preferences. *Journal of international marketing,* 8(4), 90-107.

Mahnke, F. (1996), *Colour, Environment, and Human Response*. New York: Van Nostrand Reinhold.

Margrain, T.H., Boulton, M., Marshall. J., Sliney, D.H. (2004), Do blue light filters confer protection against age-related macular degeneration?, *Progress in Retinal and Eye Research*, Vol 23 (5), 523-31.

Mayfield Ligon, E. (1930), A genetic study of colour naming and word reading, *The American Journal of Psychology,* Vol 44 (1), 103-122.

McGee, T., Kraus, N., Killion, M., Rosenberg, R., King, C. (1993), Improving the reliability of the auditory middle latency response by monitoring EEG delta activity. *Ear and hearing,* 14(2), 76-84.

Mikellides, B. (1990), Color and Physiological Arousal. *Journal of Architectural & Planning Research*, 7(1), 13 - 20.

Milner, A.D., Goodale, M.A. (1995), *The visual brain in action,* Oxford Psychology Series, Second Edition, Oxford University Press, USA.

Milner, P.M. (1974), A model for visual shape recognition, *Psychol Rev* 81:521–535 in Pollen, D.A. (1999), On the Neural Correlates of Visual Perception, Cerebral Cortex, Vol 9(1), 4-19.

Mishkin, M., Ungerleider, L.G., Macko, K.A.(1983), Object vision and spatial vision: tow cortical pathways, *T.I.N.S.* 6, 414-417.

Mollon, J.(1995), *Seeing Colour* in Lamb, T., Bourriau, J. (1995), Colour, Art & Science, Darwin College Lectures, Cambridge University Press, 127-150.

Morris, J.S., Frith, C.D., Perretti, D.I., Rowland, D., Young, A.W., Calder, A.J., Dolan, R.J.(1996), A differential neural response in the human amygdala to fearful and happy facial expressions, *Nature* 383, 812 – 815.

Müller, A., Spillmann, W. (1987), Color order and aesthetics : the oeuvre of Dr. Aemilius Müller : the Bertha and Karl Leubsdorf Art Gallery, Hunter College.

Nathans, J., Thomas, D., Hogness, D.S.(1986), Molecular Genetics of Human Colour Vision: The Genes Encoding Blue, Green, and Red Pigments, *Science,* Vol 232, 193-202.

Nathans, J.(1999), The Evolution and Physiology of Human Review Colour Vision: Insights from Molecular Genetic Studies of Visual Pigments, *Neuron*, Vol 24, 299-312.

Niven J.E., Laughlin S.B. (2008), Energy limitation as a selective pressure on the evolution of sensory systems. *J Exp Biol*.,211:1792–1804.

Noguchi, H., Sakaguchi, T.(1999), Effect of Illuminance and Colour Temperature on Lowering of Physiological Activity, *Applied Human Science, Journal of Physiological Anthropology,* 18 (4), 117-123**.**

Ou, L.C., Luo, M.R., Woodcock, A., Wright, A., (2004), A study of colour emotion and colour preference. Part I: Colour emotions for single colours, *Colour Research & Application,* Vol 29 (3), 232–240.

Pavek, J.J., Corsini, D.L., Love, S.L., Hane, D.C., Holm, D.G., Iritani, W.M., James, S.R., Martin, M.W., Mosley, A.R., Ojala, J.C., Stanger, C.E., Thornton, R.E. (1992), Ranger Russet: a long Russet Potato Variety for Processing and fresh Market with Improved Quality, Disease Resistance, and Yield, *American Potato Journal,* Vol 69 (8), 483-488.

Pollen, D.A. (1999), On the Neural Correlates of Visual Perception, *Cerebral Cortex*, Vol 9(1), 4-19.

Rajae-Joordens, R.J.E. (2011), *The effect of coloured light on Valence and Arousal*, Investigating Responses Through Subjective Evaluations and Psycho-Physiological Measurements, Chapter 5, in J. Westerink et al. (eds.), Sensing Emotions, Philips Research Book Series 12, Springer Science+Business Media B.V.

Ramachandran, V.(2006), *Het bewustzijn, Een korte inleiding,* (original title: The Emerging Mind), Bagas & partners, Nijmegen.

Ribe, N.M. (1985), Goethe's critique of Newton: A reconsideration, *Studies in History and Philosophy of Science Part A*, Vol 16 (4), 315-335.

Rosenstein, L.D.(1985), Effect of colour of the environment on Task Performance and Mood of males and females with high or low scores on the scholastic aptitude test, *Perceptual and Motor Skills,* Vol 60(2) 550-550.

Saper, C.B., Scammell, Th.E, Lu,J. (2005), Hypothalamic regulation of sleep and circadian rhythms, *Nature*, 437, 1257-1263.

Sarter, M., Bruno, J.P., Berntson, G.G.(2006), *Reticular Activating System,* Encyclopedia of Cognitive Science (1999-2013), John Wiley and Sons, Inc.

Scheuerle, H.J. (1984), Die *Gesamt-Sinnes-Organisation. Überwindung der Subjekt-Objekt-Spaltung in der Sinneslehre*, 2. neubearb. A. Thieme, Stuttgart.

Schneider, G.E. (1969), Two visual systems, Brain mechanisms for localization and discrimination are dissociated by tectal and cortical lesions, *Science* 163 (3870), 895-902.

Schneider, W. (1987), *Sinn und Un-Sinn, Umweltt Sinnlich Erlebbar Gestalten in Architektur und Design.* Wiesbaden und Berlin: Bauverlag GMBH, 43, 106.

Sennett, R. (1992), *The Conscience of the Eye,* Design and Social Life of Cities, W.W. Norton & Company, New York, London.

Sivik, L. (1973), General and Applied Research on Colour Perception, Proceedings of the Lund Conference, Dowden, Hutchinson & Ross, Stroudsburg, PA, 181–197.

Soesman, A (2005), *De twaalf zintuigen, leraren van de mensheid*, Uitgeverij Vrij Geesteleven, Zeist.

Steer-reeh, A., (2012), *Wirkung von farbigem Licht auf die Herzfrequenzvariabilität und den Puls-Atem-Quotienten gesunder Probanden* (Inaugural dissertation Eberhard Karls Universität zu Tübingen).

Steiner, R. (1909, 1910, 1911), Anthroposophie – Psychosophie – Pneumatosophie, Berlijn, 1909-1910,1911, GA 115.

Steiner, R. (1914), Buildings will speak, Dornach june 17, 1914 in Howard, M.(1998), *Art as Spiritual Activity*, *Rudolf Steiner's Contribution to the Visual Arts,* Anthroposophic Press, United States of America.

Stockman, A., Sharpe, L. T., Fach, C.(1999), The spectral sensitivity of the human short-wavelength sensitive cones derived from thresholds and colour matches, *Vision Research* 39, 2901–2927.

Stockman, A., Sharpe, L. T. (1999), Cone spectral sensitivities and color matching. Color vision: From genes to perception, 53-88.

Stockman, A., Brainard, D.H. (2010), *Colour Vision mechanism*, in the OSA Handbook of Optics (3rd edition, M. Bass, ed), McGraw-Hill, New York, 11.1-11.104.

Stone, N. J., English, A. J. (1998), Task type, posters, and workspace colour on mood, satisfaction, and performance. *Journal of Environmental Psychology*,18(2), 175-185.

Taylor, Ch., Clifford, A., Franklin, A. (2012), Colour Preferences Are Not Universal, *Journal of Experimental Psychology: General*, Advance online publication. doi:10.1037/a0030273, 1-13.

Tedford, W. H., Bergquist, S.L., Flynn, W.E. (1977), The Size-Color Illusion, *Journal of General Psychology,* Vol. 97, no.1, 1977, pp. 145-149. in Tofle, R.B., Schwartz, B., Yoon, S. and Max-Royale, A. (2004*), Colour in Healthcare Environments: A Critical Review of the Research Literature,* The Coalition for Health Environments Research (CHER), Bonita, CA.

Tofle, R.B., Schwartz, B., Yoon, S. and Max-Royale, A. (2004*), Colour in Healthcare Environments: A Critical Review of the Research Literature,* The Coalition for Health Environments Research (CHER), Bonita, CA.

Ulrich, R. S. (1981), Natural versus urban scenes some psychophysiological effects. *Environment and behavior,* 13(5), 523-556.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., Zelson, M. (1991), Stress recovery during exposure to natural and urban environments .*Journal of environmental psychology*, 11(3), 201-230.

Valdez, P., Mehrabian, A. (1994), Effects of color on emotions. *Journal of Experimental Psychology:* General, 123, 394–409.

van Beek, H. C. A. (1983), Light-induced colour changes in dyes and materials. *Color Research & Application*, 8(3), 176-181.

van den Berg, A. E., Koole, S. L., Van der Wulp, N. Y. (2003), Environmental preference and restoration:(How) are they related?, *Journal of environmental psychology*, 23(2), 135-146.

van den Berg, A. E., Hartig, T., Staats, H. (2007), Preference for nature in urbanized societies: stress, restoration, and the pursuit of sustainability. *Journal of social issues*, 63(1), 79-96.

van der Sijs, N. (samensteller) (2010), Etymologiebank, *on http://etymologiebank.nl/*

van de Weijer, J. , Gevers, Th., Gijsenij, A. (2007), Edge-Based Colour Constancy*, IEEE Transactions on Image Processing,* Vol 16 (9), 2207-2214.

von Goethe, J.W. (1810), *Zur Farbenlehre,* Tübingen : J.G. Cotta'schen Buchhandlung

von Goethe, J.W.(1981), *De metamorfose van de planten, Inleiding en toelichtingen van Rudolf Steiner*, Uitgeverij Christofoor, Rotterdam.

Vonk, R.(2003), *Cognitieve Sociale Psychologie*, 2e druk, Uitgeverij LEMMA BV, Utrecht.

Walusinki, O.(2006), Yawning: Unsuspected avenue for a better understanding of arousal and interoception, *Medical Hypotheses*, Vol 67 (1), 6-14.

Wilson, G.D.(1966), Arousal properties of red versus green, *Perceptual and Motor Skills*, 23, 947-949.

Winthrop, B.P., Simon, J.E. (2000), Shoot regeneration of young leaf explants from basil (Ocimum basilicum L.), I*n Vitro Cellular & Developmental Biology - Plant*, Vol 36(4), 250-254.

Wong-Riley, M.T.T. (2010), Energy metabolism of the visual system, *Eye and Brain* 2, 99-116.

Wright, K.P. Jr and Czeisler, C.A. (2002) Absence of circadian phase resetting in response to bright light behind the knees. Science 297, 571

Yamashita, M., Yamada, I., Yasuda, M. (2012), Psychophysiological effects of tones of coloured lights in a dark environment, *NES2012 Proceedings*, Saltsjöbaden, Sweden, August 19-22.

Yoto, A., Shimomura, Y., Iwanaga, K., Katsuura, T.(2007), Effects of Object colour Stimuli on Human Brain Activities in Perception and Attention Referred to EEG Alpha Band Response, *Journal of Physiological Anthropology*, 26(3), 373-379.

Zajonc, A.G. (1976), Goethe's theory of colour and scientific intuition, *American Journal of Physics,*Vol 44(4), 327-333.

Zajonc, A. (1993), *Het licht zien, Het verbonden bestaan van licht en bewustzijn*, Uitgeverij Vrij Geestesleven, Zeist.

Zeylmans van Emmichoven, F.W. (1923), De werking van de kleuren op het gevoel; Dissertation, Utrecht.

Zeki, S., Marini, L. (1998), Three cortical stages of colour processing in the human brain, *Brain,* 121, 1669-1685.

.

Attachement A: Researches on colour effects using physiological data

d lower heart om	Colourful room causes arousal.	Changes in alphawaves show evidence for arousal. The lowered heartbeat however shows the opposite pattern that in general indicates a decrease of arousal.	x	x			x	x	
ces in characterizing / state. Alpha tendencies ffects. In red ite.	The colour red puts the brain into a more excited state, to such an extent as to cause a paradoxical slowing of the heart rate. Red interiors are more arousing than blue ones.	A lower heartbeat means in general a decrease of arousal. Deltawaves show primarily information concerning the auditory cortex.	x					x	
SR values, but es te and le looking at	Red is a more arousing colour than yellow, green and blue.	Two indicators for arousal don't show significant effects.	x		x	x	x		dm
level of GSR.	Red is a more arousing colour than green	This research shows weaknessess in the statistical approach. The applied intervals are unnatural in colour vision. Interpretation of conductance level and GSR unclear and makes comparison difficult.	x		x	x	x		dm
pha band and the total beta ured by EEG l are higher at blue. No ire.	Blue elicits more arousal based on AAC values. Activating effect of red paper on the central cortical region with regard to perception and attention was considerably more distinguishable than the biological activating effect of bluish light.	The AAC value only indicates attention. No occipital effects are striking as alpha waves in this region are most prominent. Comparison with research Ueda (2004) is unvalid as he used beta waves that primarily indicate motoric motivation.	x	x				x	
e found of yellow, blue, alpha relative fast alpha, , theta,	These effects are translated into moods and used in the model.	No consistent patterns are shown in the results. Types of brainwaves can not be attribited to moods. VEP is only usable for short time stimuli.	x		x			x	

colour ivity	AAC values at lower colour temperature-conditions) and no effects on heart variability	Low colour temperature light creates lowering of central nervous system activity.	AAC is not yet a clear indicator	x	x	x				no
s of n and	Seeing red seems to cause arousing effects relative to heart beat and respiration rate, however HF (High Frequency Heart variability) shows a possible opposite effect. Blue has a positive influence on heart variability.	Colour causes physiological effects.	Due to the limited time periods of 10 minutes of colour experience, priming - and as such learnt opinions (cognitions) - may be a cause of the measured effects. In addition, blue has a positive effect on SDNN (method to measure heartvariability). This method currently concerns a longer duration of measuring.	x		x	x	x		dm
ects of green on	The alpha 2 waves (9-11 Hz) increase is correlated to an increase of lightness. This increase is undependent of the colour (R,G,B). The alpha2 proprotion is highest for green and lowest for red.	More lightness (the vivid, bright, light and pale) tones causes positive effects on alpha 2 waves. Green causes more alpha 2 waves than red. Alpha 2 is conceived as the most optimal condition because this wave indicates relaxation and concentration.	Exposure of light is very short which can be the cause that only differences are found in alphawaves and not in heart rate. The increase of alpha 2 waves may be caused by psychological effects due to learnt associations (cognitions). The alpha waves are not occipital measured, the location where these waves mostly are shown. The differences between significant alpha 2 waves and no significances at the other alphawaves are striking.	x		x				x
oured covery	Larger recovery period in red light exposure.	Red light causes larger cortical arousal.	No differences are made between different types of alpha waves. As alpha waves show personal values, an experiment is necessary 'within subject'. AAR is not yet a well understood measurement and can not be conceived as evidence.	x	x	x				
ects of R,G,B)	No significant effects on skin conductance and blue light causes significant higher heart rate in dimmed conditions versus bright conditions.	A discrepancy exists between questionnaires and psycho-physiological measurements.	Much attention is paid to the COH value; this value however is rather unknown. More practical is the RSA. Data are too limited to make sound conclusions.	x	x	light				dm
kages l r	Stimulation with favourite colours shows activated areas as the pons, supramarginal gyrus, paracentral lobule, midbrain and globus pallidus. Stimulation with unfavourite colours shows activated areas the body of the caudate nucleus, parahippocampal gyrus, anterior cingulate gyrus, splenium of the corpus callosum, hippocampus, orbitofrontal gyrus, amygdala, thalamus and angular gyrus.	Linkages exist between emotional response and neural mechanisms.	Presenting colours by flickering stimuli is not in accordance with environmental experience in reality. Different areas are mentioned that possibly can be related to emotions rather than positive or negative preferences.	x		x				dm