

## MASTER

### Investigating natural and non-natural temporal composition of light patterns on stress recovery

Linders, I.K.

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Eindhoven University of Technology

Department of Industrial Engineering & Innovation Sciences

**Investigating natural and non-natural temporal composition of  
light patterns on stress recovery**

I.K. (Iza) Linders

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Supervisors:

Dr. K. (Kynthia) Chamilothoni

Prof. dr. ir. Y. A.W. (Yvonne) de Kort

Ir. Ö. (Özge) Karaman-Madan

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*Iza Linders*

*Eindhoven, April 2023*

### Abstract

Environmental factors such as nature and daylight have been shown to play a role in reducing stress. Therefore, there is a growing interest in translating natural elements into indoor environments in order to recreate the beneficial effects of nature. The current study builds upon promising findings concerning the potential stress-reducing effect of temporal variation of light stimuli derived from nature and investigates for the first time movement in nature using circles devoid of any natural cues. A single factor between-subjects experimental design was used to investigate the potential of dynamic light projections that follow the temporal composition of dappled light (i.e., light filtered through leaves) to reduce perceived stress. The between-subjects factor was the projected light with three levels: natural movement based on image analysis of a dappled light video, non-natural movement, and a static condition with a single frame from the natural movement condition. The Mannheim Multicomponent Stress Test was performed to increase participants' stress levels during the experiment and to allow for investigations on stress recovery. Subjective measures of stress were collected throughout the experiment using the Activation-Deactivation Adjective Check List and the Visual Analogue Scale. Furthermore, participants were asked to evaluate the lighting conditions based on attributes such as association with nature, fascination, stressfulness, complexity, and relaxation. Results showed that there were no significant differences in stress recovery between the three lighting conditions. Both dynamic lighting conditions were reported to be perceived as more fascinating and stressful than the static condition. However, no significant difference was found between the two dynamic conditions in perceived fascination and perceived stressfulness. Furthermore, the natural temporal lighting condition was not recognized as strongly associated with nature, indicating that the manipulation in this study was ineffective. This study presents a first attempt in identifying temporal elements of natural movements in dappled light stimuli and investigates its effect on stress. It is encouraged to explore this field further to contribute to the development of interventions for indoor environments that improve well-being.

Keywords: *natural movements, association with nature, dappled light patterns, stress recovery, fascination*

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## 1. Introduction

Stress is an inevitable human response to the demands of our everyday life (Selye, 1946; Selye, 1956; Almeida, et al., 2020). For ages, this evolutionary and natural response of the body has helped human beings to stay safe and cope with environmental threats, such as encounters with predators or changes in resource availability (Taborsky, et al., 2021). Whereas this response has been extremely helpful to us in times before the rise of modern society, its role has now become more problematic.

With the evolution of technology, immense opportunities have been provided (Au-Yong-Oliveira, et al., 2019; Hampton, 2016; Shochat, 2012), and with that new types of stressors emerged. These stressors contributed to an increase in stress levels among individuals (Almeida, et al., 2020; Hall, Steele, Christofferson, & Mihailova, 2021; Hoover, 2003; Reinecke et al., 2018; Wolfers & Utz, 2022), and led to several short-term and long-term consequences for human well-being (Greenberg, Carr, & Summers, 2002). Short-term stress can consist of multiple affective and cognitive states such as anxiety or the sense of being overwhelmed (Kemeny, 2003). This emotional distress is not necessarily harmful, it is a natural and needed response to a stressor (Kirby et al., 2013). However long-term stress may cause psychological, cognitive, and behavioral changes, such as increased smoking or decreased exercise and sleep (Bosnjak, Dobovski-Poslon, Bibic, & Bosnjak, 2019; Cohen, Janicki-Deverts, & Miller, 2007; Mental Health Foundation, 2018). These changes can lead to mental health problems, burnout, sleep problems and, increase the risk of diseases (Åkerstedt, 2006; Cohen, et al., 2007; Mental Health Foundation, 2018; Zastrow, 1984). Research from different global and national organizations confirms that stress is a major issue in today's society and indicates a pressing need for action to improve overall well-being (CBS, 2022; Gallup, 2019; TNO, 2020).

Currently, there are different effective treatment methods and activities for reducing stress and anxiety, such as transcendental meditation, cognitive behavioral stress reduction, progressive muscle relaxation, and specific lifestyle changes (Ditzen & Heinrichs, 2014; Abou Elmagd, 2016; Gonzalez & Miranda-Massari, 2014; Varvogli & Darviri, 2011). In addition to the aforementioned methods, there is a growing interest in stress-reducing interventions that can be applied to everyday life with little effort.

Studies have shown that environmental factors such as nature and daylight can play a role in reducing stress responses (Beute & de Kort, 2014; Kaplan, 1995; Ulrich, 1983). However, almost 90% of our time is spent indoors and therefore people do not often experience the benefits of the outdoor environment (Dales, Liu, Wheeler & Gilbert, 2008). In order to create indoor environments that foster beneficial contact between nature and people, biophilic design has been applied to architecture (Joye, 2007; Kellert & Wilson, 1993).

Biophilic design defines several elements and attributes, such as *natural shapes and forms* (fractal geometry), and *light and space*, that are useful when creating stress-reducing interventions for indoor settings (Kellert & Wilson, 1993). For example, spatial characteristics of façade and light patterns, such as irregularity and complexity, have been investigated. It was found that they can positively influence subjective and physiological responses in indoor environments (Abboushi, Elzeyadi, Taylor, & Sereno, 2019; Chamilothoni, Wienold, & Andersen, 2019). Furthermore, Kaplan (1995) described that elements in nature, such as clouds or the motion of leaves in the breeze, hold attention and evoke soft fascination, leading to restoration. This indicates that applying moving elements of nature to indoor environments might be a promising stress-reducing intervention as well. However, little is known about the composition of natural movements, and how those (elements of) natural movements play a role in stress recovery. The following sections will elaborate further on the above described topics.

### **1.1. Benefits of exposure to nature**

Nature or natural environments can be defined as environments with little to no presence or interventions of human beings (Hartig, Mitchell, de Vries, & Frumkin, 2014). Natural environments include physical features and processes of nonhuman origin such as flora and fauna, water, geological processes, and qualities of air and weather. In practice, natural environments that are designed and created by humans, such as landscaped parks, gardens, or roadside trees, are included in the definition of nature, even though their bases are artificial (Hartig et al., 2014). Exposure to natural environments provides many psychological and physiological benefits, such as increased mood, self-esteem, concentration, connectedness to nature, attention, self-discipline (concentrating, inhibiting initial impulses, and delaying gratification), and stress recovery (Barton & Pretty, 2010; Groenewegen, van



den Berg, Maas, Verheij, & de Vries, 2012; Mayer, Frantz, Bruehlman-Senecal, & Dolliver, 2009; Pretty, Peacock, Sellens & Griffin, 2005; Taylor, Kuo and Sullivan, 2002; van den Berg, Koole, & van der Wulp, 2003). In this thesis, the terms stress recovery and stress restoration will be used interchangeably.

The psychological restorative potential of nature was already reported by Ulrich in 1979. In this study, students with anxiety were shown images of either natural scenes or urban scenes (Ulrich, 1979). Natural scenes provided a better restorative effect regarding emotional well-being than urban scenes. In line with Ulrich's work, Bratman, Daily, Levy, and Gross (2015) examined, among other things, the impact of nature on affect. It was found that participants who walked in nature experienced affective benefits, such as the preservation of positive affect and decreased anxiety, negative affect, and rumination. In contrast, participants who walked in the urban environment did not experience any positive effects. Similar conclusions were drawn in a meta-analysis on the effect of contact with natural environments on positive and negative affect (McMahan & Estes, 2015). They found that relative to urban or built settings, exposure to natural environments was associated with an increase in positive affect and a more modest but consistent decrease in negative affect.

Recent literature not only confirms that independent of the type of exposure (e.g. plants, slides, posters, VR settings), nature provides psychological restoration (e.g.: Berto, 2014, Ulrich, 1979, Grahn & Stigsdotter, 2003), but it also provides evidence for the effect of nature on physiological stress recovery (Berto, 2014; Beute & de Kort, 2014; Ulrich et al., 1991). For example, Hartig, Evans, Jamner, Davis, and Gärling (2003) found a decrease in blood pressure among participants who walked in a natural environment compared to participants walking in an urban environment. Furthermore, Laumann, Gärling, and Stormark (2003) showed a decrease in heart rate among participants who watched a natural video after performing a cognitive task (compared to their baseline), while participants' heart rates remained constant when watching the urban video. Moreover, patterns of cortisol levels show that greener environments offer better opportunities for coping with stress (Thompson et al., 2012).

The restorative effects of nature might be attributed to a preference for natural environments (van den Berg, 2003). Van den Berg and colleagues (2003) investigated the relationship between restoration and environmental preference. It was found that videos of natural environments were perceived as more beautiful than videos of built environments, which, according to the authors, was a proxy for preference. It was also found that preference for the natural environments over the built ones largely accounted for the affective restoration. Furthermore, the restorative influence of nature also depends on individuals' perceptions of naturalness (van den Berg, Jorgensen, & Wilson, 2014). Research shows a positive relationship between the self-reported likelihood of restoration and perceptions of naturalness (Dallimer et al., 2012; Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007). In the study by van den Berg and colleagues (2014), the actual relationship between restoration and perceived naturalness was investigated. It was found that the more an environment was perceived as natural, the more restoration was measured in self-rated vitality (van den Berg et al., 2014).

## **1.2. Environmental psychology theories explaining the beneficial effects of nature**

Multiple studies have found that nature has a positive impact on our health and well-being (e.g., McMahan & Estes, 2015; van den Berg et al., 2003), including recovery from stress and attentional fatigue (e.g., Beute & de Kort, 2014). Two popular theories in environmental psychology attempt to explain the restorative effect of nature; the Psycho-Evolutionary Theory (Ulrich, 1983) and the Attention Restoration Theory (Kaplan, 1995). Accordingly, these theories lay the foundation for research on restorative environments and thus will be explained in more detail in this section.

### ***1.2.1. Psycho-Evolutionary Theory***

In an attempt to explain the restorative effects of nature, Ulrich (1983) proposed the Psycho-Evolutionary Theory (PET), also called the Stress Reduction Theory. Ulrich (1983) argues that the restorative response to nature can be seen as a byproduct of immediate positive affective responses and positive physiological changes induced by (unthreatening) natural environments. This theory is based on the empirical work of Zajonc (1980) and Ulrich's earlier work (1979, 1981).

Ulrich (1981) studied the physiological and emotional responses to images of natural and urban settings. It was found that natural scenes, especially the ones including water, have a more positive

influence on affective states in contrast to urban scenes. Furthermore, recorded brain electrical activity in the alpha frequency range suggested that individuals felt more wakefully relaxed when viewing images of natural environments than when viewing urban environments. It could be concluded that exposure to images of natural environments resulted in a positive affective reaction and decreased physiological arousal.

Ulrich (1983) argued that natural environments evoke affective responses in humans. According to Ulrich's PET (1983), this affective response occurs unconsciously and immediately after exposure to the environment. Accordingly, Ulrich argued that humans prefer natural environments because this response contributed to our chances of survival. Moreover, it was proposed that there are specific environmental elements that trigger positive affective responses, called 'preferenda' (Ulrich, 1983). These preferenda include complexity, gross structural features, depth/spatiality cues, even ground surface texture, deflected vista, and absence of threats. Additionally, exposure to unthreatening natural settings or unthreatening natural elements, such as vegetation, also evokes those immediate positive affective responses. Therefore, Ulrich (1991) argued that when an individual feels stress or experiences negative emotions and exposes themselves to the (unthreatening) natural environment or (unthreatening) natural elements, the positive affective responses that are evoked can weaken the former negative experienced emotions or stress, and consequently, recovery from stress follows.

Ulrich (1984) investigated his theory by examining the restorative effect of natural views on recovering surgical patients. One group of patients was assigned to a room with a window view of a natural setting, and the other group was assigned to a room looking out on a brick wall. It was found that patients with a natural view, compared to those with a wall view, had a shorter stay at the hospital, fewer negative comments from nurses in the evaluation, somewhat lower scores for minor postsurgical complications, and took fewer pain medications. A few years later, Ulrich and colleagues (1991) examined stress recovery during exposure to videos of natural and urban settings. First, participants watched a stressful movie, and afterward, they were exposed to either a video of a natural setting or an urban setting. The results showed that participants who were exposed to the video of a natural environment recovered faster from stress than participants who were exposed to the video of an urban

environment. According to Ulrich, the influence of natural settings positively shifted emotional and physiological states, resulting in restoration and confirming his psycho-evolutionary theory.

### ***1.2.2. Attention Restoration Theory***

Another theory that aims to explain why natural environments lead to restoration is the Attention Restoration Theory (ART) by Kaplan (1995). This theory revolves around two types of attention: voluntary attention, also called directed attention, and involuntary attention. Directed attention helps individuals to focus and engage in mental processes such as planning and problem-solving. However, this requires effort, and one's capacity to apply that effort is limited. Therefore, when directed attention is intensively used, it can become depleted, resulting in mental fatigue, also called directed attention fatigue. When directed attention fatigue is experienced, individuals can encounter difficulties in concentrating, planning, decision-making, and more. To restore from directed attention fatigue, Kaplan (1995) proposed that the presence of involuntary attention is essential.

Involuntary attention is a type of attention that happens without intention and is also known as soft fascination (Kaplan, 1995). It occurs automatically and it is evoked by fascinating stimuli. According to Kaplan, fascination can be divided into soft fascination and hard fascination. Hard fascination occurs when you are, for example, watching auto racing. In this situation, the attention is held by the stimuli but it does not leave room for reflection since it fully occupies one's attention. Soft fascination, however, holds your attention, but it does not require effort, and it leaves room for introspection and reflection. Therefore, soft fascination replenishes directed attention and stimulates restoration from directed attention fatigue. Natural environments are rich in objects that bring out this soft fascination, examples are snow patterns, sunsets, clouds, and the motion of leaves in the breeze. Due to the availability of objects that evoke soft fascination, natural environments have a restorative effect.

Kaplan (1995) emphasizes that the presence of fascination is not a guarantee for the recovery of directed attention. Three additional components are integral to a restorative environment: '*being away*', '*extent*', and '*compatibility*'. The component of '*being away*' refers to distancing yourself from your thoughts and worries. A physical distance in the form of a new environment can be helpful but is not essential for an individual to enable a conceptual shift in the mind. A change in the direction of a

person's gaze can already be enough. The component 'Extent' refers to an environment that is rich and coherent enough so that one feels connected and engaged with the environment. The stimuli that the environment provides will then take up sufficient available room in their mind for the individual to use less directed attention. Finally, the component 'compatibility' touches upon the fit of what a person is trying to do and what a person wants to do. It is desirable that individuals feel comfortable in the environment without the need to search for information or have concerns about how to react in difficult situations. Thus, a compatible environment results in less need for directed attention.

### **1.3. Biophilia in the built environment**

It is argued that by incorporating nature and natural elements in indoor environments, the beneficial effects of nature can be brought into built environments (Joye et al., 2007). Therefore, multiple studies have investigated, for example, how plants can be incorporated into indoor environments to reduce stress levels among individuals (Aydogan & Cerone, 2021). Other studies have shown how wallpapers and floors can be designed to create patterns that stimulate well-being (Ghaziani, Lemon, & Atmodiwirjo, 2021; Smith, et al., 2020). Characteristics found in nature, such as complexity, seem to be important in this kind of design (Kellert & Wilson, 1993). The focus of this study, however, is the use of light patterns with characteristics from nature, which is another emerging domain. The next sections will elaborate further on using characteristics from nature in architecture and lighting design.

#### ***1.3.1. Biophilic design***

Biophilic design is a design approach within architecture that aims to connect humans more closely to nature (Kellert & Wilson, 1993). This design approach is based on the biophilia hypothesis (Wilson, 1984), which claims that humans have an innate emotional affiliation with nature. The goal of biophilic design within architecture is to create environments that foster beneficial contact between nature and people (Kellert & Wilson, 1993). In order to do so, Kellert and Wilson (1993) defined six elements that are of importance: *environmental features, natural shapes and forms, natural patterns and processes, light and space, place-based relationships, and evolved human-nature relationships*. Multiple components of those elements, such as complexity, fractals, and spatial variability of light, are investigated within research to better understand nature and its effects on humans (e.g.: Kellert &

Wilson, 1993; Taylor, Newell, Spehar, & Clifford, 2005). The current study focuses on the elements of *natural patterns and processes* and *light and space* because these are expected to be the most relevant elements for research on light patterns.

The biophilic design element of *natural patterns and processes* describes the importance of integrating elements that are found in nature into the indoor environment (Kellert & Wilson, 1993). *Fractal geometry* is one such attribute, as patterns in nature are predominantly fractal (Mandelbrot, 1977; Barnsley, 1993; Gouyet, 1996). Nature consists of complex patterns that recur at progressively smaller scales and form non-regular shapes (Taylor et al., 2005). The visual complexity of fractal complexity is measured by the fractal dimension (D). An object containing no fractal structure has a fractal dimension of 1 or 2 (e.g., a line has a D of 1 and an object that consists of a filled area has a D of 2). In a study by Aks and Sprott (1996), it was found that a fractal dimension of 1.3 frequently occurs in nature (e.g., clouds). They also concluded that a fractal dimension of 1.3 is most preferred among their participants. Similar findings were reported by Taylor and colleagues (2005), where results of visual perception tests indicated that fractals with mid-range fractal dimensions (1.3-1.5) were found to be most preferred. Moreover, fractals in this specific range decreased physiological stress responses (measured with skin conductance) and could therefore be incorporated into environments to reduce stress levels (Taylor et al., 2005).

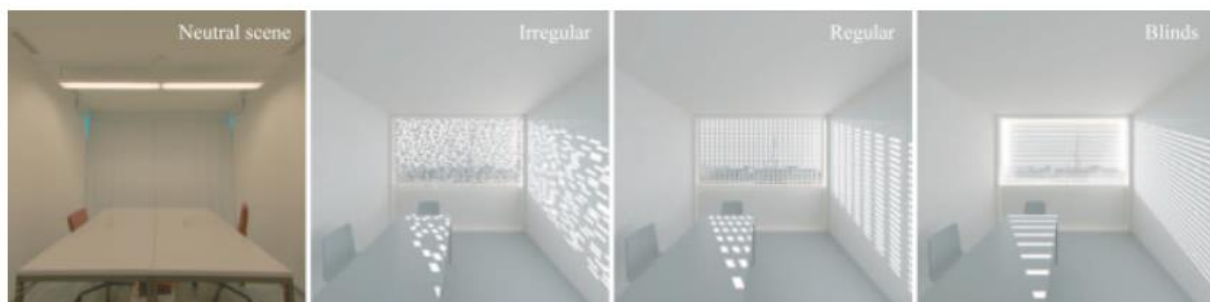
Another biophilic design element is *light and space*. Light is important for physical and psychological well-being (Beute & de Kort, 2014). It does not only help human bodies to produce vitamin D or allow them to perceive their environment, but it also positively influences circadian rhythms, productivity, mood, and stress (Knoop et al., 2020). Daylight and sunlight can both be present in indoor environments. However, the presence of sunlight is often limited due to visual or heating discomforts (Jakubiec, Reinhart & van den Wymelenberg, 2015; Ne'eman, E., Craddock, J., & Hopkinson, R. G.; 1976). This is a lost opportunity because it is found that sunlight patterns (i.e., sunlight that falls onto different surfaces in space) can influence occupants' visual comfort (Boubekri & Boyer, 1992). Furthermore, direct sunlight improves positive emotions better than diffuse daylight

(Kim, 1997). Interestingly, for improving emotional well-being, it is shown that sunlight sparkles are preferred over large areas of sunlight (Boubekri, Hull, & Boyer, 1991).

### ***1.3.2. Biophilic façade and light patterns***

Due to the positive effects of sunlight patterns and fractals, multiple studies have investigated façade geometry and the sunlight pattern geometries on occupants' responses. Although some of these studies did not explicitly investigate biophilic lighting (i.e. recreating light patterns and cycles derived from nature to promote well-being), their results and insights are still of interest to understand more about this concept.

One of the elements of façade geometry and light patterns that has been explored is regularity. For example, Chamilothoni, Wienold, and Andersen (2016) investigated the façade configuration and resulting daylight patterns in a virtual reality environment. Participants were shown three façade configurations (virtual scenes with an irregular pattern, regular patterns, and blinds, see Figure 1) and were asked questions regarding their experience of the space. Results showed that the irregular façade pattern was perceived as significantly more pleasant, interesting, complex, and exciting than the regular pattern. Similar findings were reported in the study by Chamilothoni and colleagues (2019), which examined both subjective and physiological responses to the same stimuli used in Chamilothoni (2016). Again, it was found that the irregular façade variation was perceived as more interesting and exciting than the regular façade configuration. Furthermore, the results showed that the participants' heart rate (but not their skin conductance response) was influenced by the façade and sunlight pattern geometry, and was lower under exposure to the irregular façade and sunlight pattern compared to the horizontal striped condition. According to the authors, this might be explained by either the fact that the irregular



**Figure 1.** Virtual scenes with a neutral scene, an irregular pattern, regular pattern, and blinds. (Chamilothoni et al., 2019).

pattern caught more of the participants' attention, or that this condition was more relaxing compared to the other conditions (Chamilothori et al., 2019). A similar, and more recent study investigated the effects of six different façade geometry and daylight patterns on the experience of space and physiological response (Chamilothori, Wienold, Moscoso, Matusiak, & Andersen, 2022). It was shown that the patterns that resembled natural elements, were reported as most pleasant compared to the other patterns.

The aforementioned studies were all conducted in either a simulation or a virtual environment. To validate whether those results also apply to real environments, Abboushi and colleagues (2021) examined the visual interest of sunlight and its effects on visual comfort and view quality under different window conditions in a real office environment. Office workers were exposed to three shading system configurations where windows were covered with a fractal pattern, a striped pattern or no pattern over three days (one condition per day). In comparison to the no pattern condition, the fractal pattern and striped pattern negatively influenced view quality among workers, while the shading system had no impact on the reported visual comfort and visual interest. These are conflicting findings with the study of Abboushi and colleagues (2019), who found that fractal light patterns with a medium to medium-high complexity were visually more interesting than other patterns. Therefore it is encouraged to conduct further research on the experience of light patterns in real environments.

In general, as can be seen in the studies above, mostly static conditions, and thus spatial characteristics of façade and light patterns are investigated. However, little is known about the temporal variability of light found in nature, i.e., the movement of light patterns over time. In literature, the term dynamic lighting is widely used for diurnal dynamics of light in natural or indoor settings (Pastilha, Gupta, Gross, & Hurlbert, 2020). However, in the current study, we focus on temporal changes of light in nature that can be perceived within seconds. In the ART, Kaplan (1995) already shows interest in these types of temporal changes in nature, such as moving clouds or the motion of leaves in the breeze. Kaplan (1995) argues that those movements hold attention and qualify for soft fascination, leading to restoration. The following section elaborates on the temporal variability of light in nature.



### *1.3.2. Dappled light*

In recent years, researchers have shown interest in dappled light (Chamilothori, Lemmens, Karaman Madan & de Kort, 2022; Dusseldorp, 2022). Dappled light patterns are caused by light that falls through foliage and casts shadows and sunlight patterns on surfaces nearby (Matchette, Cuthill & Scott-Samuel, 2018). Due to, e.g., the swaying of wind, the light patches and shadows change over time. In Figure 2, an example of a dappled light pattern is shown (Abboushi et al., 2019).



*Figure 2. Dappled sunlight patterns through trees. Courtesy of Steven Holl Architects/Susan Wides (Abboushi et al., 2019)*

An online study by Chamilothori and colleagues (2022) investigated the effect of the spatial and temporal composition of natural dappled light in an online study. Participants performed a task that induced stress and attention fatigue while a stimulus was projected on their laptop screen. The stimulus was either a static dappled light image, a dynamic dappled light video, or a control condition with a grayscale image. They showed that the dynamic dappled light pattern led to a higher association with nature, as well as to higher preference and higher fascination compared to the static dappled light pattern and the control condition. No significant effect was found on reported stress restoration. This study

showed a potential benefit of natural temporal composition, however, it should be noted that it was conducted in an online environment.

In a later study, Dusseldorp (2022) investigated the effects of static and dynamic dappled light patterns on stress restoration in a real environment. In a between-subjects experiment, one of three lighting stimuli was projected on a wall during the experiment: a dynamic dappled light video, a static dappled light image (single frame taken from the dappled light video), or a greyscale image with the same luminance as the static image (control condition representing a uniformly distribute light). After a stress induction task, a recovery period was followed while one of the three conditions was still projected on a wall. The results of this study confirmed the earlier findings of Chamilothoni et al. (2022) on association with nature. In addition, participants had a lower skin conductance level (baseline corrected) during the stressor task while being exposed to the dynamic lighting condition, suggesting a potential instorative effect where the dynamic dappled light lowered the effectiveness of the stressor. However, it is unclear whether the higher association with nature in the dynamic condition led to an instorative effect, or whether the dynamics itself led to this effect.

#### **1.4. Temporal dynamics in nature**

Following the aforementioned promising results about the potential of dappled light patterns for stress restoration (Chamilothoni et al., 2022; Dusseldorp, 2022), it is interesting to examine further the scientific knowledge of how humans perceive movements and how natural movements behave.

In order to survive, humans have the innate ability to detect and recognize possible threatening and non-threatening stimuli in their close environment (Anstis & Mackay, 1980). Threats often appear in the peripheral visual field of the eye and therefore this field is specifically sensitive to detecting sudden changes and movements (To, Regan, Wood, Mollon, 2011). Movement in nature can be a strong cue in identifying threats (i.e. the movement of leaves in trees during a storm versus a breeze). The often unconsciously processed environmental stimuli can trigger changes in human bodies, such as an increase in vigilance and alertness which are essential to produce fast behavioral responses when dealing with threats (Bayle, Henaff, & Krolak-Salmon, 2009).

When movements in nature are identified as unthreatening, they could provide space for fascination and restoration (Kaplan, 1995). According to the ART (Kaplan, 1995), fascination for nature is not only based on stimuli concerning fractals of natural scenes, or the rich and colorful textures of natural elements: it is also suggested that the presence of life (e.g., a flock of birds) and the constant change that is often present in nature (e.g., the flow of water, movement of clouds) can play a role (Joye, Pals, Steg, and Evans, 2014; Kaplan, Kaplan, & Brown, 1989). Similarly, Ulrich (1981) suggested that the temporal variety and visually dynamic qualities of natural scenes, such as moving water surface and wind-blown vegetation, are highly effective in terms of stimulating individuals' low arousal states to a higher level. Studies have confirmed that viewing natural scenes including movements positively influences individuals' moods and reduces stress (Meuwese, Dijkstra, Maas, and Koole, 2021). However, little is known about the specific elements in natural movements that humans recognize and (unconsciously) identify as natural.

Natural movements are defined as movement that is found in nature and is free from human impact (Anderson, 1991). Several studies have created models for different types of natural movements, such as snow falling (Moeslund, Madsen, Aagaard, Lerche, 2005), clouds moving (Gardner, 1985), swimming fish (Pavlov & Kasumyan, 2000), and the movement of leaves in the wind (Shinya & Fournier, 1992). These studies have been able to create (mathematical) rules to recreate specific movements that are found in nature. Furthermore, Reynolds (1987) explored the behavior, and thus the movement, of a flock of birds, herds, and schools. It was found that they all behave according to the same set of basic rules: 1) collision avoidance, 2) velocity matching, and 3) flock centering (Reynolds, 1987) (see Figure 3). Based on the above described models, it can be concluded that there are specific rules that can define certain natural movements.



*Figure 3. Similar rules of movements can be found in (1) schools of fish (Istock), (2) murmuration of birds (Marco Valk), and (3) herds (Dariusz Paciorek).*

In a study by van den Berg and colleagues (2014), it is even suggested that there might be an underlying pattern in all natural stimuli. They showed that there was a lack of differences in restorative impact between natural conditions. This possibly suggests that there is a common (visual) trigger of restoration that is inherent to all natural stimuli. The aforementioned study was based on static images, but it cannot be ruled out yet that this does not apply to the temporal domain as well.

The human ability to recognize natural movements via an underlying pattern might be similar to the human ability to identify body movements (biological motion) (Loula, Prasad, Harber, & Shiffrar, 2005). This ability is so advanced that even when whole body movements are reduced to a handful of point-lights that are attached to the joints of human actors, humans can still identify emotional states, vulnerability, gender, deceptive intent, motor effort, and sexual orientation of others (Johansson, 1973; Brownlow, Dixon, Egbert, & Radcliffe, 1997; Runeson & Frykholm, 1981, 1983; Ambady, Hallahan, & Conner, 1999; Dittrich, Troscianko, Lea, & Morgan, 1996). Similar to the ability to detect human body movement, it could be the case that humans have an instinct for detecting movement that can be found in nature.

An already identified common characteristic of natural environments is their specific spatial frequency:  $1/f$  (pink noise) (Tolhurst, Tadmor, Tang Choa, 1992). If an image has a frequency that deviates from the frequency found in nature, it can cause visual discomfort in humans (Fernandez & Wilkins, 2008). A study by Yoshimoto and colleagues (2017) tested whether these frequencies are also disturbing when applied to the temporal domain. It was found that light flickering with a deviation from the natural frequency increased visual discomfort. Furthermore, conditions that were rated as uncomfortable also scored low in perceived naturalness (Yoshimoto et al., 2007). The  $1/f$  noise fluctuation is found in all kinds of natural phenomena such as the sounds of the ocean, the breezing wind, or the flickering of candlelight (Ito et al., 2014; Duchowski et al., 2015; Landy, 1999). The power spectrum of the human heart rate over 24 hours also exhibits  $1/f$  spectral behavior and it is therefore suggested that this is one of the reasons why the  $1/f$  noise helps people to feel relaxed and comfortable (Ito et al., 2014).

Even though all animal species have their specific behavior, and processes (e.g. snow falling, moving leaves) found in nature have their characteristics in movement, there are some indications that there could be general main rules that govern all natural movements (e.g., van den berg, 2014; Fernandez & Wilkins, 2008). These rules might unconsciously help humans to recognize movements as natural, possibly even if the moving objects themselves are not natural (e.g. natural movement of non-natural abstract forms). It is of interest to explore this further to understand the stress-reducing effects of nature and to be able to recreate the beneficial elements of natural environments in indoor settings.

### **1.5. Aim, research questions & hypotheses**

There is a growing interest in stress-reducing interventions for indoor environments. Nature, natural movements, and light patterns with natural characteristics (e.g. dappled light) were identified as promising elements to reduce stress. However, further investigations on how movements taken from nature play a role in stress recovery are called for. Therefore, as a first step, we disentangle natural movements and use recreated dynamic dappled light patterns to further explore the relationship between natural movements and stress recovery.

Thus, the research question that this study aims to address is:

*“What is the effect of naturalness in the temporal composition of light patterns on recovery of stress?”*

The following hypotheses and sub-hypotheses are formulated:

*H1. There is an effect of the lighting condition on association with nature.*

- *H1a. The natural temporal composition of light is more associated with nature compared to the non-natural composition of light.*
- *H1b. The natural temporal composition of light is more associated with nature compared to the static condition.*

The stimulus in the natural temporal condition is based on a video that captures a real natural dappled light pattern. Therefore, we assume that the movements in this video consist of natural movements only. The elements of movement in the video have been disentangled and were used to create a stimulus for the natural temporal condition. Because the stimulus is a schematic imitation of natural movements, it is expected that it will evoke similar responses in participants as the original video of natural dappled light would do (Joye, 2007). The static and the non-natural condition do not consist of the natural elements that were identified. Therefore, we expect the natural temporal composition of light to be associated more with nature compared to the static condition and the non-natural condition.

*H2. There is an effect of the lighting condition on perceived fascination.*

- *H2a. The natural temporal composition of light is perceived as more fascinating compared to the non-natural composition of light.*
- *H2b. The non-natural temporal composition of light is perceived as more fascinating compared to the static condition.*
- *H2c. The natural temporal composition of light is perceived as more fascinating compared to the static condition.*

In two recent studies, it was found that projected dynamic dappled light patterns, compared to projected static dappled light patterns, were perceived as more fascinating and led to a higher association with nature (Chamilothori et al., 2022; Dusseldorp, 2022). By reason that these studies are similar to the current study, similar findings are expected. Moreover, the Attention Restoration Theory by Kaplan (1995) argues that moving elements in nature such as clouds or the motion of leaves in the breeze, hold our attention, and consequently evoke soft fascination. Therefore, it is argued that compositions of natural elements are seen as more fascinating than non-natural compositions (Kaplan, 1995).

*H3. There is an effect of the lighting condition on psychological restoration.*

- *H3a. The natural temporal composition of light leads to a higher psychological stress restoration compared to the non-natural temporal composition of light.*
- *H3b. The non-natural temporal composition of light leads to a higher psychological stress restoration compared to the static composition of light.*
- *H3c. The natural temporal composition of light leads to a higher psychological stress restoration compared to the static composition of light.*

According to the ART (Kaplan, 1995), dynamic stimuli (as long as they are not distressing) induce involuntary attention which replenishes directed attention and stimulates restoration. Therefore, we expect that both the natural and non-natural temporal compositions will lead to higher psychological stress restoration than the static condition. Furthermore, because nature provides stress reducing effects, we expect that the natural temporal composition leads to a higher psychological stress restoration than the non-natural one (e.g.: Ulrich, 1979a; Thompson et al., 2012).

## 2. Method

### 2.1. Design

A single factor between-subjects experimental design was used to investigate the effects of the temporal composition of light patterns on stress recovery. The independent variable in the study was the projected lighting stimulus, with three levels: (1) natural dynamics, (2) non-natural dynamics, and (3) static (control condition). The lighting stimuli were shown in a video projected on the wall and consisted of circles devoid of any cues from nature. Block randomization was performed to establish an equal number of participants among the three conditions. The psychological stress recovery of participants and their association with nature and perceived fascination with the lighting conditions were used as dependent variables. During the experiment, stress was induced to allow for the exploration of psychological stress recovery from the stressor.

### 2.2. Participants

Participants were recruited via the J.F. Schouten School for User-System Interaction Research database from the Eindhoven University of Technology (TU/e), via promotion at the TU/e, and through personal invites. They were selected based on eligibility criteria of (corrected to) normal vision, fluent use of the English language, age between 18 and 50 years, and not having photosensitive epilepsy, reading problems, or hearing impairments. Furthermore, to ensure reliable physiological measurements and to prevent possible negative effects of the stressor task, participants could not be pregnant or nursing and could not use medication other than oral contraceptives. Participants with cardiac problems and anxiety disorders were also excluded because of possible health risks due to the performance of a stressor task.

Considering restricted time and resources, the sample size of the study was based on feasibility. We aimed to conduct the study with 25 participants for each between-subjects condition, resulting in a total of 75 participants. However, due to some difficulties in recruiting participants, the final sample of the study consisted of 67 participants (29 males, 36 females, and 2 non-binary,  $M_{\text{age}} = 24$ ,  $SD_{\text{age}} = 6.13$ ). According to the sensitivity analysis in G\*Power (*ANOVA: Fixed effects, omnibus, one-way*,  $\alpha = 0.05$ ,  $\text{power} = 0.90$ ,  $n = 63$ ) it was estimated that a moderate effect size of  $f = 0.46$  could be detected given



this sample size (Faul, Erdfelder, Lang & Buchner, 2007; Cohen, 1988). Due to the uneven sample sizes per condition, the smallest sample size ( $n = 21$ ), found in the static condition, was taken to calculate the effect size. The sensitivity analysis is depicted in Appendix A. A similar effect size was reported in comparable studies investigating psychological and physiological stress recovery. For example, in a study on the viewing of videos of nature and its relation with physiological stress recovery (i.e., via skin conductivity, heart rate, and heart rate variability), a  $\eta_p^2 = .15$  (effect size converted to  $f = 0.42$ ) was found (Snell, McLean, McAsey, Zhang & Maggs, 2019). Furthermore, Dusseldorp (2022) investigated the effect of lighting conditions on physiological (i.e., via skin conductivity) and reported stress recovery (i.e., via the Activation-Deactivation Adjective Check List). An  $\eta_p^2 = .12$  (effect size converted to  $f = 0.37$ ) was reported. The study by Dusseldorp (2022) is closely related to the current study and therefore we could state that the expected effect size of  $f = 0.46$  was reasonable.

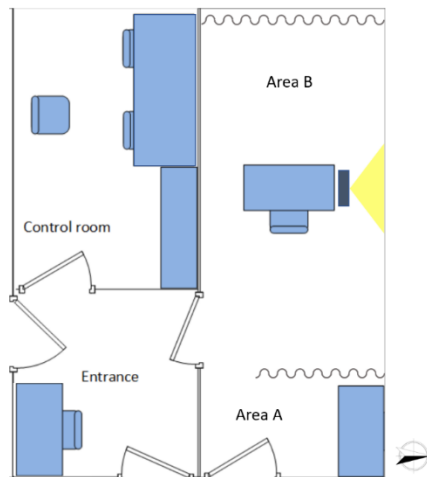
This study (ID: 1733) was approved by the Ethical Review Board of the Human-Technology Interaction group of the TU/e. All participants signed an informed consent form at the start of the experiment. The informed consent form can be found in Appendix B. Participants from TU/e and Fontys Hogeschool were compensated with €5,-. An additional €2,- was provided for participants that did not work or study at the aforementioned institutions.

## **2.3. Setting and apparatus**

### **2.3.1. Experimental setting**

The experiment was conducted in Lighting Lab B (09.206) in the Atlas building of the TU/e. The laboratory was divided into two areas, A and B, separated by a white blackout curtain (see Figure 4a). In area A (4.1 m<sup>2</sup>), participants were instructed on how to wear the equipment for physiological measurements of electrocardiography (ECG) and galvanic skin response (GSR). A tissue box, disinfection materials, the physiological measurement equipment Mobi8-6 (TMSi), and an image of how to attach the ECG electrodes, were positioned on the desk (see Figure 4b). Under the desk, a bin was placed. The curtain provided privacy to the participants when they needed to attach the ECG electrodes to their chests.

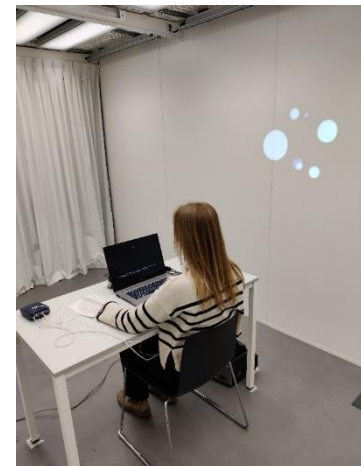
The experiment took place in area B (10.5 m<sup>2</sup>). A desk (1.20 m x 0.60 m x 0.75 m) with a chair was placed in the middle of the room to recreate a single-person office environment. The table was positioned in a way that, during the recovery phase, the seated participant could observe the lighting projections on the right wall (see Figure 4c). The windows were entirely covered with a blackout curtain to block the view and the daylight.



**Figure 4a.** Floor plan of the lighting lab, indicating area A & B, the control room, and the entrance.



**Figure 4b.** The desk in area A with physiological devices and other materials.



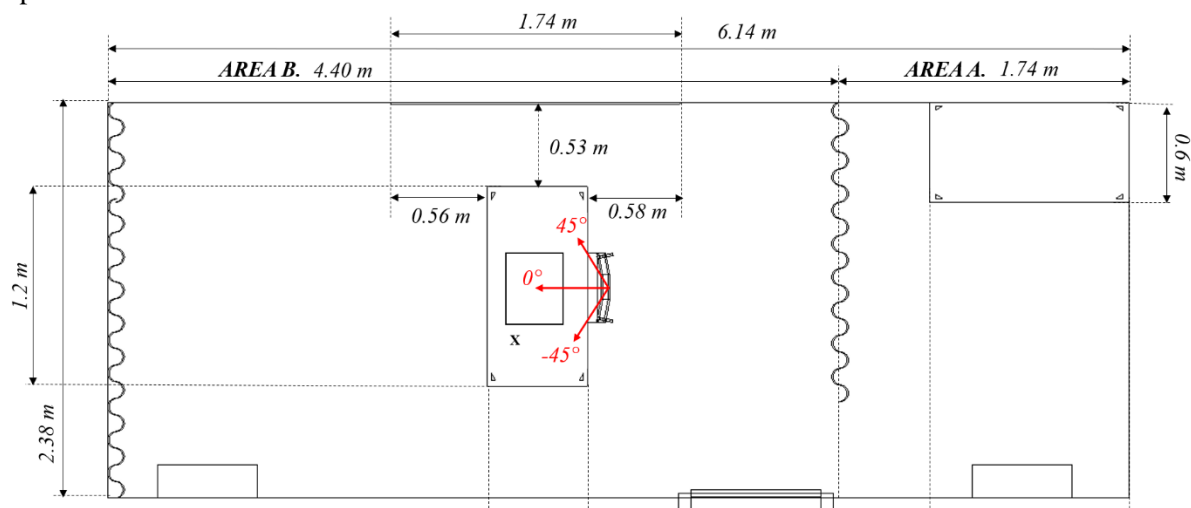
**Figure 4c.** The position of the participant during the experiment (area B).



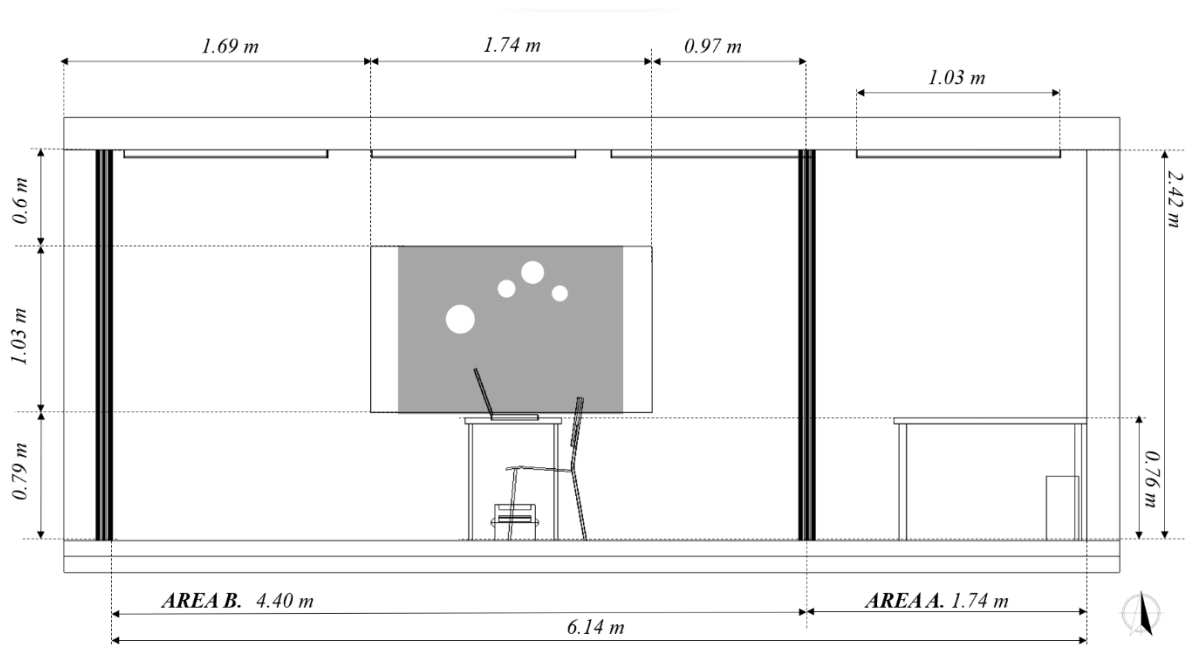
**Figure 5.** Side view rendering of the laboratory, showing area A (right) and area B (left) separated by a curtain (DIALux evo). Note that, in contrast to the image, the edges of the projector screen were not visible during the experiment.

A laptop (HP Zbook Studio G5, display resolution 1920 x 1080) with a wireless mouse was placed on the desk in area B and was set to full brightness. The program InquisitPlayer was used to present the instructions, collect subjective measures, and perform the stressor task on the laptop. A cross on the desk, next to the laptop, indicated the position of the participant's non-dominant hand once the physiological measurement device was connected. The device was placed next to their hand. Note that the cross only indicated the position for participants with a dominant right hand when using the computer mouse. The few left-handed persons were instructed to place their hand on the other side of the laptop.

On the right side of the desk, a projector (NEC WT610) was positioned on the floor 0.53 meters from the right wall. The projector was connected to the laptop and was used to project the experimental lighting conditions on the wall (see Figure 4c). The gamma factor of the projector was 0.64, the brightness of the projector screen was set to a value of 26, and the contrast of the screen to a value of 80 from the projector settings. The projector was set up in such a way that the luminance of the wall and the luminance of the projected screen were almost similar. Accordingly, the edges of the projected screen were not visible (as seen in Fig 4c). In Figures 6 and 7, detailed measurements of the room are depicted.



**Figure 6.** Floor plan of the laboratory, showing the areas used for preparation (area A) and the performance of the experiment (area B). The red arrows indicate the directions of vertical illuminance measurements (see section 2.3.2.).



**Figure 7.** Side view of the laboratory, showing the areas used for preparation (area A) and the performance of the experiment (area B).

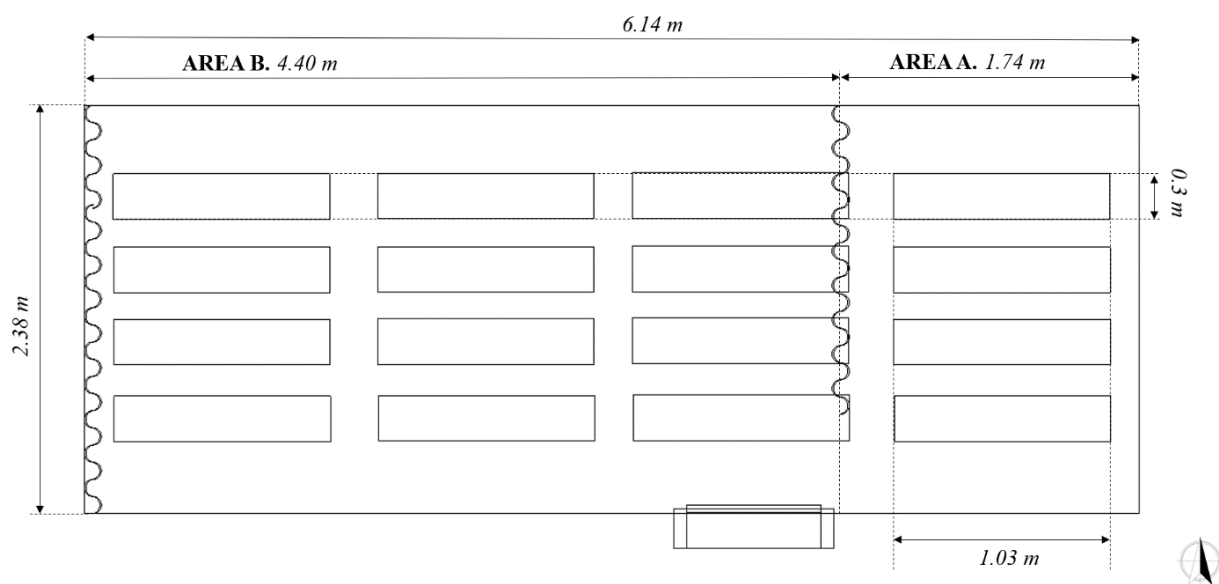
The entrance of the laboratory was equipped with a coat rack to store personal belongings and a computer where participants were able to check in for the experiment. The control room was used by the experimenters during the experiment. The cameras of the laboratory were turned on to observe the participant during the experiment and to make sure that the equipment was working correctly. The physiological measurement equipment Mobi8-6 was connected to a laptop in the control room.

### 2.3.2. Indoor environmental conditions

The temperature and relative humidity in the room was measured every five minutes using the Escort RH iLog data logger. This device was placed on the left back leg of the table from the position of the participant at a height of 0.64 m. The mean temperature according to this device, during the experimental sessions, was 22.8 °C (range 19.8 – 27.3°C) and the average relative humidity in the room was 30.1 % (range 21.7 – 38.6 %).

The sound level in the room was measured using the decibel meter Tenna 72-945. A baseline sound level of 44 dB was detected with both the projector and the air conditioning turned on. The laptop that was used for the experiment was set to a volume of 58 which established a sound level of 60 – 78 dB during the stressor task (MMST) of the experiment. The white noise that is part of the MMST was generated using the software Audacity.

As depicted in Figure 8, the lab was illuminated by 16 ceiling-mounted light panels (Philips Savio Lighting TCS760C, 1.3 m x 0.3 m). The lamps were set to an illuminance of 150 lux and a correlated color temperature of 3500 Kelvin via the software Savio Interact. The UPRtek MK350D spectrometer was used to measure the horizontal illuminance on the desk in area B and the vertical illuminance in three directions from the participant's perspective. During the measurements, the laptop screen and projector screen were turned off. The illuminance values can be found in Table 1, and the measurement directions for vertical illuminance are depicted with red arrows in Figure 6.



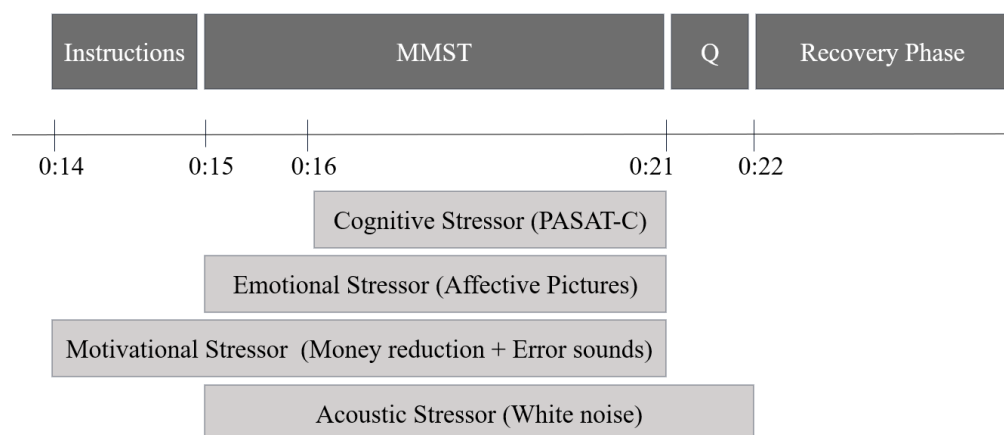
*Figure 8. Lighting plan of the ceiling-mounted light panels in the laboratory (area A & B).*

Measurement	Lux
Horizontal illuminance at desk height (0.76 m)	532.5
Vertical illuminance in a forward direction ( $0^\circ$ ), at eye level height (1.20 m)	227.6
Vertical illuminance at $45^\circ$ to the left ( $-45^\circ$ ), at eye level height (1.20 m)	238.0
Vertical illuminance at $45^\circ$ to the right ( $45^\circ$ ), at eye level height (1.20 m)	224.5

*Table 1. Results of the measurements for horizontal and vertical illuminance in area B. The directions for the vertical illuminance measurements are depicted in Figure 6.*

## 2.4. Stressor Task

Following the experimental paradigm used in restorative environments research (i.e., Joye & van den Berg, 2018), recovery from stress was measured during a recovery period after stress induction. Due to a preference for feasibility, ecological validity, a short procedure, but a strong stress response, the Mannheim Multicomponent Stress Test (MMST) was chosen as a way to induce stress (Reinhardt, Schmahl, Wüst, & Bohus, 2012). The MMST is found to be effective in inducing affective and physiological stress, while not using social-evaluative components, which are often costly and laborious (Bali & Jaggi, 2015; Reinhardt et al., 2012). The MMST has a duration of five minutes and consists of four types of stressors with each their duration: a cognitive stressor, an emotional stressor, a motivational stressor, and an acoustic stressor (see Figure 9). The instructions and the execution of the MMST in InquisitPlayer can be found in Appendix C, and the different components of the MMST are discussed in the sections below.

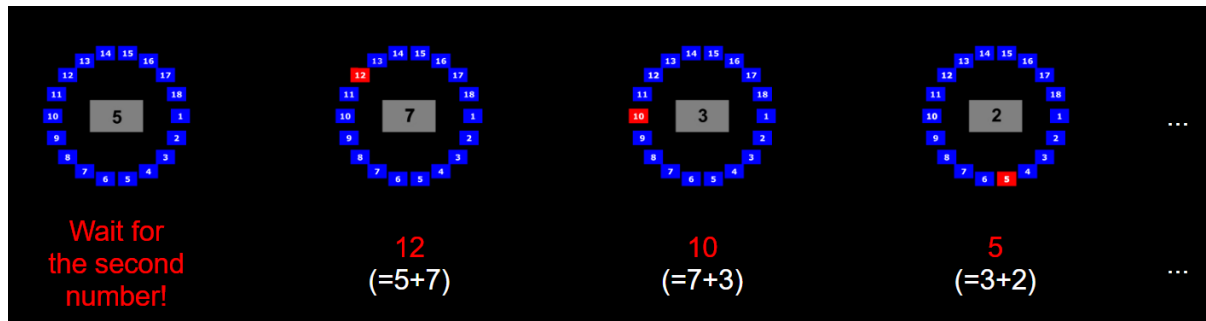


*Figure 9. Overview of the four components of the Mannheim Multicomponent Stress Test.*

### 2.4.1. Cognitive stressor

Following the original MMST, a modified computer version of the Paced Auditory Serial Addition Task (PASAT-C) was applied as a cognitive stressor (PASAT-C, Lejuez, Kahler & Brown, 2003). The PASAT-C is a challenging arithmetic task and has been proven to induce negative affect, psychological stress, as well as physiological reactivity (Brown, Lejuez, Kahler & Strong, 2002). In this task, a series of single digit numbers are shortly presented on a laptop screen (see Figure 10). Participants are asked to sum the current number with the previously presented number and click on the correct answer as fast

as possible. The correct answer can be chosen from the number circle that is positioned around the presented digit. When the next digit appears, participants need to sum the current number with the previously presented number while ignoring the sum of the previous calculation.



*Figure 10. Example of the PASAT-C test. The digit in grey indicates the presented number, and the numbers 1-18 in blue can be chosen as an answer to the sum (Lejuez et al., 2003).*

In the original PASAT-C there are three levels defined, however, in the MMST only two levels are applied (Lejuez et al., 2003; Reinhardt et al., 2012). Therefore, in the MMST, the PASAT-C has a duration of four minutes, including two levels of each two minutes. To increase stress, the time latency between the presented digits is decreased after the first two minutes. This results in a time latency of 3 seconds between the presented digits in Level 1, and a 2-second latency in Level 2.

#### **2.4.2. Emotional stressor**

As described in the original MMST procedure, before and during the PASAT-C, positive and negative affective valence pictures were shown in the background as an emotional stressor. These images were presented in the middle of the laptop screen, and just below the presented digit during the PASAT-C so that they would draw the participant's attention (see Figure 11).



*Figure 11. Example of the PASAT-C during the MMST, including the IAPS pictures (emotional stressor).*

The pictures were selected from the International Affective Picture System (IAPS, Lang, Bradley & Cuthbert, 2005). The IAPS provides ratings of affect for a large set of photographs that include a variety of contents for experimental investigations of attention and emotion (Lang et al., 2005). Following the MMST procedure, 44 negative affective valence images, including disgust and fear, and nine positive valence images were selected. It was not clear which specific pictures were used in the original MMST procedure, so it was decided to choose pictures based on a positive or negative valence of 1.5 standard deviations from the mean. Images that included blood, nudity of kids and adults, and dead bodies were disregarded from the list. The list of pictures can be found in Appendix D. Similar to the original procedure of the MMST, a positive valence image was displayed after five negative valence images to avoid habituation of the negative valence images. The images with negative valence were shown for five seconds and the images with positive valence were shown for three seconds. A minute before the start of the PASAT-C, 13 affective pictures were presented to the participant to induce a high level of attention toward the pictures. Three of the pictures were presented two times and participants were instructed to pay attention to those pictures (see Appendix D).

#### ***2.4.3. Motivational stressor***

Following the MMST procedure, the instructions of the cognitive test stated that after each wrong answer, five cents would be reduced from the participant's final compensation. The amount of reduction per wrong answer deviated from the original MMST (Reinhardt et al., 2012). When the participant made a mistake or did not provide an answer, a loud beep indicating an error was presented. In the right upper corner of the screen, participants were able to see the number of correct answers. Participants were informed about the misleading motivational stressor during the debriefing.

#### ***2.4.4. Acoustic stressor***

Acoustic stress was induced via exposure to white noise through the speakers of the laptop. The white noise was present in the background during the stressor task (five minutes). To avoid habituation to the noise, the intensity of the audio was gradually increased from 60 to 78 decibels. In the original



MMST procedure, a decibel level of 78 – 93 was used, however, the levels were lowered in the current study to prevent hearing impairment in participants (Daniel, 2007).

To measure the stress level of participants after the stressor, but before the recovery phase, the participants needed to fill in a questionnaire (see Section 2.6.). To prevent the possibility of instant relaxation after the stressor task, the white noise continued during the questionnaire. This was done to ensure better accuracy of self-reported stress and arousal and to capture the full recovery during the recovery phase. Once the recovery phase started, the acoustic stressor disappeared.

## **2.5. Stimuli**

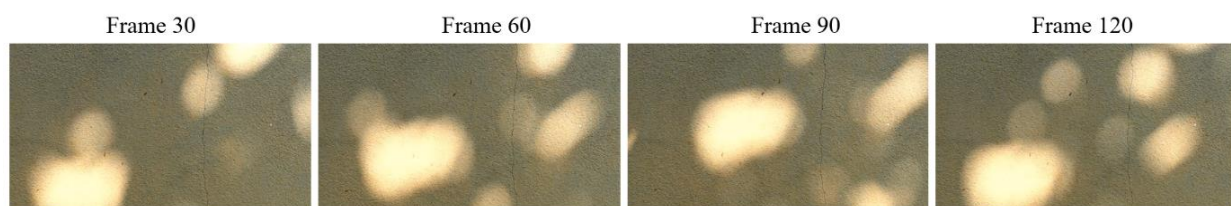
To investigate whether the natural and non-natural temporal composition of light patterns affects recovery from stress, three lighting conditions were explored: (1) a condition with a temporal composition of light patterns derived from nature (natural dynamics), (2) a condition with a temporal composition of light patterns not derived from nature (non-natural dynamics), and (3) a static condition with a single frame from the natural dynamics condition (control condition).

To create the lighting conditions, a video of a real dappled light pattern was used as a basis (Adobe Stock, 2022). The video shows a pattern that is created by real daylight and nature, and therefore it was assumed that this video represents a spatial and temporal composition from nature. The HD – quality video of the dappled light pattern (1920 x 1080 pixels) has a duration of 13 seconds and was downloaded from the Adobe Stock website. The name of the video is '[leaf shadow on the wall](#)' (file number: 141515812). The video consists of many light patches that often merge into each other. This made it difficult to identify and detect components of movements within the video. Therefore, we decided to crop the video in a way that it mostly captures light patches that do not often merge with other light patches (see Figure 12). This resulted in a video (960 x 540 pixels) with mostly individual light patches that occasionally merge into each other.



*Figure 12. Single frame of the dappled light video from Adobe Stock. The red box indicates the frame of the cropped video that is used in this study.*

During the creation of the stimuli, the spatial and temporal composition of the different types of movements that occur within the real dappled light video was analyzed. When spatial characteristics, such as the amount or shape of light patches, change over time, they are called temporal characteristics. Therefore, both the spatial and temporal composition of dappled light is difficult to separate from each other. In order to only focus on the temporal composition, it was important to deconstruct the video to find out which components described the movement of the light patches. The following key movements could be found: the increase and decrease of the area of a light patch, the change of the position of the light patches (coordinates), and the change in saturation of the patches (see Figure 13). Other movements such as the change of shape of the light patches, the gradient, and the contrast were disregarded in this study. The following sub-sections describe which movements are incorporated into the stimuli and how they were applied to create the stimuli.



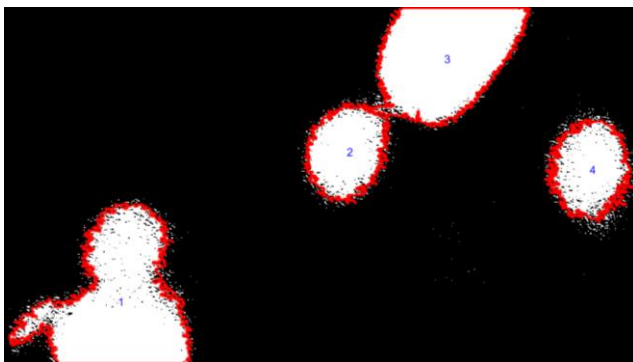
*Figure 13. Frames from the video of natural dappled light that show how the light patches move over time.*

### **2.5.1. Natural stimulus**

The creation of the condition with a natural temporal composition of light consisted of two parts. In the first part, the light patches of the original dappled light video were detected, and information regarding the light patches was retrieved. The second part consisted of recreating the movement of light

patches by using this retrieved information from the original video. In this manner, a simple video using circles was created, which attempted to recreate the exact movements of natural dappled light as presented in the original video, but without showing the exact visual image of natural dappled light. In doing so, the focus was only on the temporal composition of the stimulus which was needed to investigate the research question.

To detect the light patches, the original video of natural dappled light was analyzed with MATLAB R2022b and the MATLAB Image Analysis Toolbox. The video consisted of 370 frames. First, the pixels of the frames were converted into binary values using a threshold of 175, which turned the light patches in all frames to a white color and the background to a black color. This was necessary so that the borders between the colors, and thus the different light patches, could be detected with the function *bwboundaries()*. To illustrate, in Figure 14, the borders between the black and white areas are indicated by red dots. Thereafter, the function *regionprops()* was used to retrieve the properties of the white regions (the light patches). The following information was extracted for each region: the frame number, the area of the light patch, and the coordinates of the geometric center of each light patch (see Figure 15). Further information on how the light patches were tracked throughout the video can be found in Appendix E.



**Figure 14.** Single frame of the dappled light video, indicating borders between the light patches with red dots. The digits in the light patches indicate the numbering.



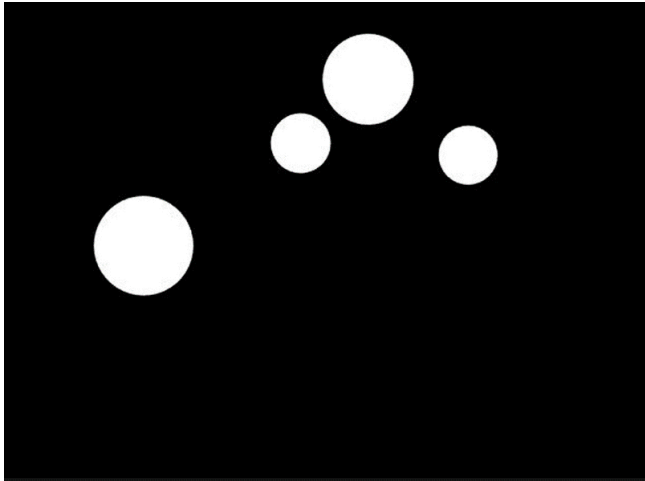
**Figure 15.** Single frame of the dappled light video with red crosses that indicate the geometric center of the light patches.

In the second step, the information that was retrieved from the natural dappled light video was used to recreate the natural temporal composition of light patches. As previously mentioned, multiple movements (i.e. changes in circle position, shape, size, and saturation) can be found within dappled

light patterns. To decide which of the movements should be considered in the stimulus, a small pilot study was conducted. In the pilot study, participants were asked to judge five different videos with white circles that moved following different combinations of movement types and answer questions on how fascinating and distressing the video is, and how much the video reminded them of nature. More detailed information about this pilot study can be found in Appendix F. The stimulus that was perceived as the most natural, included changes in the area and position of the patches, and therefore, these two movements were included in the video for recreating a natural temporal composition of light.

In MATLAB, both movements were applied to basic white circles. The circles moved according to the coordinates that were retrieved from the original light patches. The radius of each circle was based on the area of the light patches in the natural video and was calculated with the following formula:  $(\sqrt{Area/\pi}) * 0.5$ . Both movements that were applied to the circles were thus exactly copied from the original dappled light video, leading to a natural temporal composition. The recreated dappled light video consisted of the same frames per second as the original video and therefore the created stimulus had a duration of 13 seconds. Finally, the instances were inverted and used to create a loop in combination with the non-inverted frames, resulting in a five-minute video ( $700 \times 525$  pixels) that could be presented in the recovery phase of the experiment. The transition from the non-inverted frames to the inverted frames, and vice versa, was slightly visible in the video.

A frame of the final natural stimulus can be found in Figure 16, and the full video can be found [here](#). The MATLAB script for detecting the light patches in the original video can be found in Appendix G, the script for creating the table with all information can be found in Appendix I, and the script for recreating the light patches can be found in Appendix J.



*Figure 16. A single frame of the video that recreated the natural temporal composition of dappled light (natural dynamics).*

### **2.5.2. Non-natural stimulus**

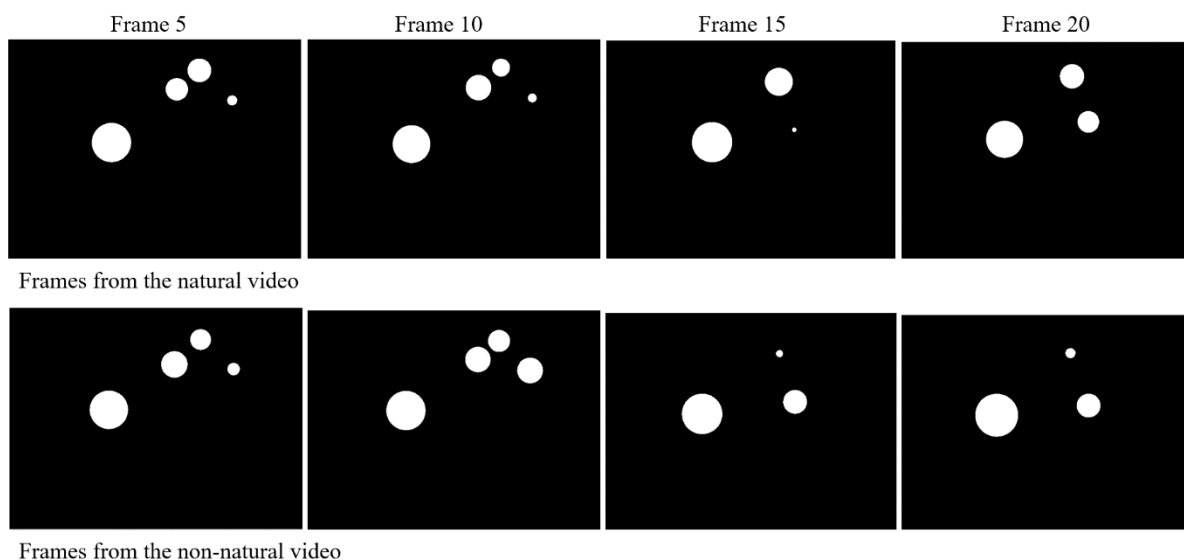
To create a non-natural temporal composition of light patterns, the retrieved information from the natural dappled light video was used. The aim was to have natural and non-natural stimuli that were as similar as possible, with differences only in temporal composition. Therefore, we randomized the existing properties of the natural dynamic patterns so that non-natural dynamic patterns were visible, while we kept the other properties of the video the same (i.e. the amount, color, and composition of the circles). Accordingly, the non-natural stimulus only included the movements in position and area, just like the stimulus in the natural condition. The pilot study showed that the non-natural stimulus with the aforementioned type of movements moving in an unnatural way scored second lowest on the item of ‘reminded me of nature’ (see Appendix F). Because of this result, the two movements, regarding the random circle position and area, were deemed sufficient to illustrate non-natural dynamics.

The randomization of the area of the circles was achieved by ordering the sizes for all the light patches, individually, from small to large. Note that the ordering took place from the moment that a patch appeared until a patch disappeared. When the same lighting patch appeared a few seconds later, this data was again sorted for the next period. By doing so, the original instance of the appearing and disappearing of the light patches was kept the same between stimuli.

In order to position the circles in a new random location, while keeping the Euclidean distance the same from one frame to the next frame, a random angle was created. This random angle was multiplied

by the coordinates of the geometric center of the light patches from the natural video for each frame. Subsequently, each circle got a new direction assigned for each frame. The new direction was used to create randomized coordinates for the circle.

The new randomized area and randomized coordinates were then used to create the non-natural stimulus. This resulted in a five-minute video ( $700 \times 525$  pixels) with white shaking circles that became gradually larger when they appear. All properties, except the area and coordinates of the light patches, were equivalent to the properties in the natural stimulus. The video can be found [here](#). The script to create the randomized area and coordinates can be found in Appendix K. The script of the creation of the non-natural stimulus can be found in Appendix L. In Figure 17, frames from both the natural and non-natural video are depicted and show a difference in movements.



*Figure 17. Frames from the recreated natural and non-natural videos that show how the circles move over time.*

### 2.5.3. Static stimulus

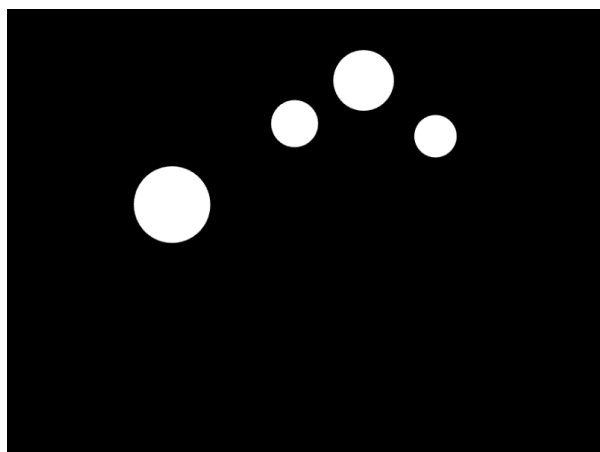
The static condition was included in the experimental design so that it could be compared to the two dynamic conditions with natural and non-natural temporal composition. It could also be seen as the control condition. The static stimulus was an image extracted from a representative frame of the videos that was used in the other two other conditions (see Figure 18). Because both the natural and non-natural conditions were based on the information retrieved from the original dappled light video, the static stimulus was also created based on that information.

The representative frame of the video was calculated by using both the average total area of light patches per frame and the average number of light patches per frame (see Table 2). Then, the frame that was closest to the values of the aforementioned properties, was used for the static image (the MATLAB script can be found in Appendix N). The script that calculates the average total area of light patches and the average number of light patches across all frames can be found in Appendix M.

	<b>Average</b>	<b>Median</b>	<b>Min</b>	<b>Max</b>
<b>Number of circles</b>	4	4	2	7
<b>Circle area</b>	82600	82800	64.48	131039

[pixels returned as a scalar]

*Table 2. Summary of the light patches in the natural condition.*



*Figure 18. The static lighting condition.*

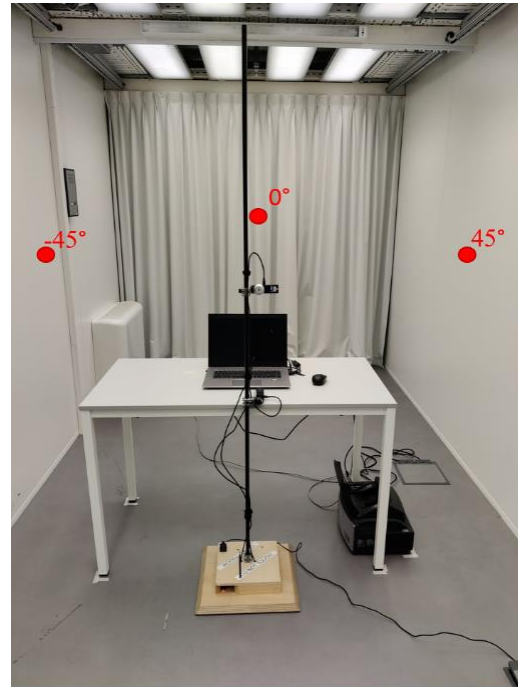
#### **2.5.4. Lighting characteristics of the stimuli and setting**

The lighting conditions were intentionally created to minimize differences in luminance values among them. To check whether this was programmed correctly, several illuminance measurements were performed. The Lighting Pole of the Human-Technology Interaction Lab in combination with two UPRtek MK350D spectrometers was used for this (See figures 19a and 19b). The Lighting Pole is a pole that holds the spectrometers and can be programmed in such a way that it can automatically measure the illuminance every few seconds or hours. In order to measure the average illuminance of each lighting condition in the recovery phase, a horizontal and vertical illuminance measurement was

taken every three seconds for five minutes. The measurements for the first baseline period and the MMST phase were taken each 30 seconds for ten minutes. Vertical illuminance measurements were taken in a forward direction ( $0^\circ$ ), left direction ( $-45^\circ$ ), and right direction ( $45^\circ$ ) (see Figure 19b). During the measurements, a person was seated on the chair behind the desk to recreate the situation of the experiment.



*Figure 19a.* Set-up of the lighting pole to perform illuminance measurements. On the right wall, the stimuli are projected.



*Figure 19b.* Set-up of the lighting pole to perform illuminance measurements. The red dots indicate the measurement directions for the vertical illuminance measurements.

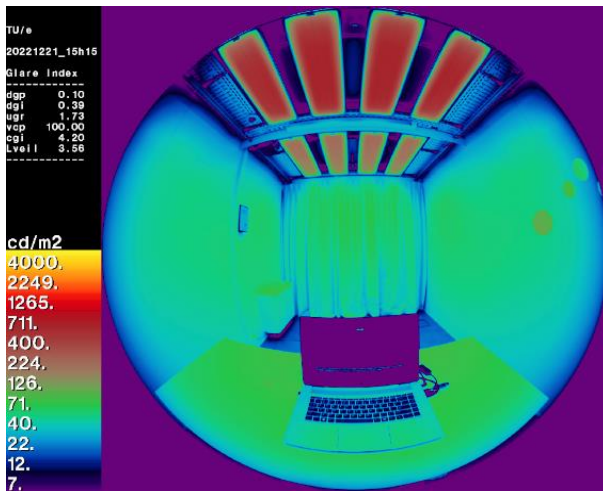
The average illuminance, the minimum and maximum illuminance, and the CCT can be found in Table 3. It can be concluded that the lighting conditions have minor differences in illuminance levels. However, when calculating the ratio between the most extreme illuminance levels (minimum: 212.3 lx, maximum: 244 lx) across the conditions, a factor of 1.15 is found. A factor of 1.5 is the threshold for the smallest significant difference for a just noticeable change in lighting intensity as mentioned in EN 12464-1-2011” (European Committee for Standardization (CEN), 2011). Therefore, we could state that even though there were fluctuations in the measurements, the illuminance differences were acceptable throughout the conditions.



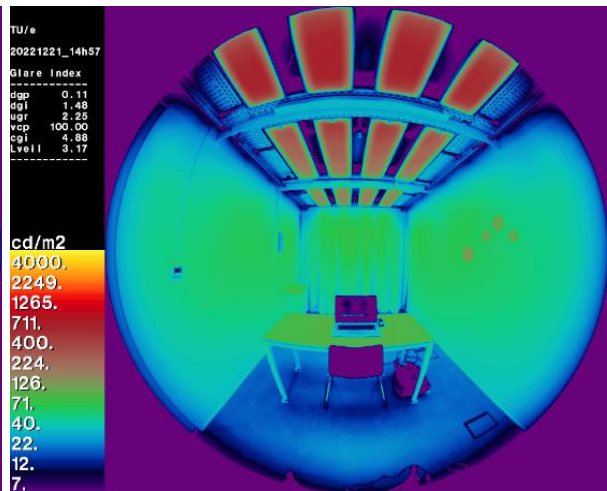
Measurement	Vertical illuminance [lx]		Horizontal Illuminance [lx]			Correlated Color Temperature [K]	
	<i>Average</i>	<i>Max</i>	<i>Min</i>	<i>Average</i>	<i>Max</i>	<i>Min</i>	<i>Average</i>
Baseline + MMST (-45°)	240.9	243.5	239.1	-	-	-	3327
Baseline + MMST (0°)	237.1	240.4	233.3	565.4	579.8	555.6	3352
Baseline + MMST (45°)	243.8	244.6	243.3	-	-	-	3303
Recovery phase - Condition 1 (-45°)	239.5	240.0	238.0	-	-	-	3320
Recovery phase - Condition 1 (0°)	218.5	224.3	212.3	505.8	524.6	475.0	3373
Recovery phase - Condition 1 (45°)	238.5	241.0	240.6	-	-	-	3338
Recovery phase - Condition 2 (-45°)	237.3	240.3	226.7	-	-	-	3317
Recovery phase - Condition 2 (0°)	235.2	237.6	232.7	549.7	566.5	515.0	3350
Recovery phase - Condition 2 (45°)	240.3	240.9	238.4	-	-	-	3336
Recovery phase - Condition 3 (-45°)	240.2	241.0	229.3	-	-	-	3316
Recovery phase - Condition 3 (0°)	242.3	243.4	240.9	566.9	587.9	523.0	3341
Recovery phase - Condition 3 (45°)	242.3	244.0	241.2	-	-	-	3334

*Table 3. Summary of horizontal and vertical illuminance, and color correlated temperature measurements. The directions of the measurements can be found in Figure 19b.*

HDR images of area B while the static lighting condition was projected on the wall were taken with a Konica Minolta luminance Camera. Due to the carefully calculated static lighting condition, the luminance values of the two dynamic lighting conditions were expected to be similar to the luminance values of the static condition. One of the HDR images was taken from the seating position of the participant at an eye level height of 1.2 m and the other HDR image was taken 1.10 m away from the seating position at a height of 1.40 m (see Figures 20 and 21). It is found that the wall has a luminance of 40-71  $\text{cd}/\text{m}^2$ , and the projections have a luminance of 126-224  $\text{cd}/\text{m}^2$ .



*Figure 20. HDR image of the experimental setting taken from the seating position of the participant at eye level height of 1.2 m. On the left, the color index of the luminance values in  $\text{cd}/\text{m}^2$  is shown.*



*Figure 21. HDR image of the experimental setting taken at 1.10 m away from the seating position of the participant at a height of 1.40 m. On the left, the color index of the luminance values in  $\text{cd}/\text{m}^2$  is shown.*

The Konica Minolta luminance spot meter was used to measure the luminance of different surfaces in the room. A reference plate with a reflection factor of 94,7% was used. The calculated reflection factor of the surfaces in the room can be found in Appendix O.

## 2.6. Measures

Subjective and physiological measures were collected during the experiment. The physiological measurements were performed to measure physiological stress. However, these measurements will not be analyzed in the scope of this thesis, and therefore there will be no further elaboration. Subjective measures include subjective stress, association with nature, and perceived fascination with lighting conditions. The chosen measures are partially based on the study by Chamilothoni and colleagues

(2022), van Dusseldorp (2022), and Wahlen (2022) who performed similar studies regarding lighting conditions and stress restoration.

### **2.6.1. Perceived Stress Restoration**

Perceived stress during the experiment is measured by the use of the shortened Activation-Deactivation Adjective Check List (AD-ACL; Thayer, 1986) and the Visual Analogue Scale (VAS; Huskisson, 1974). The AD-ACL is a multidimensional self-rating test validated for conducting rapid (10 – 60 seconds) and easy assessments of momentary activation or arousal states (Thayer, 1986). Considering that stress is associated with increased emotional arousal (Schlotz, et al., 2008), this is a useful method for examining stress. Arousal consists of two bipolar dimensions: tense arousal and energetic arousal (Thayer, 1986). Therefore, both dimensions are taken into account within the AD-ACL. The following 10 items are presented: *active, energetic, vigorous, lively, full-of-pep, jittery, intense, fearful, clutched-up, and tense* (see Table 4). The first five of the aforementioned items apply to the subscale *energetic*, and the last five items apply to the subscale *tension*. Participants were asked to fill in the following four-point rating scale for each of the ten items: “*Definitely feel*”, “*Feel slightly*”, “*Do not feel*”, and “*Definitely do not feel*”.

In order to test the internal consistency of the core dimensions the Cronbach’s alpha was calculated. The subscale tense arousal showed a Cronbach’s alpha between 0.46 and 0.90, and the subscale energetic arousal showed a Cronbach’s alpha between 0.71 and 0.93 (see Table 5 in Section 3). In total, only one Cronbach’s  $\alpha$  score was reported to be smaller than 0.50, and one Cronbach’s  $\alpha$  score was found to be between 0.60 and 0.70. All the other scores were reported to be higher than 0.70, which is considered sufficient (Bland & Altman, 1997). Thus, the subscales of tense and energetic arousal were satisfactory and could be averaged for further analyses.

The VAS is originally known as a clinical measure to assess pain (Hayes and Patterson, 1921; Huskisson, 1974). However, it is also recommended and used for the assessment of stress (Mitchell, Crane & Kim, 2008; Lesage & Berjot, 2011). It is considered a valid measure and comparable with the 14-item Perceived Stress Scale by Cohen (1988) (Lesage & Berjot, 2011). The VAS-stress allows for a rapid and simple way of measuring stress by rating participants’ current stress levels (‘ How stressed

are you at the moment?') on a scale from 0 (*Not at all*) – 10 (*Very much*) (see Table 4). This measure is often used in studies investigating stress restoration (Li & Sullivan, 2016; Stigsdotter, Corazon, Sidenius & Kristiansen, 2017; Kjellgren, Buhrkall, 2010)

Both the VAS and the AD-ACL are performed three times throughout the experiment: before the stressor task, after the stressor task, and after the recovery period. The results of the second and third sets of measurements were used to analyze stress restoration and test H3.

### ***2.6.2. Association with nature and fascination***

In the final questionnaire, additional demographic questions (age and gender) and questions concerning the evaluation of the lighting conditions were asked (see Appendix P). In addition, in a single-item scale, participants were asked to what extent the projected light condition reminded them of nature in order to test H1. Based on the study by Van Rietschoten (2021), an 11-point Likert scale ranging from 0 (*Not at all*) – 10 (*Very much*) was used to score the statement: “*The projected light reminds me of nature.*” (see Table 4). Another single-item scale was used to measure to what extent participants were fascinated by the projected light condition to test H2. The following statement: “*The projected light is fascinating*”, was also scored on an 11-point Likert scale ranging from 0 (*Not at all*) – 10 (*Very much*) (see Table 4). The same scale was used for the other exploratory items in the study. Participants were asked to what extent they experienced the lighting condition as *pleasant, interesting, distracting, exciting, relaxing, complex, and attention grabbing*. These items are based on the questions used in the study by Chamilothoni et al. (2022).

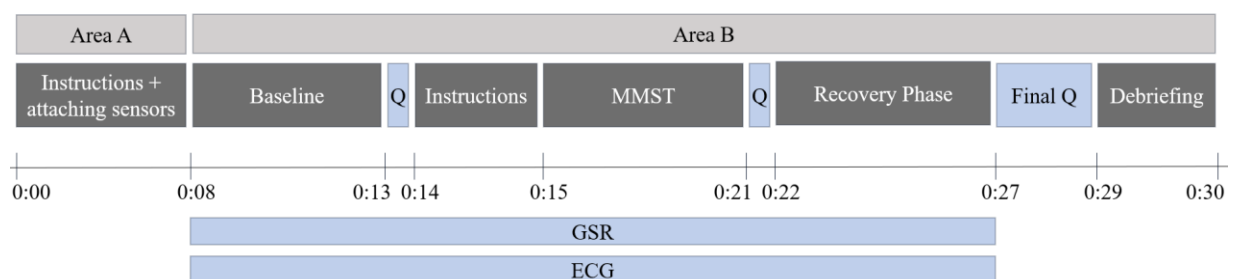
The exploratory items are not included in Table 4 because they are outside the main focus of the study. An overview of the exploratory items can be found in Appendix P.

Concept	Item	Answer
VAS	<i>How stressed are you at the moment?</i>	Likert scale: 0 (Not at all) – 10 (Very much)
AD-ACL	<i>Active</i>	For all items in the AD-ACL: Definitely feel, Feel slightly, Cannot decide, Definitely do not feel
	<i>Jittery/Nervous</i>	
	<i>Energetic</i>	
	<i>Intense</i>	
	<i>Vigorous</i>	
	<i>Fearful</i>	
	<i>Lively</i>	
	<i>Clutched-up/Anxious</i>	
	<i>Full-of-pep/Animated</i>	
	<i>Tense</i>	
Association with nature	<i>The projected light reminds me of nature.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Fascination	<i>The projected light is fascinating.</i>	Likert scale: 0 (Not at all ) – 10 (Very much)

*Table 4. Summary of the main subjective measures.*

## 2.7. Procedure

The experiments were conducted in the period from November 29<sup>th</sup>, 2022 to January 20<sup>th</sup>, 2023. The duration of each experimental session was 30 minutes. Figure 22 shows the procedure of the experiment for one participant and the details of the procedure are discussed in this section.



*Figure 22. Timeline of the procedure.*

Before entering the laboratory, participants believed that they were participating in a study measuring cognitive performance when multitasking. In both the invitation and the informed consent form of the experiment it was specified that the images that participants would see during the experiment could be disturbing and evoke strong negative emotions. Therefore, it was stated that if

participants have had a traumatic experience and/or were sensitive to visuals that include violence, traffic accidents, or domestic abuse, they were asked to reconsider their participation in line with this warning. Furthermore, participants were informed that the noise level of the audio can be moderately disturbing and that they might be exposed to mildly flashing lights that can trigger seizures for people with photosensitive epilepsy.

When the participant arrived at the laboratory, they were welcomed by the experimenter via the main entrance. They were asked to put away their personal belongings, including mobile phones and smartwatches. Participants read and signed the informed consent form, and logged into their accounts in the Archie Participant Database to indicate their presence.

Thereafter, the participant was guided toward area A. Here, instructions were given about how the ECG electrodes should be placed. The participants placed the electrodes on their upper bodies, while the experimenter waited on the other side of the curtain to give the participants their privacy. Afterward, the experimenter checked whether the electrodes were placed correctly, and attached the GSR sensors on the participant's fingers of their non-dominant hand when using a computer mouse. Subsequently, the participant was asked to sit down at the desk in area B. They were asked to place their non-dominant hand on the cross on the table so that their elbows could comfortably lie down and their hand was relaxed. A tissue was placed on the participant's non-dominant hand, to remind them to not move their hand. The participants were instructed to minimize movement during the experiment, however, they were allowed to move their heads and look around. All instructions for the experiment were shown on the laptop (see Appendix C). To start the experiment, participants could click on the 'continue' button on the laptop when the door of the room was closed by the experimenter.

First, participants were instructed to sit still for five minutes so that baseline measurements for the ECG and GSR could be collected. A timer was visible that showed how much time was left to prevent boredom or frustration among participants. The baseline measurement was followed by the first subjective questionnaire, including the AD-ACL and the VAS. Thereafter, instructions on the PASAT-C were presented and the motivational stressor was introduced (see Appendix C). Participants were then instructed to start the MMST with a duration of five minutes. Further information on the MMST

can be found in Section 2.4. Directly after the MMST, the second subjective questionnaire was conducted. During the questionnaire, the audio stressor was still present and only disappeared when the questionnaire was finished (see Section 2.4.4.). Then, the five-minute recovery phase started. In this phase, the projector showed one of the three lighting conditions on the wall. Via the laptop, participants were instructed to sit still so that the ECG and GSR measurements could be performed (see Appendix C). Finally, the participants were asked to fill in the final questionnaire.

Participants were misled about the aim of the study and the compensation (motivational stressor) before the stressor task. All participants were properly debriefed at the end of the experiment about the aim of the study and the motivational stressor. They were asked to refrain from sharing their experience with others that might participate in the study. Participants received compensation and were thanked for their participation.

## **2.8. Statistical Analysis**

The statistical software StataIC 16 was used to analyze the data. After visual inspections of odd cases within the data and careful comparisons of the comments that were noted during the experiments, two participants were removed from the data set. One of the participants did not correctly follow our instructions during the experiment, and the other was exposed to technical issues during the experiment. Thereafter, the data were checked for missing values and outliers. Although outliers were identified, they were not excluded from the data set as a thorough inspection showed that they corresponded to participants that have understood the questionnaires and appeared to give possible, realistic responses. The final data set consisted of responses from 67 participants.

The three main hypotheses were tested with the use of different analyses, using a significance level  $\alpha$  of 0.05. Before each analysis, corresponding assumptions were checked. The normality assumption was tested with the Skewness and Kurtosis test and with the Shapiro-Wilk test. If both tests revealed a  $p > 0.05$ , the variable was assumed to be normally distributed, and a parametric test was performed. However, if the assumption of normality was violated, a non-parametric test was conducted. If both tests gave a different indication of normality, the Shapiro-Wilk test was used as a guideline.

All three hypotheses were tested with a Kruskal-Wallis analysis of variance (ANOVA) or a one-way ANOVA for respectively the non-normally and normally distributed variables. If a main effect was found, the one-way ANOVA was followed up by Tukey post-hoc tests, and the Kruskal-Wallis analysis was followed up by the Wilcoxon Signed Rank Sum Test to examine which conditions were significantly different from each other. For the third hypothesis, which tests the effect of lighting conditions on psychological restoration, the dependent variables were the difference in stress arousal between the second measurement (post-stressor) and third measurement (post recovery) of the experiment, calculated for all three measures of interest (VAS-stress, energetic arousal, and tense arousal). An additional ANCOVA test with post-stressor measures as a covariate was conducted to control for post-stressor stress (or arousal) levels while testing the influence of the conditions on post-recovery stress (or arousal) levels. Finally, it was tested whether the conditions allowed for full recovery by using the paired-t-test or the Wilcoxon matched-pairs signed-rank to compare the baseline measurements with the post-recovery measurements for each condition separately.

Before investigating the third hypothesis, we tested differences in the baseline measurements and differences in the post-stressor measurements for the VAS-stress, energetic arousal, and tense arousal. Again, a Kruskal-Wallis analysis of variance (ANOVA) or a one-way ANOVA was performed, depending on the normality of the variables. If the outcomes of a measurement were similar across conditions per variable, randomization was successful, and further analyses were conducted. Moreover, it was investigated whether the stressor task was effective. To test whether the task had a significant effect on the stress level or arousal level of participants a Wilcoxon matched-pairs signed-rank or a paired sample t-test was performed, depending on normality.

Lastly, we performed exploratory analyses to better understand the manipulation within this study and the effect of condition on perceived stressfulness, relaxation, and perceived complexity.

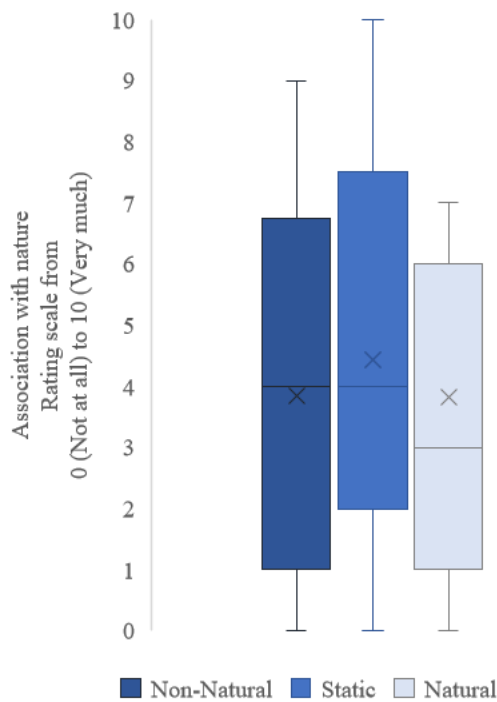


### 3. Results

In the subsequent sections, the results of the statistical analysis are reported. In Table 5, descriptive statistics of the variables are presented.

#### 3.1. Association with nature

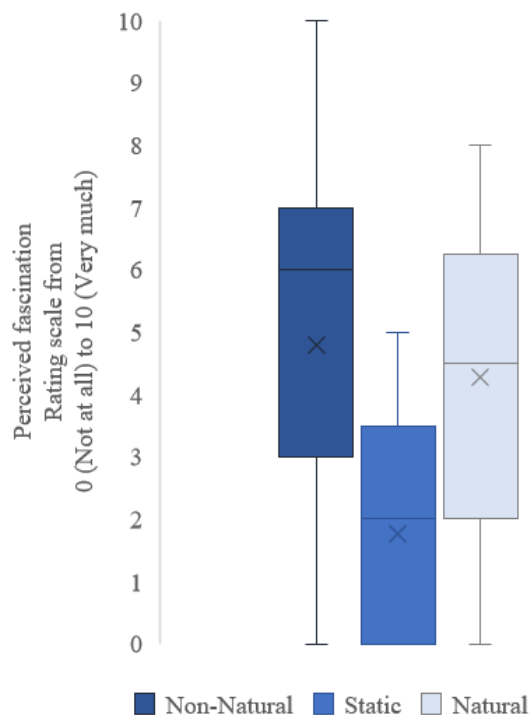
As can be seen in Table 5, the mean association with nature within the static condition is slightly higher compared to the mean association with nature within the natural and non-natural conditions. However, a Kruskal-Wallis analysis revealed that the association with nature did not vary significantly across lighting conditions,  $H(2) = 0.533$ ,  $p = .766$ ,  $\eta^2 = -0.023$ . This indicated that H1 ‘*There is an effect of the lighting conditions on association with nature*’ and its sub-hypotheses are not supported. Thus, the experimental manipulation was not effective. The distribution of the ratings of association with nature across the three conditions is shown in Figure 23.



**Figure 23.** Boxplot of the ratings on association with nature. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values.

### 3.2. Perceived Fascination

A one-way ANOVA indicated significant differences in perceived fascination across the three lighting conditions,  $F(2,64) = 9.21$ ,  $p < .001$ ,  $\eta^2 = 0.224$ . As shown in Table 5, a higher perceived fascination was reported in the non-natural condition ( $M = 4.79$ ,  $SD = 2.90$ ), followed by the natural condition ( $M = 4.27$ ,  $SD = 2.59$ ), and the static condition ( $M = 1.76$ ,  $SD = 1.79$ ). A Tukey post-hoc test revealed that perceived fascination was significantly lower in the static condition compared to the non-natural condition ( $p < .001$ ) and the natural condition ( $p = .004$ ). However, there were no statistically significant differences between the natural condition and the non-natural condition ( $p = .761$ ). Therefore, the main hypothesis H2 ‘*There is an effect of the lighting conditions on perceived fascination*’, and the sub-hypotheses H2b and H2c are supported. However, the sub-hypothesis H2a.: ‘*The natural temporal composition of light is perceived as more fascinating compared to the non-natural temporal composition of light.*’ is not supported. The distribution of the ratings of association with nature across the three conditions is shown in Figure 24.



**Figure 24.** Boxplot of the ratings on perceived fascination. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values.

**Table 5.** Descriptive statistics of ‘Association with nature’, ‘perceived fascination’, VAS-stress, ‘Tense Arousal’, and ‘Energetic Arousal’.

<b>Variable</b>	<b>Condition</b>	<b>n</b>	<b>Mean</b>	<b>SD</b>	<b>Median</b>	<b>Mode</b>	<b>Min</b>	<b>Max</b>	<b>Shapiro-Wilk Statistics</b>	<b>Shapiro-Wilk p-values</b>	<b>Skewness statistics</b>	<b>Kurtosis statistics</b>	<b>Skewness &amp; kurtosis p-values</b>	
<i>Association with nature</i>	Non-Natural	24	3.83	3.05	4	1	0	9	0.91	.033	0.10	1.52	.014	
	Static	21	4.43	3.17	4	2	0	10	0.95	.316*	0.12	1.76	.138*	
	Natural	22	3.82	2.56	3	3	0	7	0.96	.477*	-0.16	1.58	.037	
	All conditions	67	4.01	2.91	4	6	0	10	0.94	.003	0.09	1.73	< .001	
<i>Perceived Fascination</i>	Non-Natural	24	4.79	2.90	6	6	0	10	0.96	.448*	-0.32	2.21	.527*	
	Static	21	1.76	1.79	2	0	0	5	0.92	.076*	0.53	1.94	.166*	
	Natural	22	4.27	2.59	4.5	3, 5, 6, 8	0	8	0.99	.993*	-0.12	1.87	.230*	
	All conditions	67	3.67	2.79	4	0	0	10	0.95	.015	0.19	1.95	.011	
<i>VAS-stress</i>	Baseline	Non-Natural	24	2.17	2.08	1.5	1	0	8	0.87	.004	1.32	4.15	.014
		Static	21	1.67	1.46	2	0	0	5	0.94	.225*	0.50	2.46	.493*
		Natural	22	2.18	1.97	2	0, 1	0	6	0.93	.103*	0.66	2.29	.249*
		All conditions	67	2.01	1.85	2	1	0	8	0.92	< .001	1.06	3.71	.005
	Post-stressor	Non-Natural	24	7.50	2.23	8	8	2	10	0.89	.014	-1.01	3.20	.069*
		Static	21	7.29	2.24	7	7	2	10	0.90	.029	-1.05	3.74	.048
		Natural	22	7.73	1.98	8	8	2	10	0.85	.004	-1.38	4.63	.009
		All conditions	67	7.51	2.13	8	8	2	10	0.90	< .001	-1.14	3.77	.003
	Post-recovery	Non-Natural	24	2.67	2.22	2	0	0	7	0.93	.095*	0.38	1.88	.141*
		Static	21	3	1.67	3	2	0	6	1	1.000*	0.13	2.46	.940*
		Natural	22	3.68	2.01	4	3, 4	0	7	0.94	.209*	-0.53	2.52	.458*
		All conditions	67	3.10	2.01	3	2	0	7	0.97	.158*	0.003	2.02	.032

Notes: \* normally distributed (Shapiro-Wilk test outcome:  $p > 0.05$ )

**Table 5.** (continued) Descriptive statistics of ‘Association with nature’, ‘perceived fascination’, VAS-stress, ‘Tense Arousal’, and ‘Energetic Arousal’.

Variable	Condition	n	Mean	SD	Median	Mode	Min	Max	Cronbach's Alpha	Shapiro-Wilk Statistics	Shapiro-Wilk p-values	Skewness statistics	Kurtosis statistics	Skewness & kurtosis p-values	
<i>Tense Arousal</i>	Baseline	Non-Natural	24	3.43	0.64	3.7	4	2	4	0.78	0.89	.013	-0.75	2.19	.145*
		Static	21	3.68	0.33	3.8	4	3	4	0.46	0.94	.239*	-0.56	2.02	.202*
		Natural	22	3.44	0.48	3.5	4	2.4	4	0.65	0.95	.370*	-0.49	2.29	.429*
		All conditions	67	3.51	0.51	3.6	4	2	4	-	0.91	<.001	-0.92	3.00	.019
	Post-stressor	Non-Natural	24	1.88	0.75	1.7	2.4	1	3.8	0.81	0.92	.063*	0.81	3.00	.140*
		Static	21	1.82	0.67	1.6	1, 1.6	1	3.6	0.83	0.94	.249*	0.69	3.42	.153*
		Natural	22	1.58	0.74	1.2	1, 1.2	1	4	0.90	0.78	<.001	1.83	6.40	.001
		All conditions	67	1.76	0.72	1.6	1	1	4	-	0.90	<.001	1.08	3.89	.003
	Post-recovery	Non-Natural	24	3.14	0.66	3.2	4	2	4	0.78	0.98	.912*	-0.14	1.79	.122*
		Static	21	2.91	0.80	3	2.4, 3.2, 3.8	1.4	4	0.88	0.97	.773*	-0.32	2.04	.395*
		Natural	22	2.75	0.85	2.8	2.8, 4	1.4	4	0.88	1.00	1.000*	0.07	1.91	.296*
		All conditions	67	2.94	0.77	2.8	4	1.4	4	-	0.99	.642*	-0.23	2.04	.033
<i>Energetic Arousal</i>	Baseline	Non-Natural	24	3.15	0.58	3.1	2.4, 3, 4	2.2	4	0.71	0.99	.994*	0.07	1.82	.149*
		Static	21	3.18	0.67	3.4	4	2	4	0.81	0.96	.622*	-0.32	1.73	.103*
		Natural	22	2.85	0.67	2.7	2.4	1.8	4	0.74	0.98	.846*	0.41	2.04	.310*
		All conditions	67	3.06	0.65	3	4	1.8	4	-	0.98	.552*	0.01	1.78	<.001
	Post-stressor	Non-Natural	24	2.33	0.62	2.3	2.8	1	3.2	0.73	0.98	.827*	-0.24	2.10	.463*
		Static	21	2.32	0.85	2.2	1.8, 2.8	1	4	0.90	0.96	.610*	0.40	2.26	.538*
		Natural	22	2.23	0.60	2.1	1.8, 2	1.2	3.6	0.79	0.97	.716*	0.56	2.85	.379*
		All conditions	67	2.29	0.69	2.2	1.8	1	4	-	0.98	.587*	0.32	2.57	.425*
	Post-recovery	Non-Natural	24	2.95	0.70	2.8	2.2	1.8	4	0.84	0.97	.639*	0.14	1.71	.074*
		Static	21	2.91	0.81	3	2, 4	1.8	4	0.93	0.95	.356*	0.10	1.41	.007
		Natural	22	3.01	0.58	3	3	2	4	0.75	0.99	.985*	0.05	2.19	.744*
		All conditions	67	2.96	0.69	3	2.2	1.8	4	-	0.98	.416*	0.06	1.73	<.001

Notes: \* normally distributed (Shapiro-Wilk test outcome:  $p > 0.05$ )

### 3.3. Baseline measurements, post-stressor measurements, and effectiveness of stressor

In order to test whether the stress levels at baseline- and post-stressor were similar for each of the conditions, individual statistical tests were performed for the VAS-stress, energetic arousal, and tense arousal.

A Kruskal-Wallis Test showed that stress levels at baseline did not vary significantly across lighting conditions on VAS stress,  $H(2, N = 67) = 0.521, p = .771, \eta^2 = -0.023$ , or tense arousal,  $H(2, N = 67) = 2.386, p = .303, \eta^2 = 0.006$ . Furthermore, a one-way ANOVA indicated no statistically significant differences for energetic arousal at baseline,  $F(2,64) = 1.83, p = .168, \eta^2 = 0.054$ . Thus, the randomization of participants was successful.

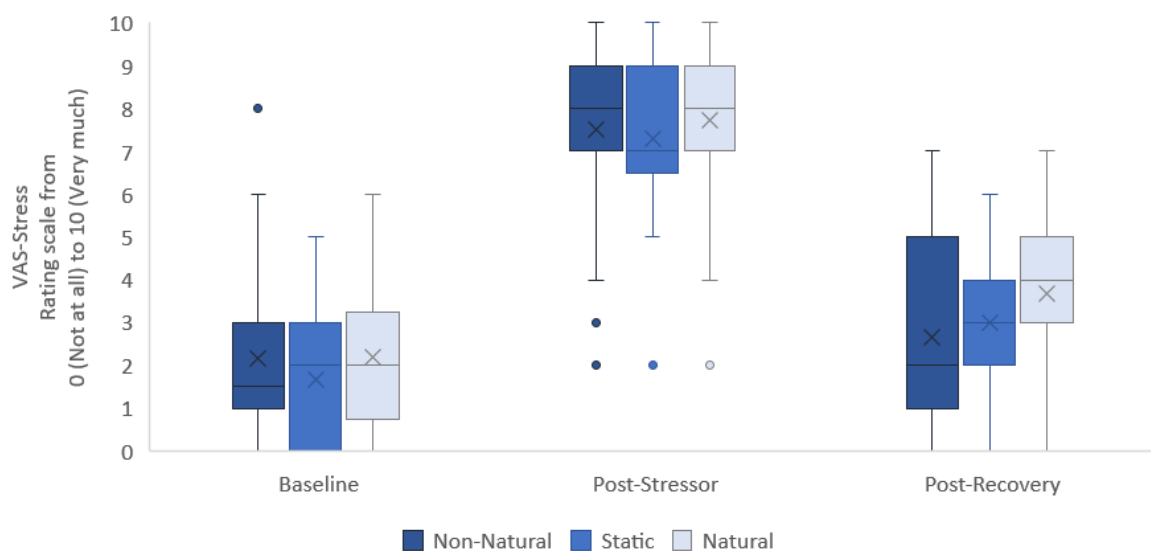
Furthermore, a Kruskal-Wallis test showed that stress levels at post-stressor did not vary significantly across lighting conditions on VAS stress,  $H(2, N = 67) = 0.668, p = .716, \eta^2 = -0.02$ , or tense arousal,  $H(2, N = 67) = 3.349, p = .187, \eta^2 = 0.021$ . Moreover, the energetic arousal did not significantly vary between lighting conditions at post-stressor,  $F(2,64) = 0.14, p = .866, \eta^2 = 0.004$  (one-way ANOVA). Again, the results confirm that the randomization of participants was successful.

We then determined whether the stressor task successfully induced stress among participants. The Wilcoxon matched-pairs signed-rank test revealed that there was a statistically significant increase in VAS-stress between baseline ( $M = 2.01, SD = 1.85$ ) and post-stressor ( $M = 7.51, SD = 2.13$ ),  $N = 67, z = -7.108, p < .001, r = -0.868$ . Similarly, there was a statistically significant increase in tense arousal between the baseline ( $M = 3.51, SD = 0.51$ ) and post-stressor ( $M = 1.76, SD = 0.72$ ) measurements,  $N = 67, z = -7.031, p = .000, r = -0.859$ . Lastly, a paired samples t-test revealed a statistically significant increase in energetic arousal between baseline ( $M = 3.06, SD = .08$ ) and post-stressor ( $M = 2.29, SD = .08$ ),  $t(66) = 7.5975, p < .001, \eta^2 = 0.47$ . These results indicate that the stressor task led to a significant increase in the stress and arousal level of participants

### 3.4. Psychological Restoration

#### 3.4.1. VAS- Stress

In order to explore whether there was an effect of lighting condition on psychological restoration (H3), the difference in stress at post-stressor and post-recovery was calculated. The descriptive statistics of this variable can be found in Table 6. A one-way ANOVA on the effect of condition on the VAS-Stress difference scores showed that there were no significant differences found in stress recovery between the non-natural, static, and natural conditions,  $F(2,64) = 0.91, p = .409, \eta^2 = 0.028$ .<sup>1</sup> Therefore, the H3: 'There is an effect of lighting conditions on psychological restoration' and its sub hypotheses are not supported based on the VAS-Stress.<sup>2</sup> The distribution of VAS-stress at three measurements across the three conditions is shown in Figure 25.



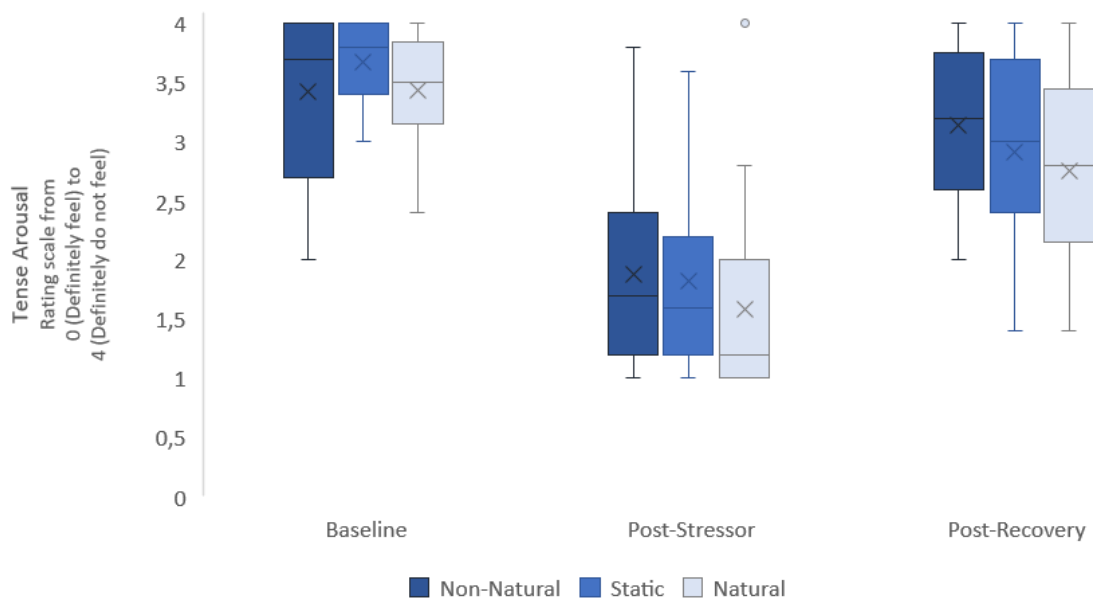
**Figure 25.** Boxplot of the ratings on VAS-stress at the three measurements. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values and the dots indicate the outliers.

<sup>1</sup> In addition, an ANCOVA was performed to explore whether the lighting condition affected psychological restoration at post-recovery while controlling for the variation of VAS-stress at post-stressor (covariate). The assumption of linearity was violated. The covariate significantly predicted the stress level at post-recovery,  $F(1,63) = 23.05, p = .000, \eta^2 = 0.256$ . However, there was no influence of the conditions on a person's stress level at post-recovery when accounting for stress levels at post-stressor,  $F(2,63) = 1.59, p = .211, \eta^2 = 0.035$ .

<sup>2</sup> The Wilcoxon matched-pairs signed-rank test revealed that there was no statistically significant difference in VAS-stress between baseline and post-recovery in the non-natural condition, and thus suggests full recovery from stress,  $N = 24, z = -1.438, p = .150, r = -0.294$ . However, both paired sample t-tests for the static,  $t(20) = -3.765, p = .001, \eta^2 = 0.415$ , and natural condition,  $t(21) = -2.730, p = .013, \eta^2 = 0.262$ , do not show full recovery from stress. Although there was no full recovery in these conditions, there was still some degree of recovery as can be seen in Table 5.

### 3.4.2. Tense Arousal

The difference in tense arousal at post-stressor and post-recovery was calculated to investigate whether there was an effect of lighting conditions on psychological restoration. The descriptive statistics of this variable can be found in Table 6. A one-way ANOVA was performed with the aforementioned difference scores. The one-way ANOVA revealed that there were no statistically significant differences found in the difference scores of tense arousal across the conditions,  $F(2,64) = 0.30$ ,  $p = .743$ ,  $\eta^2 = 0.009$ .<sup>3</sup> Therefore, the H3: 'There is an effect of lighting conditions on psychological restoration' and its sub-hypotheses are not supported based on tense arousal.<sup>4</sup> The distribution of tense arousal at three measurements is shown in Figure 26.



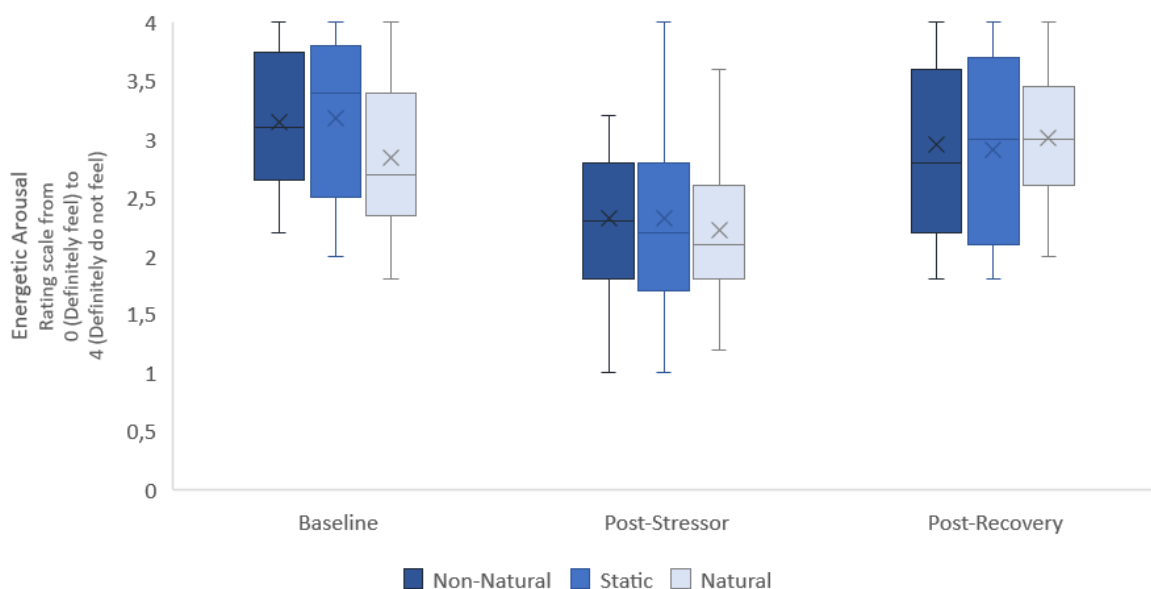
**Figure 26.** Boxplot of the ratings on tense arousal at the three measurements. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values and the dots indicate the outliers.

<sup>3</sup> In addition, an ANCOVA showed that there was no influence of the conditions on tense arousal level at post-recovery when controlling for tense arousal at post-stressor,  $F(2,63) = 0.75$ ,  $p = .476$ ,  $\eta^2 = 0.017$ . However, it was found that the level of tense arousal at post-stressor significantly predicted tense arousal level at post-recovery,  $F(1,63) = 22.20$ ,  $p = .000$ ,  $\eta^2 = 0.249$ . Note that the assumption of linearity was violated for this test.

<sup>4</sup> The paired-sample t-test revealed that there was no statistically significant difference in tense arousal between baseline and post-recovery in the non-natural condition, and thus suggests full recovery,  $t(23) = 1.602$ ,  $p = .123$ ,  $\eta^2 = 0.100$ . However, both paired-sample t-tests for the static,  $t(20) = 4.239$ ,  $p < .001$ ,  $\eta^2 = 0.473$ , and natural condition,  $t(21) = 2.973$ ,  $p = .007$ ,  $\eta^2 = 0.296$ , do not show full recovery. Although there was no full recovery in these conditions, there was still some degree of recovery as can be seen in Table 5.

### 3.4.3. Energetic Arousal

Similar to the VAS-stress and tense arousal, the difference in energetic arousal between the second and third measurements was calculated to investigate the effect of lighting conditions on psychological restoration. Table 6 presents the descriptive statistics of the variable. Assumptions of normality were violated and therefore a non-parametric test was conducted on the difference scores between post-stressor and post-recovery. A Kruskal-Wallis analysis indicated that the energetic arousal did not significantly vary across lighting conditions,  $H(2) = 1.396$ ,  $p = .498$ ,  $\eta^2 = -0.009$ .<sup>5</sup> Therefore, the H3: 'There is an effect of lighting conditions on psychological restoration' and its sub hypotheses are not supported based on the energetic arousal.<sup>6</sup> The distribution of energetic arousal at three measurements across the three conditions is shown in Figure 27.



**Figure 27.** Boxplot of the ratings on energetic arousal at three measurements. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values.

<sup>5</sup> In addition, an ANCOVA showed that there was no influence of the conditions on energetic arousal level at post-recovery when controlling for energetic arousal at post-stressor,  $F(2,63) = 0.38$ ,  $p = .685$ ,  $\eta^2 = 0.008$ . However, it was found that the level of energetic arousal at post-stressor significantly predicts energetic arousal level at post-recovery  $F(1,63) = 28.20$ ,  $p = .000$ ,  $\eta^2 = 0.308$ . Note that the assumption of linearity and the assumption of homogeneity of variances were both violated for this test.

<sup>6</sup> The Wilcoxon matched-pairs signed-rank test revealed that there was no statistically significant difference in energetic arousal between baseline and post-recovery in the non-natural condition, and thus suggests full recovery,  $N = 24$ ,  $z = 1.686$ ,  $p = .092$ ,  $r = 0.344$ . Similar results indicating a full recovery were shown in the paired-sample t-tests for the static condition,  $t(21) = 1.455$ ,  $p = .161$ ,  $\eta^2 = 0.092$ , and the natural condition,  $t(22) = -1.216$ ,  $p = 0.238$ ,  $\eta^2 = 0.063$ .



**Table 6.** Descriptive statistics of calculated difference scores between the second measurement (post-stressor) and the third measurement (post-recovery).

<b>Variable</b>	<b>Condition</b>	<b>n</b>	<b>Mean</b>	<b>SD</b>	<b>Median</b>	<b>Mode</b>	<b>Min</b>	<b>Max</b>	<b>Shapiro-Wilk Statistics</b>	<b>Shapiro-Wilk p-values</b>	<b>Skewness statistics</b>	<b>Kurtosis statistics</b>	<b>Skewness &amp; kurtosis p-values</b>
<i>Δ Post-stressor post-recovery VAS-stress</i>	Non-Natural	24	4.83	2.37	5	5	1	9	0.97	.692*	2.24	1.98	.297*
	Static	21	4.28	1.74	4	3, 5	2	8	0.96	.456*	0.66	2.86	.276*
	Natural	22	4.05	1.91	4	3, 4	1	8	0.94	.201*	0.73	2.75	.227*
<i>Δ Post-stressor post-recovery tense arousal</i>	Non-Natural	24	1.26	0.80	1.2	0.8, 1.2	0	3	0.95	.322*	0.47	2.54	.510*
	Static	21	1.10	0.61	1.0	0.8, 1.6	0.2	2.4	0.94	.201*	0.56	2.42	.412*
	Natural	22	1.2	0.71	1.2	2	0	2	0.95	.274*	-0.35	1.75	.095*
<i>Δ Post-stressor post-recovery energetic arousal</i>	Non-Natural	24	0.66	0.63	0.6	0.2, 0.8	0	3	0.78	< .001	2.20	9.24	< .001
	Static	21	0.72	0.60	0.6	0, 1.2	0	2	0.92	.109*	0.63	2.67	.337*
	Natural	22	0.80	0.54	0.8	1	0	2.4	0.92	.088*	0.95	4.61	.030*

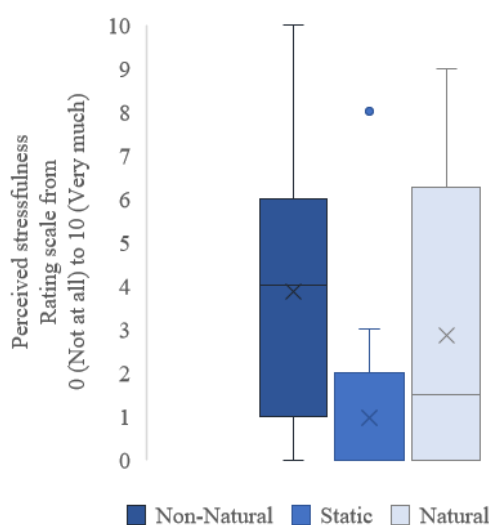
Notes: \* normally distributed (Shapiro-Wilk test outcome:  $p > 0.05$ )

### 3.5. Exploratory research

According to the reported results, the manipulation of naturalness within the experimental design was not effective. The lighting condition that was programmed to recreate specific attributes of a natural temporal condition was not perceived as more natural compared to the other conditions. Therefore, exploratory research was conducted to better understand the reason for the ineffectiveness of the manipulation.

#### 3.5.1. Perceived stressfulness

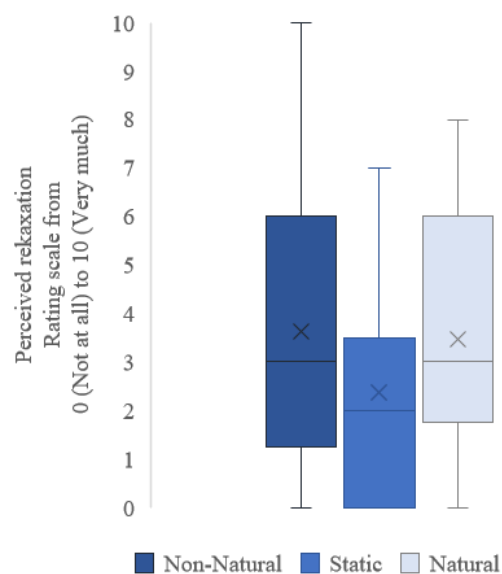
In Table 7, it can be seen that a higher mean perceived stressfulness was reported in the non-natural condition ( $M = 3.88$ ,  $SD = 3.04$ ), followed by the natural condition ( $M = 2.86$ ,  $SD = 3.08$ ), and the static condition ( $M = 0.95$ ,  $SD = 1.88$ ). A Kruskal-Wallis analysis of variance showed that the perceived stressfulness significantly varied across lighting conditions,  $H(2) = 12.997$ ,  $p < .002$ ,  $\eta^2 = 0.172$ . Post-hoc analyses with a Wilcoxon Signed Rank Sum Test showed that the perceived stressfulness in the static condition ( $n = 21$ ) was significantly lower compared to the perceived stressfulness in the non-natural condition ( $n = 24$ ),  $z = 3.598$ ,  $p < .001$ ,  $r = 0.439$ , and the natural condition ( $n = 22$ ),  $z = -2.333$ ,  $p = .019$ ,  $r = -0.285$ . There was no statistically significant difference found between the natural condition ( $n = 22$ ) and the non-natural condition ( $n = 24$ ),  $z = 1.223$ ,  $p = .225$ ,  $r = 0.149$ . The distribution of the ratings of the measure of perceived stressfulness is shown in Figure 28.



**Figure 28.** Boxplot of the ratings on perceived stressfulness. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values and the dots indicate the outliers.

### 3.5.2. Perceived relaxation

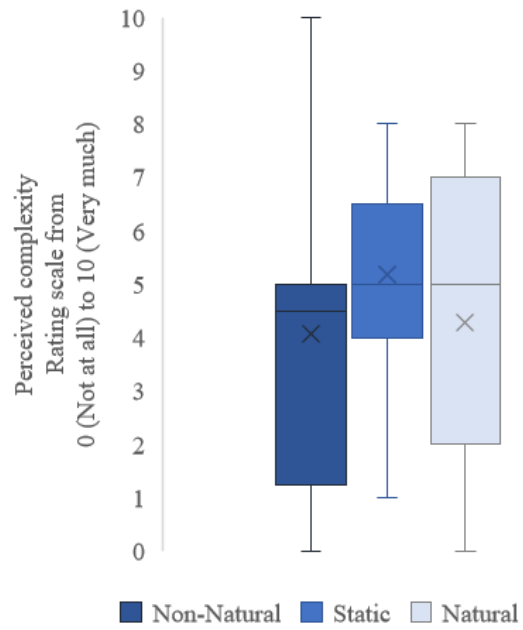
As can be seen in Table 7, mean relaxation was reported to be higher in the non-natural condition ( $M = 3.63$ ,  $SD = 2.90$ ), followed by the natural condition ( $M = 3.45$ ,  $SD = 2.63$ ), and the static condition ( $M = 2.38$ ,  $SD = 2.13$ ). However, a one-way ANOVA indicated no significant differences in perceived relaxation across the three lighting conditions,  $F(2,64) = 1.47$ ,  $p = .237$ ,  $\eta^2 = 0.044$ . The distribution of the ratings of the measure on perceived relaxation is shown in Figure 29.



*Figure 29.* Boxplot of the ratings on perceived relaxation. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values.

### 3.5.3. Perceived complexity

As shown in Table 7, a higher mean perceived complexity was reported in the static condition ( $M = 5.19$ ,  $SD = 1.89$ ), followed by the natural condition ( $M = 4.27$ ,  $SD = 2.49$ ), and the non-natural condition ( $M = 4.08$ ,  $SD = 2.96$ ). A one-way ANOVA showed that there were no statistically significant differences in perceived complexity across the three different lighting conditions,  $F(2,64) = 1.21$ ,  $p = .304$ ,  $\eta^2 = 0.037$ . The distribution of the ratings of the measure of perceived complexity is shown in Figure 30.



**Figure 30.** Boxplot of the ratings on perceived complexity. The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values.

**Table 7.** Descriptive statistics of ‘perceived stressfulness, ‘perceived relaxation’ and ‘perceived complexity’.

<b>Variable</b>	<b>Condition</b>	<b>n</b>	<b>Mean</b>	<b>SD</b>	<b>Median</b>	<b>Mode</b>	<b>Min</b>	<b>Max</b>	<b>Shapiro-Wilk Statistics</b>	<b>Shapiro-Wilk p-values</b>	<b>Skewness statistics</b>	<b>Kurtosis statistics</b>	<b>Skewness &amp; kurtosis p-values</b>
<i>Perceived stressfulness</i>	Non-Natural	24	3.88	3.04	4	0, 4, 6	0	10	0.94	.187*	0.29	1.91	.190*
	Static	21	0.95	1.88	0	0	0	8	0.80	.001	2.69	10.43	< .001
	Natural	22	2.86	3.08	1.5	0	0	9	0.85	.004	0.64	1.84	.087*
	All conditions	67	2.63	2.96	2	0	0	10	0.87	< .001	0.85	2.35	.017
<i>Perceived relaxation</i>	Non-Natural	24	3.63	2.90	3	6	0	10	0.94	.171*	0.34	2.11	.393*
	Static	21	2.38	2.13	2	0	0	7	0.93	.169*	0.53	2.36	.425*
	Natural	22	3.45	2.63	3	2	0	8	0.96	.472*	0.26	1.85	.179*
	All conditions	67	3.18	2.61	3	0	0	10	0.95	.007	0.46	2.24	.072*
<i>Perceived complexity</i>	Non-Natural	24	4.08	2.96	4.5	5	0	10	0.96	.483*	0.44	2.52	.553*
	Static	21	5.19	1.89	5	5	1	8	0.97	.675*	-0.10	2.66	.967*
	Natural	22	4.27	2.49	5	7	0	8	0.92	.093*	-0.24	1.79	.133*
	All conditions	67	4.49	2.52	5	5	0	10	0.99	.698*	-0.01	2.43	.598*

Notes: \* normally distributed (Shapiro-Wilk test outcome:  $p > 0.05$ )

## 4. Discussion

This study investigated the effects of natural and non-natural temporal composition of light on stress recovery. In the following sections, the results, limitations of the current study, and implications for future studies are discussed.

### 4.1. Main findings and comparison with the literature

The results of this study show that the lighting conditions allowed for psychological stress recovery, however, there were no statistically significant differences in stress recovery between the conditions. This not only indicates that there was no difference in stress recovery between the natural and non-natural temporal compositions, but it also indicates that there was no difference between the static and dynamic conditions. In the study by Dusseldorp (2022) on the effect of dappled light on stress restoration, it was found that the dynamic dappled light condition was more restorative than the static condition based on physiological measures. Because of the strong resemblance between the study of Dusseldorp (2022) and the current study, similar results were expected. Furthermore, studies show that natural scenes provide a better restorative effect than scenes from urban environments (e.g. Ulrich, 1979a). Both literal imitations of natural objects, such as plants, but also more abstract natural objects, such as the fractal geometry of nature, have been shown to facilitate this restoration (e.g., Joye, 2007; Taylor et al., 2005). Based on the available literature, it was unexpected to not find a difference in stress recovery between the natural and non-natural conditions.

A possible explanation for these unexpected results can be found in the reported association with nature. Results show that the association with nature did not differ between the conditions with a natural temporal composition, non-natural temporal composition, and static composition. However, it was hypothesized that the natural temporal composition of light would be more associated with nature compared to the non-natural temporal and static composition. In the study by Dusseldorp (2022), the dynamic dappled light pattern was rated higher in association with nature compared to the static dappled light pattern. Similar results were reported in the online study by Chamilothoni and colleagues (2022), where the dynamic dappled light reminded participants of nature more than the static dappled light. The

contradictory results with the current study might be traced back to the creation of the stimuli. The creation of the natural stimulus was based on a real dappled light video and included similar movements of position and size as the light patches in this video. Therefore, we assumed that the natural stimulus consisted of a similar natural temporal composition as natural dappled light. The non-natural stimulus was created with randomized values and was therefore expected to be perceived as non-natural. Results show, however, that both the natural and non-natural conditions were perceived as somewhat not associated with nature. Based on this result, it can be assumed that the temporal elements in the stimuli did not differ enough to create a difference in association with nature between the conditions. Furthermore, it also indicates that the current natural temporal elements were not sufficient to create a condition that was strongly associated with nature. The manipulation of stimuli is discussed more elaborately in Section 4.2.1.

Fascination may also be used to explain why no differences in stress recovery were found between the conditions. According to Kaplan (1995), natural stimuli evoke fascination which replenishes directed attention and stimulates restoration. Based on this mechanism, if both stimuli were equally associated with nature, it might be expected that they evoke almost a similar level of fascination. Consequently, no difference between the natural and non-natural dynamic conditions is shown regarding the recovery of stress. However, there was a difference found in perceived fascination between the static and the dynamic conditions. This finding was in line with studies that reported that dynamic dappled light patterns were perceived as more fascinating than static dappled light patterns (Chamilothori et al., 2022; Dusseldorp, 2022). However, in those studies, there was a difference in association with nature between the static and dynamic conditions, which was not the case in the current study. This might indicate that the reported association with nature does not influence whether something is (perceived as) fascinating or not. Thus, it could be that dynamics in general, whether they are perceived as natural or not, induce fascination. On the other hand, it can also be that we do not perceive some natural temporal elements as natural, but we unconsciously identify them as natural. Even though we assumed that we created dynamic conditions that consisted of a natural and a non-natural temporal composition, and both were reported as somewhat not natural, it could still be that we

captured some natural temporal or spatial composition in both conditions. This could be because all the recreated videos, despite some randomization in movements, were based on a natural dappled light video. The maybe unconscious captured elements from the natural dappled light video might have led to a higher fascination in both these conditions compared to the static one. For example, the non-natural condition was the only condition that allowed for a full recovery from stress, tense arousal, and energetic arousal from the stressor. This could indicate that this condition includes elements that are important for full stress recovery.

Moreover, the exploratory analysis shows that there was no difference in perceived stressfulness between the natural and non-natural conditions. This might explain why there was also no difference found in association with nature, as it is expected that natural settings are perceived as less stressful, than non-natural settings (e.g. Ulrich, 1979). Furthermore, results show a higher perceived stressfulness in the dynamic conditions compared to the static condition. However, the dynamic conditions were still reported as somewhat not stressful. When individuals process a potentially threatening stimulus in their environment, an increase in vigilance and alertness is triggered in order to quickly deal with the threat (Bayle, Henaff, & Krolak-Salmon, 2009). However, when an unthreatening stimulus is detected, it can lead to fascination and restoration (Kaplan, 1995). Because both dynamic and static conditions, were not perceived as very stressful, the theory by Kaplan (1995) might explain why all conditions allowed for a certain degree of stress recovery. Even though there was a difference found in stressfulness between the static and dynamic conditions, the levels of stress might still be too weak to show a difference in stress recovery between these conditions. The exploratory analysis also showed that there were no statistically significant differences in perceived relaxation and complexity between the conditions. Natural scenes provide relaxation and are perceived as more complex compared to non-natural scenes (e.g.: Taylor et al., 2005; Anderson et al., 2017). Therefore, if there is no difference in perceived relaxation and complexity between conditions, it is expected that there were no differences in stress recovery and association with nature between the lighting conditions.

It should be noted that the results of this study are purely based on psychological measures. The responses towards the natural or non-natural conditions of this study might show different results when



taking into account the physiological measures, which are not analyzed in the present work. A similar study by Dusseldorp (2022) did include physiological measures and indeed found an effect of lighting conditions on physiological restoration. As many environmental stimuli are unconsciously processed, it can be the case that we do not consciously perceive movements as natural, fascinating, or stressful, but our body still (unconsciously) reacts to these movements (Bayle et al., 2009). However, literature also indicates that the extent to which something is perceived as natural will stimulate stress recovery (Van den Berg et al., 2014). So the current results, even though only measured through subjective measures, are still relevant in this context.

## **4.2. Limitations and future research**

### *4.2.1. Manipulation of stimuli*

In this study, we have carefully created a natural temporal composition of light based on an original video of natural dappled light. With the awareness that multiple elements might contribute to the temporal composition of dappled light, only the position and size of the light patches have been taken into account. Evidently, these (combinations of) elements were not enough to find a difference in association with nature between the condition with a natural temporal composition and the condition with a non-natural temporal composition. Therefore, future studies are encouraged to further disentangle the elements of the temporal composition of dappled light, so that a new attempt can be done in order to explore the relationship between dynamic lighting characteristics and stress recovery.

A good starting point for this research would be to investigate, for example, what factors influence the temporal variability of dappled light, such as the position of the sun (season and time of day), the type of vegetation, the weather (cloudy versus bright day), and the wind (breeze versus storm). These factors influence for example the brightness, shape, edges, contrast, and speed of the dappled light over time, and thus contribute to the natural temporal composition of the light. In this study, we might have removed too many elements of natural movements, leading to a natural condition that was not strongly associated with nature. Furthermore, it could be that we have over-simplified the videos for each of the conditions. For example, the videos consisted of a maximum of seven light patches, while in nature, dappled light often consists of many more. Therefore, we might not have fully captured the relationship

between the movements of each of the light patches. Moreover, the light stimuli were only projected on the wall, while natural dappled light, depending on the façade structures and surroundings, can also appear on the ground and objects in the room. Testing which of the specific elements and combinations impact the perceived naturalness of the movements might help in understanding which of the factors can be used to recreate the beneficial elements/effects of nature.

It is also important to consider the spatial composition of the light projection. In the current study, simple white circles were used as stimuli. The reason for this is that we wanted to solely investigate natural movements, and did not want the confounding effect of the figure itself (i.e., a figure from nature). Therefore, we used a simple geometric shape. However, it might be the case that in order to find the underlying mechanism of natural movements, the spatial composition also needs some degree of natural characteristics. Similar to the phenomenon of the uncanny valley within the field of robotics, where a humanoid object that imperfectly imitates a human being can provoke feelings of unease and discomfort (Brenton, Gillies, Balling, & Chatting, 2005), it might be the case that our participants noticed that the recreated natural movements were not perfectly imitated, leading to a movement that people perceived as stressful or that they don't associate with nature.

It should also be noted that the final stimuli in the current study were chosen based on the results of a pilot study. However, the pilot study had a within-subjects design while the main study followed a between-subjects design. Therefore, the videos in the main study might have been judged differently because participants in the main study could not compare the videos between them, whereas participants in the pilot study could. The specific design of the study should therefore be carefully considered when further investigating the temporal composition of natural light stimuli.

#### *4.2.2. Stressor task and procedure*

According to the results, the stressor task effectively induced stress among participants. However, still, a few limitations in the stressor task and the procedure can be identified.

Participants indicated via open questions in the final questionnaire and during the debriefing that they expected something to happen in the recovery phase due to the appearing of the lighting condition,

even though they were told that the stressor task was finished. Therefore, not all participants were fully relaxed and this may have affected their stress recovery levels. Instead of introducing participants to the stimuli in the recovery phase, future studies can consider already showing the stimuli during the stressor task followed up by the recovery phase, as was done in a similar study (Dusseldorp, 2022), which allows us to account for the novelty effect. However, note that when this is applied in the current experimental design, an instorative effect might be found instead of a restorative effect, because the stimuli affect the level of stress during the stressor (Korpela & Ratcliffe, 2021).

All conditions showed some degree of stress recovery, however, there were no differences found in the level of stress recovery between the conditions. A possible explanation for this might be that the stressor recovery from the stressor was too short, and therefore the recovery might not have been accurately measured. A consideration for future research could be to increase the duration of the stressor task to extend the duration of stress recovery. On the other hand, it can also be the case that the stress recovery phase was too long and that groups were already recovered before answering the post-recovery questionnaire. For example, it might have been that one of the groups recovered from the stressor in three minutes and that another group needed five minutes to recover. However, in the current study, this is not taken into account and future research is encouraged to further explore this.

It was also concluded that the temperature in the room was considered too warm (range 19.8 – 27.3°C). This could have affected participants' comfort, mental performance, and breadth of attention leading to sleepiness or an increase in stress (Wyon & Wargocki, 2006). However, a one-way ANOVA revealed that there was no significant difference in temperature between the three groups,  $F(2,66) = 1.87$ ,  $p = .163$ ,  $\eta^2 = 0.055$ . Therefore, it is expected that the individual responses to the temperature in the room did not influence our final results.

Furthermore, more than half of the participants indicated during the debriefing that they did not believe that we would subtract money from their final compensation for every wrong answer in the cognitive stressor. This can be explained by the fact that most participants were students from the TU/e and therefore have been aware of the ethical rules or procedures within experiment designs. However, participants told the experimenters during the debriefing that they still tried their best to not make

mistakes. Furthermore, the error beeps during the PASAT-C became progressively quieter as the participant approached the end. This happened because the volume of white noise increased during the test. Because of this, participants might have felt less stress towards the end from this specific stressor. Even though both above described components of the motivational stressor did not function as expected, participants still indicated in the open questions of the final questionnaire and during the debriefing that they experienced the stressor task as very stressful. The effectiveness of the MMST was also confirmed in the results of the analysis. Therefore we recommend the use of this stressor task to induce acute stress in future studies.

After the stressor task, participants filled in the post-stressor questionnaire while they were still exposed to the auditory part of the stressor. This was done to prevent participants from recovering from the stressor while filling in the questionnaire. The aforementioned procedure was not performed in the original MMST, however, due to the effectiveness of the MMST in the current study, it is a recommended addition for future studies. Future studies could also consider introducing questions during the stressor task or to have multiple phases of questionnaires and stressor tasks to measure participants' peak stress levels more accurately.

Even though the manipulation of association with nature was ineffective, and improvements are suggested for future research, the current study presents a promising first step into exploring the temporal variability of natural dappled light and its effects on recovery from stress. Further investigations in this field are needed to understand which temporal elements contribute to natural movements (of light stimuli) and how they affect stress levels.

## 5. Conclusion

In this study, we investigated natural and non-natural temporal compositions of light projections and their effect on stress recovery. A single factor between-subjects experimental design was used to compare three conditions: a dynamic condition with a temporal composition of light patterns derived from dynamic dappled light (natural movement), a dynamic condition with a non-natural temporal composition of light (non-natural movement), and a static condition using a single frame from the natural movement condition (control/static). During the experiment, stress was induced to allow for the exploration of subjective stress recovery from the stressor. Furthermore, the effects of temporal variability on association with nature and perceived fascination were investigated.

Results show that there were no significant differences in stress recovery between the natural temporal composition, the non-natural temporal composition, and the static composition of projected light patterns. It should be noted that the condition with a natural temporal composition was not perceived as more strongly associated with nature than the other conditions. Therefore, the manipulation of this study was ineffective which shows that the movements (i.e., change of position and area of light patches) derived from natural dappled light in the natural condition were not sufficiently different from the randomized movements in the non-natural condition. Future studies are encouraged to further explore the relationship between stress recovery and temporal variation of light stimuli with a natural temporal composition of light that has a stronger association with nature compared to the natural stimuli in this study. Furthermore, the dynamic lighting conditions (the natural and non-natural temporal compositions) were perceived as more fascinating and stressful compared to the static condition. Interestingly, this could not be explained by the level of association with nature and suggests a different underlying mechanism. Finally, no difference was found in perceived fascination and stressfulness between the dynamic conditions, which might explain why no difference was found in association with nature between these conditions.

This study explores for the first time the potential of varying temporal compositions of dappled light stimuli on stress recovery. Future studies are encouraged to continue with the exploration of the

stress-restorative aspects of temporal compositions of nature in order to contribute to the development of indoor lighting technologies that support stress recovery and improve occupant well-being.

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## 7. Appendices

### Appendix A – Sensitivity Analysis

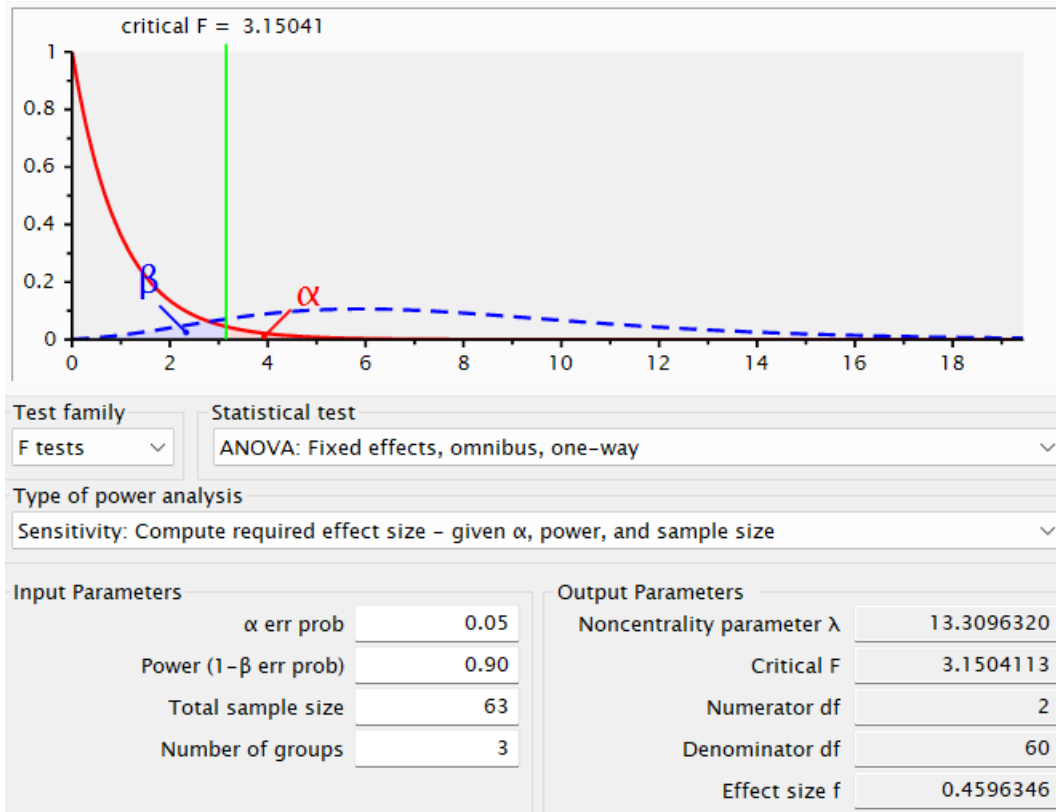


Figure A1. The sensitivity analysis in G\*power (ANOVA: Fixed effects, omnibus, one-way,  $\alpha = 0.05$ , power = 0.90,  $n = 63$ ) (Faul, Erdfelder, Lang & Buchner, 2007).

## Appendix B – Informed consent form



### Information form for participants

This document gives you information about the study “Measuring cognitive performance during multitasking”. Before the study begins, it is important that you learn about the procedure followed in this study and that you give your informed consent for voluntary participation. Please read this document carefully.

#### Aim and benefit of the study

The aim of this study is to measure your cognitive performance while you are performing several other tasks simultaneously in a working environment. Data will be collected through your performance in the task, physiological measurements, and subjective assessments of your experience.

This study is performed by Iza Linders (MSc student), and Özge Karaman Madan (PhD Student) under the supervision of Dr. Kynthia Chamilothoni and Prof. Yvonne de Kort of the Human-Technology Interaction group at TU/e. The research team also includes Dr. Mariëlle Aarts of the Building Lighting group of the department of the Built Environment at TU/e.

#### Procedure

Prior to the beginning of the experiment, you will be asked to wear physiological measurement devices (galvanic skin response electrodes on two fingers, measuring electrodermal activity, and electrocardiogram electrodes on the chest, measuring the electrical activity of the heart). During the experiment, you will be asked to perform a cognitive task while at the same time doing other tasks (including viewing images and listening to audio) and fill in questionnaires about your experience during these tasks.

#### Risks

The study does not involve any risks or detrimental side effects. Please be aware that some of the images that you will see can be disturbing or evoke strong negative emotions. You might see, for example, images of violence, traffic accidents, or domestic abuse. Therefore, please carefully consider your participation in line with this warning, especially if you have a traumatic experience and/or are sensitive to such visuals. Also, The noise level of the audio might be mildly disturbing. During this experiment, you might also be exposed to mildly flashing lights which might trigger seizures for people with photosensitive epilepsy.

#### Duration

The instructions, measurements, and debriefing will take approximately 30 minutes.

#### Participants

You were selected because you were registered as participant in the participant database of the Human Technology Interaction group of the Eindhoven University of Technology.

#### Voluntary

Your participation is completely voluntary. You can refuse to participate without giving any reasons and you can stop your participation at any time during the study. You can also withdraw your permission to use your data up to 24 hours after they were recorded. None of this will have any negative consequences for you whatsoever.

### Compensation

The compensation for this study is 5 euros (plus an additional 2 euros if you do not study or work at the TU/e or Fontys Eindhoven). The payment can be done with cash or with Tikkie payment depending on your preference. Tikkie payment requires a phone number, which would be temporarily stored in a restricted access online data repository and would be deleted after the Tikkie payment is completed. It is also possible to make a request for payment using a QR code created with your banking app. This would not require a phone number.

### Confidentiality and use, storage, and sharing of data.

All research conducted at the Human-Technology Interaction Group adheres to the Code of Ethics of the NIP (Nederlands Instituut voor Psychologen – Dutch Institute for Psychologists), and this study has been approved by the Ethical Review Board of the department.

In this study demographic data (age, gender), personal data (participant database ID) and experimental data (skin conductance and heart rate measures, performance, and responses to questionnaires) will be recorded, analyzed, and stored. This study is conducted using the application Inquisit Web by Millisecond. As a result, your anonymous responses to the questionnaire (including age and gender, if you provide them) will be stored at the EU servers of Millisecond, following the EU GDPR data privacy regulations. The terms and conditions for Inquisit Web can be found [here](#), and the privacy policy for Inquisit Web can be found [here](#). The goal of collecting, analyzing, and storing this data is to answer the research question and publish the results in the scientific literature. Personal data (participant database ID) will be shared between the members of the research team through a password-protected folder in ResearchDrive, a GDPR-compliant cloud storage for Dutch universities. To protect your privacy, all data that can be used to personally identify you will be stored on an encrypted server of the Human Technology Interaction group that is only accessible by selected HTI staff members for at least 10 years. No information that can be used to personally identify you will be shared with others.

The data collected in this study might also be of relevance for future research projects within the Human Technology Interaction group as well as for other researchers. The aim of those studies might be unrelated to the goals of this study. The collected anonymized data will therefore also be made available to the general public in an online data repository, if you consent to this (see below). The anonymized data collected in this study and that will be released to the public will (to the best of our knowledge and ability) not contain information that can identify you. It will include all data collected during the study (physiological, subjective, and performance responses), including demographic variables (e.g., age and gender) if you choose to provide these during the study.

At the bottom of this consent form, you can indicate whether or not you agree with participation in this study. You can also indicate whether you agree with the distribution of your anonymized data by means of a secured online data repository with open access for the general public. No video or audio recordings are made that could identify you.

### Further information

If you want more information about this study, the study design, or the results, you can contact Iza Linders ([i.k.linders@student.tue.nl](mailto:i.k.linders@student.tue.nl)) or Özge Karaman Madan ([o.karaman.madan@tue.nl](mailto:o.karaman.madan@tue.nl)).

If you have any complaints about this study, please contact the supervisor, Kynthia Chamilothoni (contact email: [k.chamilothoni@tue.nl](mailto:k.chamilothoni@tue.nl)). You can report irregularities related to scientific integrity to confidential advisors of the TU/e.



## Informed consent form

Study “Measuring cognitive performance during multitasking”

- I have read and understood the information of the corresponding information form for participants.
- I have been given the opportunity to ask questions. My questions are sufficiently answered, and I had sufficient time to decide whether I participate.
- I know that my participation is completely voluntary. I know that I can refuse to participate and that I can stop my participation at any time during the study, without giving any reasons. I know that I can withdraw permission to use my data up to 24 hours after the data have been recorded.
- I agree to voluntarily participate in this study carried out by the research group Human Technology Interaction of the Eindhoven University of Technology.
- I know that no information that can be used to personally identify me or my responses in this study will be shared with anyone outside of the research team.
- I  do  do not give permission to make my anonymized recorded data available to others in a public online data repository, and allow others to use this data for future research projects unrelated to this study.

### Certificate of consent

I, (NAME) .....  
want and provide consent to participate in this study.

\_\_\_\_\_  
Participant’s Signature

\_\_\_\_\_  
Date



### Appendix C – Formulation of the instructions during the experiment

Note that the background of the instruction screens were black and the font color of the instruction text was white. Some figures below deviate from this to increase readability.

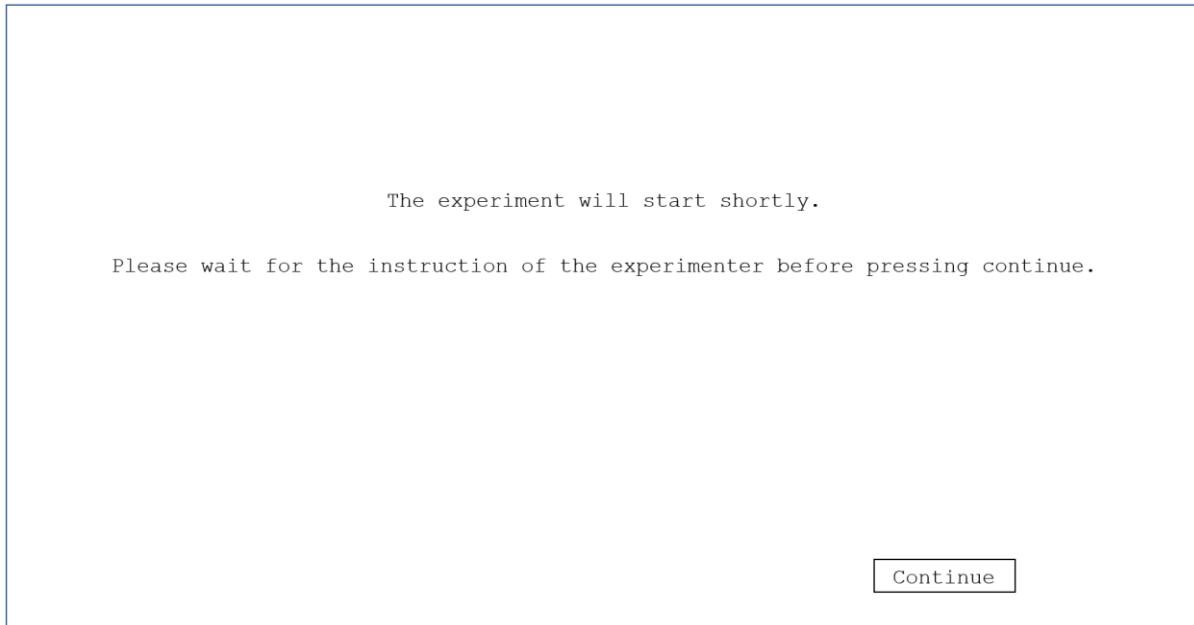


Figure C2. Instructions at the start of the experiment.

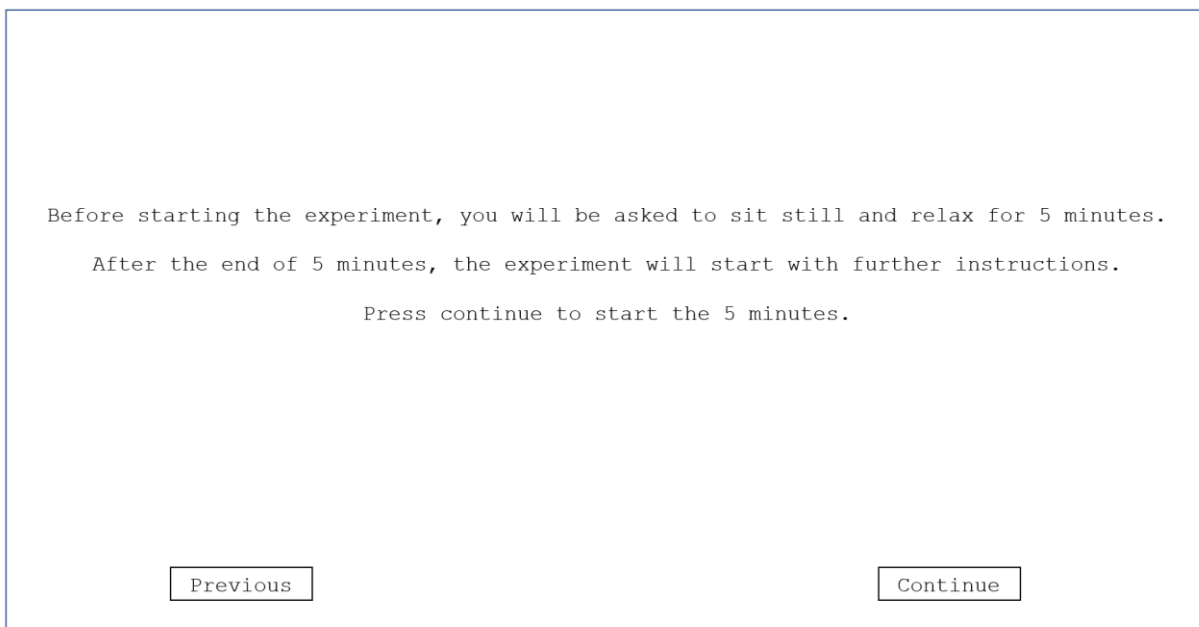
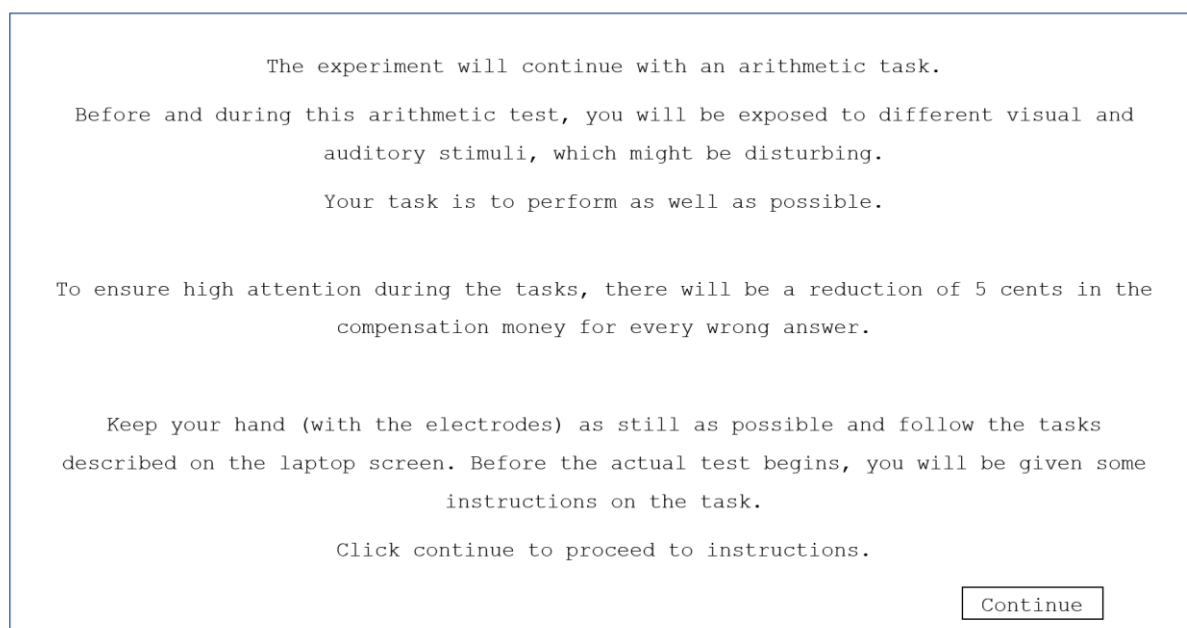


Figure C2. Instructions before the start of the baseline measurements.



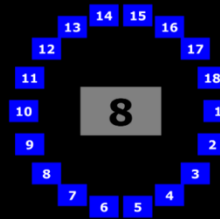
*Figure C3. Instructions during the baseline measurements.*



*Figure C4. Instructions after the baseline measurements.*

## Serial Addition Task

You will see a series of single digit numbers presented once every 3 seconds. The numbers are presented together with this number circle:

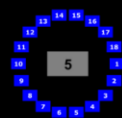


Wait to the first two numbers, add them up in your head, and indicate your answer on the number circle as fast possible. When you see the next number, add it to the one presented right before it. Continue to add the next number to each preceding one.

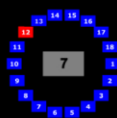
You will earn points for each correct response.

Figure C5. Instructions on the PASAT-C.

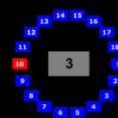
## Serial Addition Task: Example



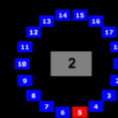
Wait for  
the second  
number!



12  
(=5+7)



10  
(=7+3)



5  
(=3+2)

*Respond as fast as possible.*

This is a challenging task. If you lose your place, just jump right back in - wait for two numbers in a row and add them up and keep going.

Figure C6. Instructions on the PASAT-C, including a visual example.

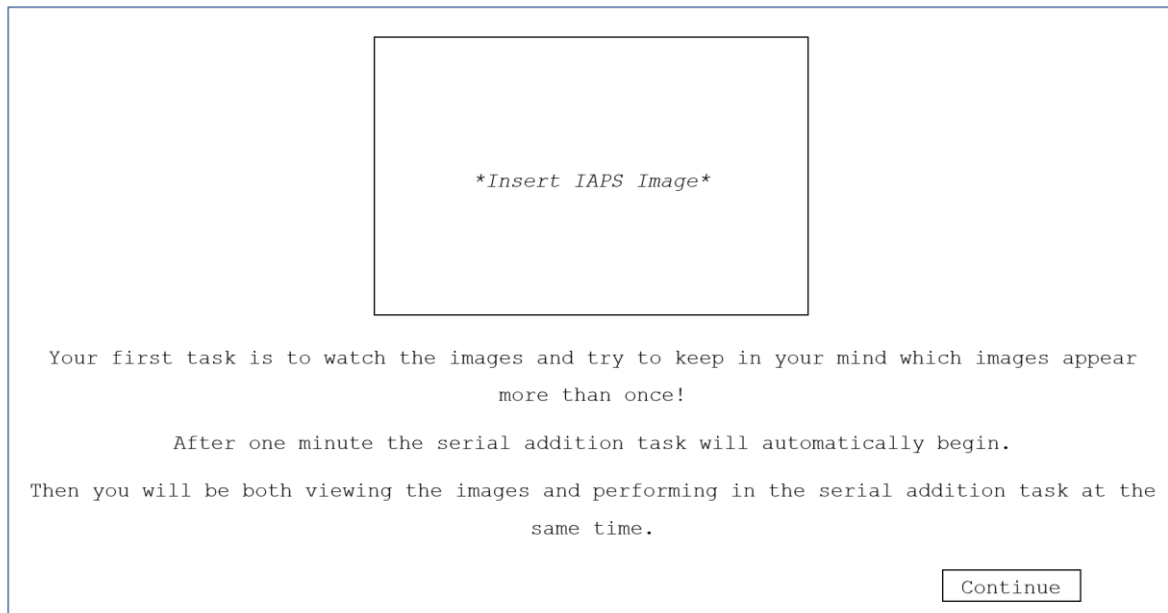
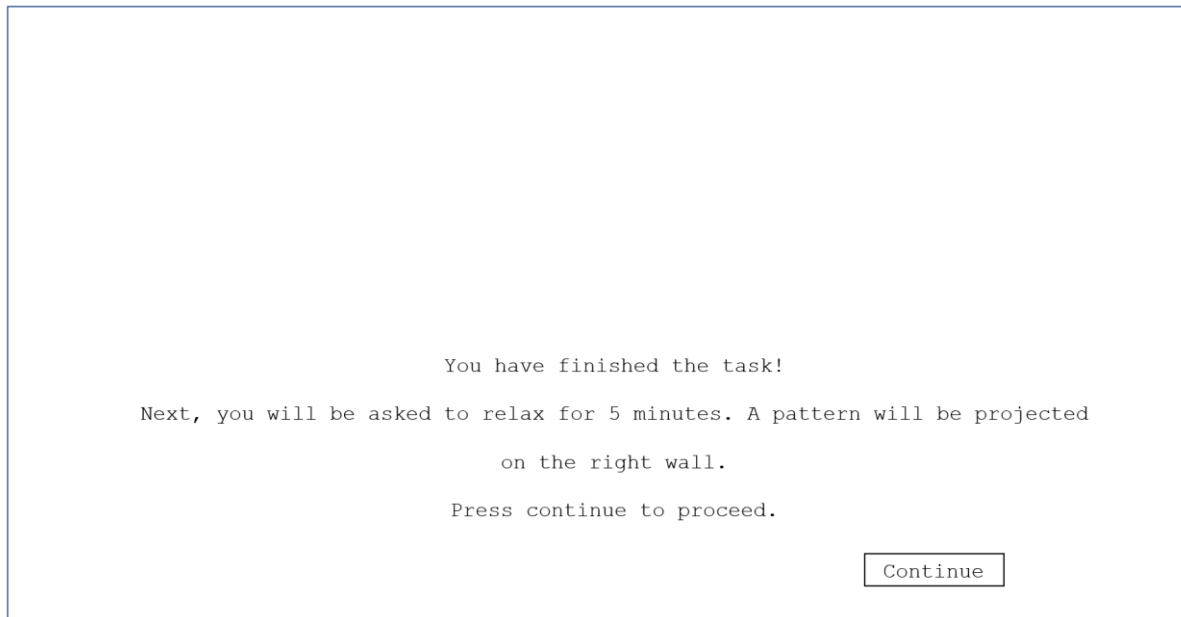


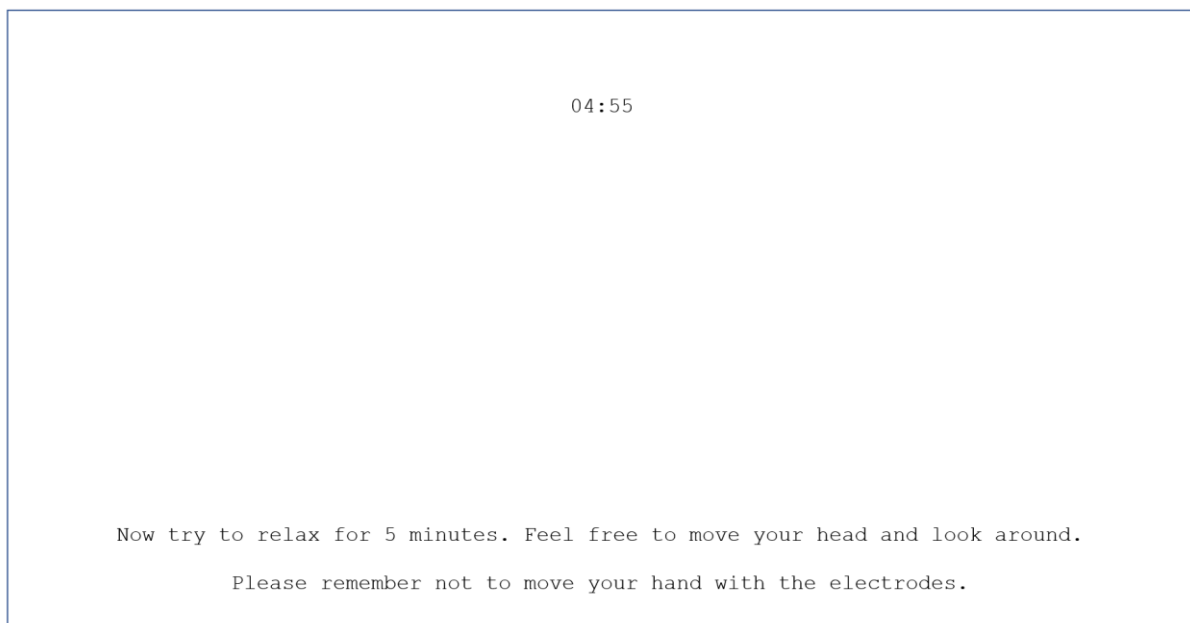
Figure C7. Instructions during the first minute of the MMST. A series of 13 different IAPS images were displayed in the box above the text.



Figure C8. The PASAT-C Test during the MMST.



*Figure C9. Instructions after the MMST.*



*Figure C10. Instructions during the recovery phase of the experiment.*

### Appendix D – Selected IAPS pictures for the emotional stressor in the MMST

Slide no.	Description	Frequency of display
5829	Sunset	1
9419	Assault	2
2345.1	Black eye	1
9901	Car accident	2
9300	Dirty	1
7502	Castle	1
9600	Ship	2
6315	Beaten female	1
9421	Soldier	1
8470	Gymnast	1

*Table D1. List of positive and negative affective pictures from the IAPS database that were selected to be used in the first minute of the emotional stressor during the MMST.*

Slide no.	Description	Slide no.	Description
1610	Rabbit	5829	Sunset
2091	Girls	5831	Seagulls
2209	Bride	7502	Castle
2332	Family	8080	Sailing
2360	Family	8470	Gymnast

*Table D2. The list of positive affective pictures from the IAPS database that were selected to be used in the last four minutes of the emotional stressor during the MMST.*

<b>Slide no.</b>	<b>Description</b>	<b>Slide no.</b>	<b>Description</b>
2141	Grieving female	9000	Cemetery
2345.1	Black eye	9007	Needles
2375.1	Woman	9043	Teeth
2710	Drug addict	9050	Plane crash
2799	Funeral	9184	Injured dog
2900	Crying boy	9295	Garbage
3181	Battered female	9300	Dirty
3220	Hospital	9301	Toilet
3500	Attack	9302	Toilet
6212	Soldier	9332	Crying woman
6230	Aimed gun	9340	Garbage
6231	Aimed gun	9419	Assault
6243	Aimed gun	9421	Soldier
6260	Aimed gun	9600	Ship
6263	Aimed gun	9830	Cigarettes
6312	Abduction	9900	Car accident
6315	Beaten female	9901	Car accident
6360	Attack	9902	Car accident
6510	Attack	9903	Car accident
6540	Attack	9904	Car accident
6570	Suicide	9905	Car accident
6821	Gang	9908	Car accident
6838	Police	9911	Car accident
7380	Roach on pizza	9920	Car accident

*Table D3. The list of negative affective pictures from the IAPS database that were selected to be used in the emotional stressor during the MMST.*

## **Appendix E – Tracking light patches in MATLAB**

To get an overview of the behavior of a light patch, it was important to number each of the light patches so that the movements of the patches could be tracked throughout the whole video. However, due to the appearance and disappearance of light patches between frames, and the changing of the light patches' position in each frame, the patches were not numbered correctly. For example, a situation could occur in which light patch number 1 in frame 1, was identified as light patch number 3 in frame 2, due to the appearance of two new light patches. Therefore, the numbering of the light patches was adjusted to account for this situation. This was achieved by calculating, for each light patch, the Euclidean distance between the centroids of the current frame and the previous frame. Repeating this for every frame enabled the script to find anomalies that suggested an error in the patch numbering. For these cases, the script calculated the distances between the problematic patch and all the other patches. Then, if a patch was found with a smaller distance to the problematic patch, the script swapped the numbers of the problematic patch and the closest patch. This ensured that all wrong instances were renumbered and that each light patch was consistently numbered throughout the whole video. The MATLAB script for correctly numbering the light patches can be found in Appendix I.



## **Appendix F – Pilot Study**

### ***Introduction and method***

A within-subjects design was used to investigate which of the movements derived from a dappled light video should be included in the stimuli of this study to recreate a natural and non-natural temporal lighting condition. During the five-minute online study via Lime Survey, participants were asked to watch five videos, including different combinations of movements (i.e., changes in the position, size, and saturation level of the projected circles), and answer three questions per video. Based on the participants' evaluations of the videos, a careful decision could be made for the final stimuli. The video that scored the highest on association with nature was chosen as stimulus for the natural temporal composition. The video that scored lowest on association with nature was chosen as stimulus for the non-natural temporal composition.

Because this was a pilot study, no power analysis was performed, however, the aim was to find as many participants as possible within the available time frame, recruiting them from the researcher's social network. In total, 28 responses were considered usable.

During the online study, participants were exposed to five different 30-second videos. The videos included different combinations of movements (see Table F1). Video A and C included a change in position and area of the light patches based on the natural dappled light video (see Section 2.5.1.) and video B, D and E included non-natural changes (see Section 2.5.2.). The area change in video E differed from the others. In this case, all area sizes that were found in the natural dappled light video were randomly applied to video E based on a normal distribution. Furthermore, the circles in video A, B, and E were visualized as white circles (no saturation change), and the circles in videos C and D were visualized as circles with a grey-scale saturation change (see Appendix H for the retrieval of RGB values to create the grey-scale saturation change). Participants were encouraged to watch the videos until the end. The order of the videos was randomized for each participant. After each video, three questions were asked. These questions included items on fascination, distress, and association with nature (see Table F2).

Condition	Change of position	Saturation	Area	Link
A	Natural	No saturation change	Natural	<a href="#">Video A</a>
B	Non-Natural	No saturation change	Non-Natural	<a href="#">Video B</a>
C	Natural	Grey saturation change	Natural	<a href="#">Video C</a>
D	Non-Natural	Grey saturation change	Non-Natural	<a href="#">Video D</a>
E	Non-Natural	No saturation change	Normal distribution	<a href="#">Video E</a>

*Table F1. Summary of the five conditions in the pilot study.*

Concept	Item	Answer
Perceived Fascination	The video is fascinating	0 (Strongly disagree) – 10 (Strongly agree) (Likert scale)
Perceived Stressfulness	The video is distressing	0 (Strongly disagree) – 10 (Strongly agree) (Likert scale)
Association with nature	The video reminds me of nature	0 (Strongly disagree) – 10 (Strongly agree) (Likert scale)

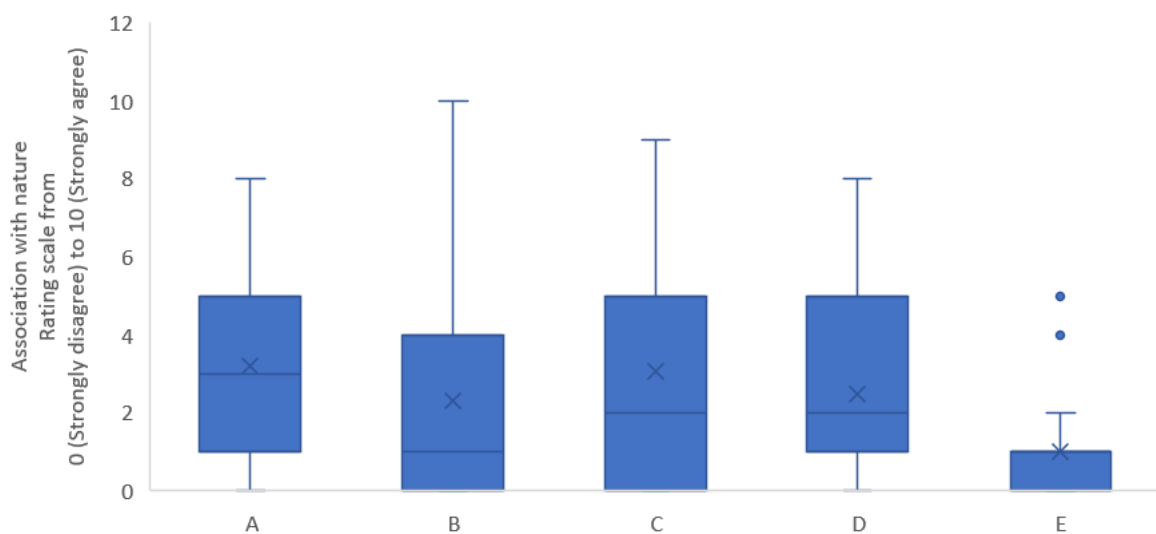
*Table F2. Summary of the subjective measures in the pilot study.*

## **Results**

In this section, the results regarding the association with nature are presented. The other two variables are not discussed as they are not the main focus of the pilot study. An overview of the descriptives of statics of the variables ‘Perceived Fascination’, ‘Perceived Distress’ and ‘Association with nature’ can be found in Table F3.

Based on the descriptive statistics it is found that the video with the highest association with nature is A ( $M = 3.19$ ,  $SD = 2.45$ ), followed by C ( $M = 3.07$ ,  $SD = 2.76$ ), D ( $M = 2.48$ ,  $SD = 2.14$ ), B ( $M = 2.30$ ,  $SD = 2.46$ ) and E ( $M = 1$ ,  $SD = 1.47$ ). The variable association with nature is not normally distributed (see Table F3). In order to explore whether this variable is different across the five groups,

a non-parametric test is conducted. A Friedman analysis of variance by ranks test indicated that association with nature differed across the five groups,  $X^2(2) = 75.6967$ ,  $p < .001$ ). A follow-up pairwise comparison with a Wilcoxon Signed Rank Sum Test showed that the association with nature in the condition A,  $z = 3.432$ ,  $p < .001$ ,  $r = 0.649$ , condition B,  $z = 2.281$ ,  $p = .022$ ,  $r = 0.431$ , condition C,  $z = 2.876$ ,  $p = .004$ ,  $r = 0.543$ , and condition D,  $z = 3.174$ ,  $p = .004$ ,  $r = 0.600$ , was significantly higher compared to the association with nature in condition E. The other pairwise comparisons did not show statistically significant differences between them.



**Figure F1.** Boxplots of the rating distribution of association with nature for all five conditions (A-E). The box marks the first and third quartiles. The median is presented with a horizontal line and the mean is presented with a cross. The whiskers indicate the minimum and maximum values and the dots indicate the outliers.

### **Discussion & conclusion**

Video E scored significantly lower on association with nature compared to the other videos. When only exploring the means, video E scored lowest on association with nature, followed by video B. The highest association of nature was found for video A. Even though video E was reported as least associated with nature, this video was not chosen as final non-natural stimuli. We preferred to have a natural and a non-natural video that included the same type of movement in order to minimize differences in temporal variation between the videos (e.g. video A and B included changes in position and area, and video C and D included changes in position, area and saturation). We did not include a

video with a natural temporal composition with similar movements as video E in the pilot-study, and therefore this video was disregarded as option for the final stimuli. Based on the results, video A was chosen to represent the stimuli for natural temporal composition, and video B was chosen to represent the stimuli for non-natural composition.

*Table F3. Descriptive statistics of the variables: 'Perceived Fascination', 'Perceived Stressfulness', 'Association with nature'.*

<b>Variable</b>	<b>Condition</b>	<b>n</b>	<b>Mean</b>	<b>SD</b>	<b>Median</b>	<b>Mode</b>	<b>Min</b>	<b>Max</b>	<b>Shapiro-Wilk Statistics</b>	<b>Shapiro-Wilk p-values</b>	<b>Skewness statistics</b>	<b>Kurtosis statistics</b>	<b>Skewness &amp; kurtosis p-values</b>
<i>Perceived Fascination</i>	A	27	4.07	1.86	5	5	0	7	0.97	.711*	-0.37	2.24	.452*
	B	27	2.96	1.93	3	5	0	6	0.96	.379*	-.04	1.69	.042
	C	27	3.74	1.99	3	3	1	7	0.96	.331*	0.07	1.72	.055*
	D	27	3.11	1.83	3	2, 5	0	7	0.97	.509*	0.26	2.08	.361*
	E	27	2.85	1.94	2	2	0	7	0.95	.208*	0.37	2.03	.230*
<i>Perceived Stressfulness</i>	A	27	3.30	2.38	3	0, 3	0	8	0.96	.462*	0.16	2.06	.380*
	B	27	5.67	2.37	7	7	1	9	0.91	.023	-0.55	1.91	.092*
	C	27	3.44	2.29	3	2	0	10	0.96	.328*	0.77	3.67	.089*
	D	27	5.33	2.09	6	6	1	8	0.97	.701*	-0.38	2.05	.247*
	E	27	6.15	2.35	6	6	0	10	0.97	.571*	-.49	3.14	.345*
<i>Association with nature</i>	A	27	3.19	2.45	3	0	0	8	0.94	.146*	0.18	1.82	.107*
	B	27	2.30	2.46	1	0, 1	0	10	0.85	.001	1.31	4.52	.009
	C	27	3.07	2.76	2	0	0	9	0.91	.028	0.37	1.86	.104*
	D	27	2.48	2.14	2	1, 2	0	8	0.90	.014	.85	2.82	.125*
	E	27	1	1.47	1	0	0	5	0.76	< .001	1.79	5.23	.001

Notes: \* normally distributed (Shapiro-Wilk test outcome:  $p > 0.05$ )

## Appendix G – MATLAB script: Detecting light patches and creating information table

```
%DETECTING BLOBS + CREATING TABEL WITH CENTROID COORDINATES X - Y PER BLOB
%%%%
clear all; close all; clc; % Clear all variables and close all windows
T = table; % Make table T to save data there
%DETECTING BLOBS
%%%%
count = 0; % Initialize counter to count frames
% Create a VideoReader object for the input video file, and specify the timestamp of the frame to read as 0.
vidReader = VideoReader('AdobeCutLQ.mp4','CurrentTime',1);
while hasFrame(vidReader) % While there is a new frame
    count = count+1; % Add 1 to counter
    frameRGB = readFrame(vidReader); % Read frame
    frameGray = im2gray(frameRGB); % Make it gray
    frameBW = frameGray > 175; % Find the binary image
    [B,L,N,A] = bwboundaries(frameBW); % Trace boundaries with command bwboundaries
    Figure % Display the image with the boundaries overlaid.
    imshow(frameBW); hold on;
    % Code from here: https://nl.mathworks.com/matlabcentral/answers/1740310-save-plotted-lines-in-an-matrix?s_tid=srchtitle
    for regionk = 1:N % Loop through object boundaries
% Boundary k is the parent of a hole if the k-th column of the adjacency matrix A contains numBlobs non-zero element
        if (nnz(A(:,regionk)) > 0)
            boundary = B{regionk};
            plot(boundary(:,2),...
                boundary(:,1),'r','LineWidth',2);
        end
        %red = parent boundary & green = parents' holes
        CC = bwconncomp(frameBW); % Find and count connected components in binary image
        [labeledImage, numBlobs] = bwlabel(frameBW);
        props = regionprops(CC, 'Centroid', 'BoundingBox', 'Area'); %Save all region properties to props(properties)
        % See https://nl.mathworks.com/help/images/ref/regionprops.html
        temp_table = struct2table(props); % Create table from the structure props
        temp_table.Frame(:) = count; % Add variable Frame and save current frame there in all entries
        temp_table.NumBlobs(:) = numBlobs;
        temp_array = table2array(temp_table); % sort table in first column (Area)
        if count == 371 % set amount of frames
            return
        end
    end
end
[labeledImage, numberOfBlobs] = bwlabel(frameBW); % Add temporary table with data from frames to table T
allAreas = [props.Area]; % Get all the areas - No semicolon so it will print to the command window.
menuOptions{1} = '0'; % Add option to extract no blobs.
countArray = [1 2 3 4 5];
bigBlobscounter = 0;
for k = 1 : numberOfBlobs %% Display areas on image & loop through all blobs.
    if props(k).Area > 400
        bigBlobscounter = bigBlobscounter+ 1;
        thisCentroid = [props(k).Centroid(1), props(k).Centroid(2)];
        message = sprintf(string(bigBlobscounter) ,allAreas(k));
        text(thisCentroid(1), thisCentroid(2), message, 'Color', 'b');
        menuOptions{k+1} = sprintf('%d', k);
        temp_table.blobNumber(k) = bigBlobscounter;
    end
end
temp_table2 = temp_table(temp_array(:,1)>400,:); % Create temp table
T = vertcat(T, temp_table2); % create table
T = movevars(T, 'Frame', 'Before', 'Area'); % Change order of columns in table T so that Frame is the first one
frames = 370; %Set frames
originalCoordinates = zeros(frames,14); %Create empty matrix
% CREATING TABLE WITH CENTROID COORDINATES X - Y PER BLOB
%%%%
% Loop to fill the T- Table with variables from T(X1, Y1, X2, Y2, etc..)
i=1;
j=1;
for n=1:height(T)
    if T.Frame(n) == i
        originalCoordinates(i,j) = T.Centroid(n,1);
        originalCoordinates(i,j+1) = T.Centroid(n,2);
        j = j + 2;

    else
        i = i + 1;
        j = 1;
        originalCoordinates(i,j) = T.Centroid(n,1);
        originalCoordinates(i,j+1) = T.Centroid(n,2);
        j = j + 2;
    end
end
distanceMatrix = zeros(frames-1, 7); %Create empty matrix
%Fill the new matrix with euclidean distance between the different coordinates in current frame and last frame.
for n=1:frames-1
    i=1;
    for b=1:7
        X = [originalCoordinates(n,i),originalCoordinates(n,1+i);originalCoordinates(n+1,i),originalCoordinates(n+1,1+i)];
        distanceMatrix(n,b) = pdist(X,'euclidean'); %calculation of Euclidean distance
    end
end
```

```

    i=i + 2;
end
end
%Use the distance matrix to switch the coordinates that are closer to another coordinate of the previous frame, so
%that the coordinates of each blob can be identified.
if count == frames
    for n=1:frames-1
        for b=1:7
            if distanceMatrix(n,b) > 20
                distances = zeros(1,7);
                for d=1:7
                    p = 2*b-1;
                    q = 2*d-1;
                    X = [originalCoordinates(n,p),originalCoordinates(n,p+1);originalCoordinates(n+1,q),originalCoordinates(n+1,q+1)];
                    distances(d) = pdist(X,'euclidean');
                end
                minimum = min(distances);
                index = find(distances==minimum);
                if length(index) == 1
                    if index ~= b
                        p = 2*b-1;
                        q = 2*index-1;
                        xFrom = originalCoordinates(n+1,p);
                        yFrom = originalCoordinates(n+1,p+1);
                        xTo = originalCoordinates(n+1,q);
                        yTo = originalCoordinates(n+1,q+1);
                        originalCoordinates(n+1,p) = xTo;
                        originalCoordinates(n+1,p+1) = yTo;
                        originalCoordinates(n+1,q) = xFrom;
                        originalCoordinates(n+1,q+1) = yFrom;
                    end
                end
            end
        end
    end
end
end
end
tableNew1 = array2table(originalCoordinates,... %Create new table with the switched coordinates
'VariableNames',{'X1','Y1','X2','Y2','X3','Y3','X4','Y4','X5','Y5','X6','Y6','X7','Y7'});
writetable(tableNew1,'originalCoordinates.csv'); % Save table as CSV
save('originalCoordinates.mat','T');% Save table as .mat
End

```

## Appendix H – MATLAB script: Calculating RGB-values of the light patches

```

% SUBSTRACT THE SATURATION FROM THE ORIGINAL VIDEO
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all; close all; clc; % Clear all variables and close all windows
count = 0; % Initialize counter to count frames
% LOAD THE ORIGINALCOORDINATES TABLE SO THAT WE CAN USE COORDINATES OF THE CENTROIDS OF THE BLOBS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Create a VideoReader object for the input video file, and specify the timestamp of the frame to read as 0.
vidReader = VideoReader('AdobeCutLQ.mp4','CurrentTime',1);
opts = delimitedTextImportOptions("NumVariables", 28); % Set up the Import Options and import the data
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S1", "A2", "X2", "Y2", "S2", "A3", "X3", "Y3", "S3", "A4", "X4", "Y4", "S4", "A5", "X5", "Y5", "S5", "A6", "X6",
"Y6", "S6", "A7", "X7", "Y7", "S7"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinates = readtable("C:\Users\originalCoordinates.csv", opts); % Import the data
clear opts % Clear temporary variables
% PREPARE DATA FOR SUBTRACTING THE SATURATION
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
saturation1 = table; %Create empty tables to store the saturation of each blob
saturation2 = table;
saturation3 = table;
saturation4 = table;
saturation5 = table;
saturation6 = table;
saturation7 = table;
% use original coordinates of centroids of blobs as an array and round them so they can be used. Done for all blobs.
%BLOB1
x1 = originalCoordinates(:,1);
x1 = table2array(x1);
x1new = round(x1);
y1 = originalCoordinates(:,2);
y1 = table2array(y1);
y1new = round(y1);
%BLOB2
x2 = originalCoordinates(:,3);
x2 = table2array(x2);
x2new = round(x2);
y2 = originalCoordinates(:,4);
y2 = table2array(y2);
y2new = round(y2);
%BLOB3
x3 = originalCoordinates(:,5);
x3 = table2array(x3);
x3new = round(x3);
y3 = originalCoordinates(:,6);
y3 = table2array(y3);
y3new = round(y3);
%BLOB4
x4 = originalCoordinates(:,7);
x4 = table2array(x4);
x4new = round(x4);
y4 = originalCoordinates(:,8);
y4 = table2array(y4);
y4new = round(y4);
%BLOB5
x5 = originalCoordinates(:,9);
x5 = table2array(x5);
x5new = round(x5);
y5 = originalCoordinates(:,10);
y5 = table2array(y5);
y5new = round(y5);
%BLOB6
x6 = originalCoordinates(:,11);
x6 = table2array(x6);
x6new = round(x6);
y6 = originalCoordinates(:,12);
y6 = table2array(y6);
y6new = round(y6);
%BLOB7
x7 = originalCoordinates(:,13);
x7 = table2array(x7);
x7new = round(x7);
y7 = originalCoordinates(:,14);
y7 = table2array(y7);
y7new = round(y7);
% RUN THROUGH ALL FRAMES TO SUBSTRACT THE SATURATION PER BLOB

```



```

%%%%%%%%%%%%%%
%%%%%%%%%%%%%%
i=1;
while hasFrame(vidReader) While there is a new frame
    count = count+1;
    frame = readFrame(vidReader); % Read frame
    c = x1new(i);
    r = y1new(i);
    a = x2new(i);
    b = y2new(i);
    d = x3new(i);
    e = y3new(i);
    f = x4new(i);
    g = y4new(i);
    h = x5new(i);
    o = y5new(i);
    j = x6new(i);
    k = y6new(i);
    l = x7new(i);
    m = y7new(i);
    % Use the coordinates to indicate the pixel that we want for each frame. Create a temp table with these pixels, % and add the frame number as a column as
    well. Indicate a cross on the frame so that we can see that the right % coordinates are used. Do this for all blobs.
    %Blob1
    i = i + 1;
    pixels1 = impixel(frame,c,r);
    temp_table1 = array2table(pixels1);
    temp_table1.Frame(:) = count;
    plot(c,r, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob2
    pixels2 = impixel(frame,a,b);
    temp_table2 = array2table(pixels2);
    temp_table2.Frame(:) = count;
    plot(a,b, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob3
    pixels3 = impixel(frame,d,e);
    temp_table3 = array2table(pixels3);
    temp_table3.Frame(:) = count;
    plot(d,e, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob4
    pixels4 = impixel(frame,f,g);
    temp_table4 = array2table(pixels4);
    temp_table4.Frame(:) = count;
    plot(f,g, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob5
    pixels5 = impixel(frame,h,o);
    temp_table5 = array2table(pixels5);
    temp_table5.Frame(:) = count;
    plot(h,o, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob6
    pixels6 = impixel(frame,j,k);
    temp_table6 = array2table(pixels6);
    temp_table6.Frame(:) = count;
    plot(j,k, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    %Blob7
    pixels7 = impixel(frame,l,m);
    temp_table7 = array2table(pixels7);
    temp_table7.Frame(:) = count;
    plot(l,m, 'r+', 'MarkerSize', 30, 'LineWidth', 2);
    saturation1 = vertcat(saturation1, temp_table1); %Fill the empty tables with the extracted pixels per Blob
    saturation2 = vertcat(saturation2, temp_table2);
    saturation3 = vertcat(saturation3, temp_table3);
    saturation4 = vertcat(saturation4, temp_table4);
    saturation5 = vertcat(saturation5, temp_table5);
    saturation6 = vertcat(saturation6, temp_table6);
    saturation7 = vertcat(saturation7, temp_table7);
    saturation1 = fillmissing(saturation1,'constant', 0); %Fill in the NaN values with 0
    saturation2 = fillmissing(saturation2,'constant', 0);
    saturation3 = fillmissing(saturation3,'constant', 0);
    saturation4 = fillmissing(saturation4,'constant', 0);
    saturation5 = fillmissing(saturation5,'constant', 0);
    saturation6 = fillmissing(saturation6,'constant', 0);
    saturation7 = fillmissing(saturation7,'constant', 0);
    allsaturation = join(saturation1, saturation2); %Make one big table with all saturation values per blob
    allsaturation = join(allsaturation, saturation3);
    allsaturation = join(allsaturation, saturation4);
    allsaturation = join(allsaturation, saturation5);
    allsaturation = join(allsaturation, saturation6);
    allsaturation = join(allsaturation, saturation7);
    allsaturation = removevars(allsaturation, {'Frame'}); % Remove frame column from Table with all saturation values
    figure % Display the image
    imshow(frame); hold on;
    if count == 10 % set amount of frames
        return
    end
    writetable(allsaturation,'allsaturation.csv'); % Save table as CSV
end

```

## Appendix I – MATLAB script: Numbering light patches and update information table

```

%CREATING A TABLE: WITH ORIGINAL CENTROID COORDINATES X & Y & AREA OF BLOBS & SATURATION VALUES
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all; close all; clc; % Clear all variables and close all windows
T = table; % Make table T to save data there
count = 0; % Initialize counter to count frames
% LOAD THE SATURATION TABLE SO THAT WE CAN PUT THEM IN THE LARGER TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
opts = delimitedTextImportOptions("NumVariables", 21); % Set up the Import Options and import the data
% Specify range and delimiter
opts.DataLines = [2, Inf];
opts.Delimiter = ",";
% Specify column names and types
opts.VariableNames = ["pixels11", "pixels12", "pixels13", "pixels21", "pixels22", "pixels23", "pixels31", "pixels32", "pixels33", "pixels41", "pixels42",
"pixels43", "pixels51", "pixels52", "pixels53", "pixels61", "pixels62", "pixels63", "pixels71", "pixels72", "pixels73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
allsaturation = readtable("C:\Users\allsaturation.csv", opts); % Import the data
% DETECTING BLOBS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear opts % Clear temporary variables
% Create a VideoReader object for the input video file, and specify the timestamp of the frame to read as 0.
vidReader = VideoReader('AdobeCutLQ.mp4','CurrentTime',1);
while hasFrame(vidReader) % While there is a new frame
    count = count+1; % Add 1 to counter
    frameRGB = readFrame(vidReader); % Read frame
    frameGray = im2gray(frameRGB); % Make it gray
    frameBW = frameGray > 175; % Find the binary image
    frameGray(frameBW) = 0; % Make those pixels black.
    [B,L,N,A] = bwboundaries(frameBW); % Trace boundaries with command bwboundaries
    figure % Display the image with the boundaries overlaid.
    imshow(frameBW); hold on;
    % Code from here: https://nl.mathworks.com/matlabcentral/answers/1740310-save-plotted-lines-in-an-matrix?s_tid=srchtitle
    for regionk = 1:N % Loop through object boundaries
        % Boundary k is the parent of a hole if the k-th column
        % of the adjacency matrix A contains numBlobs a non-zero element
        if (nnz(A(:,regionk)) > 0)
            boundary = B{regionk};
            plot(boundary(:,2),...
                boundary(:,1),'r','LineWidth',2);
        end % red = parent boundary & green = parents' holes
        CC = bwconncomp(frameBW); % Find and count connected components in binary image
        [labeledImage, numBlobs] = bwlabel(frameBW);
        % figure
        props = regionprops(CC, 'Centroid', 'BoundingBox', 'Area'); Save all region properties to props (properties)
        % See https://nl.mathworks.com/help/images/ref/regionprops.html;
        temp_table = struct2table(props); % Create table from the structure props
        temp_table.Frame(:) = count; % Add variable Frame and save current frame there in all entries
        temp_table.NumBlobs(:) = numBlobs;
        temp_array = table2array(temp_table); % sort table in first column (Area)
        if count == 371 % set amount of frames
            return
        end
    end
end
[labeledImage, numberofBlobs] = bwlabel(frameBW); % Add temporary table with data from frames to table T
% Get all the areas
allAreas = [props.Area]; % No semicolon so it will print to the command window.
menuOptions{1} = '0'; % Add option to extract no blobs.
countArray = [1 2 3 4 5];
bigBlobscounter = 0;
% Display areas on image
for k = 1 : numberofBlobs % Loop through all blobs.
    if props(k).Area > 400
        bigBlobscounter = bigBlobscounter+ 1;
        thisCentroid = [props(k).Centroid(1), props(k).Centroid(2)];
        message = sprintf(string(bigBlobscounter), allAreas(k));
        text(thisCentroid(1), thisCentroid(2), message, 'Color', 'b');
        menuOptions{k+1} = sprintf("%d", k);
        temp_table.blobNumber(k) = bigBlobscounter;
    end
end
temp_table2 = temp_table(temp_array(:,1)>400,:); % Create temp table
T = vertcat(T, temp_table2); % Create table
T = movevars(T, 'Frame', 'Before', 'Area'); % Change order of columns in table T so that Frame is the first one
frames = 370; %Set frames
originalCoordinates = zeros(frames,42); %Create empty matrix
% CREATE TABLE WITH ALL VARIABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Loop to fill the originalCoordinates Table with variables from T(A1, X1, Y1, S11, S12, S13, A2, X2, Y2, S21, S22, S23, etc..)

```

```

i=1;
j=1;
for n=1:height(T)
    if T.Frame(n) == i
        originalCoordinates(i,j) = T.Area(n);
        originalCoordinates(i,j+1) = T.Centroid(n,1);
        originalCoordinates(i,j+2) = T.Centroid(n,2);
        originalCoordinates(i,j+3) = T.Frame(n);
        originalCoordinates(i,j+4) = T.Frame(n);
        originalCoordinates(i,j+5) = T.Frame(n);
        j = j + 6;
    else
        i = i + 1;
        j = 1;
        originalCoordinates(i,j) = T.Area(n);
        originalCoordinates(i,j+1) = T.Centroid(n,1);
        originalCoordinates(i,j+2) = T.Centroid(n,2);
        originalCoordinates(i,j+3) = T.Frame(n);
        originalCoordinates(i,j+4) = T.Frame(n);
        originalCoordinates(i,j+5) = T.Frame(n);
        j = j + 6;
    end
end
%add saturation of blob 1 to originalCoordinates Table
originalCoordinates(:,4) = allsaturation.pixels11;
originalCoordinates(:,5) = allsaturation.pixels12;
originalCoordinates(:,6) = allsaturation.pixels13;
%add saturation of blob 2 to originalCoordinates Table
originalCoordinates(:,10) = allsaturation.pixels21;
originalCoordinates(:,11) = allsaturation.pixels22;
originalCoordinates(:,12) = allsaturation.pixels23;
%add saturation of blob 3 to originalCoordinates Table
originalCoordinates(:,16) = allsaturation.pixels31;
originalCoordinates(:,17) = allsaturation.pixels32;
originalCoordinates(:,18) = allsaturation.pixels33;
%add saturation of blob 4 to originalCoordinates Table
originalCoordinates(:,22) = allsaturation.pixels41;
originalCoordinates(:,23) = allsaturation.pixels42;
originalCoordinates(:,24) = allsaturation.pixels43;
%add saturation of blob 5 to originalCoordinates Table
originalCoordinates(:,28) = allsaturation.pixels51;
originalCoordinates(:,29) = allsaturation.pixels52;
originalCoordinates(:,30) = allsaturation.pixels53;
%add saturation of blob 6 to originalCoordinates Table
originalCoordinates(:,34) = allsaturation.pixels61;
originalCoordinates(:,35) = allsaturation.pixels62;
originalCoordinates(:,36) = allsaturation.pixels63;
%add saturation of blob 7 to originalCoordinates Table
originalCoordinates(:,40) = allsaturation.pixels71;
originalCoordinates(:,41) = allsaturation.pixels72;
originalCoordinates(:,42) = allsaturation.pixels73;
% SWITCH THE ROWS SO THAT THE COORDINATES BELONG TO THE RIGHT BLOBS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
distanceMatrix = zeros(frames-1, 7); %Create empty matrix for
%Fill the new matrix with euclidean distance between the different coordinates in current frame and last frame.
for n=1:frames-1
    i=1;
    for b=1:7
        X = [originalCoordinates(n,1+i),originalCoordinates(n,2+i);originalCoordinates(n+1,1+i),originalCoordinates(n+1,2+i)];
        distanceMatrix(n,b) = pdist(X,'euclidean'); %calculation of Euclidean distance
        i = i + 6;
    end
end
%Use the distance matrix to switch the coordinates that are closer to another coordinate of the previous frame, so that the coordinates of each blob can be
identified.
if count == frames
    for n=1:frames-1
        for b=1:7
            if distanceMatrix(n,b) > 20
                distances = zeros(1,7);
                for d=1:7
                    p = 6*b - 4;
                    q = 6*d - 4;
                    X = [originalCoordinates(n,p),originalCoordinates(n,p+1);originalCoordinates(n+1,q),originalCoordinates(n+1,q+1)];
                    distances(d) = pdist(X,'euclidean');
                end
                minimum = min(distances);
                index = find(distances==minimum);
                if length(index) == 1
                    if index ~= b
                        p = 6*b - 4;
                        q = 6*index - 4;
                        AFrom = originalCoordinates(n+1,p-1);
                        xFrom = originalCoordinates(n+1,p);
                        yFrom = originalCoordinates(n+1,p+1);
                    end
                end
            end
        end
    end
end

```

```

    Ato = originalCoordinates(n+1,q-1);
    xTo = originalCoordinates(n+1,q);
    yTo = originalCoordinates(n+1,q+1);
    originalCoordinates(n+1,p-1) = Ato;
    originalCoordinates(n+1,p) = xTo;
    originalCoordinates(n+1,p+1) = yTo;
        originalCoordinates(n+1,q-1) = AFrom;
    originalCoordinates(n+1,q) = xFrom;
    originalCoordinates(n+1,q+1) = yFrom;
end
end
end
end
end
end
end
tableNew1 = array2table(originalCoordinates,... %Create new table
'VariableNames',{ 'A1','X1','Y1','S11','S12','S13','A2','X2','Y2','S21','S22','S23','A3','X3','Y3','S31','S32','S33', 'A4','X4','Y4','S41','S42','S43', 'A5','X5','Y5',
'S51','S52','S53','A6','X6','Y6','S61', 'S62','S63','A7','X7','Y7','S71', 'S72', 'S73'});
writetable(tableNew1,'originalCoordinatesv2.csv'); % Save table as CSV
save("originalCoordinatesv2.mat","T"); % Save table as .mat
end

```

## Appendix J – MATLAB script: Creating the video for the natural stimulus

```

clear; close all;
% LOAD THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
opts = delimitedTextImportOptions("NumVariables", 42); % Set up the Import Options and import the data
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S11", "S12", "S13", "A2", "X2", "Y2", "S21", "S22", "S23", "A3", "X3", "Y3", "S31", "S32", "S33", "A4", "X4",
"Y4", "S41", "S42", "S43", "A5", "X5", "Y5", "S51", "S52", "S53", "A6", "X6", "Y6", "S61", "S62", "S63", "A7", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinatesv2 = readtable("originalCoordinatesv2.csv", opts); % Import the data
clear opts % Clear temporary variables
% PREPARING THE SATURATION DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Blob1
FramesSaturationBlob1 = [originalCoordinatesv2(:,4), originalCoordinatesv2(:,5),originalCoordinatesv2(:,6)];
% Use this code when using Gray scales:
RGBBlob1 = table2array(FramesSaturationBlob1); % set from table to array
RGBMatlabBlob10 = RGBBlob1./(255); % so that Matlab understands the colors
Gray1 = rgb2gray(RGBMatlabBlob10); % set colors to gray
% To create the loop
flipRGB1 = flip(Gray1);
RGB11 = cat(1, Gray1, flipRGB1);
RGBMatlabBlob1 = cat(1, RGB11);
RGBMatlabBlob11 = cat(1, RGBMatlabBlob1, RGBMatlabBlob1);
% Use this code when using color scales:
% RGBBlob1 = table2array(FramesSaturationBlob1);
% RGBMatlabBlob10 = RGBBlob1./(255);
% % To create the loop
% flipRGB1 = flip(RGBMatlabBlob10);
% RGB11 = cat(1, RGBMatlabBlob10, flipRGB1);
% RGBMatlabBlob1 = cat(1, RGB11);
% RGBMatlabBlob11 = cat(1, RGBMatlabBlob1, RGBMatlabBlob1);
% Blob2
FramesSaturationBlob2 = [originalCoordinatesv2(:,10), originalCoordinatesv2(:,11),originalCoordinatesv2(:,12)];
RGBBlob2 = table2array(FramesSaturationBlob2);
RGBMatlabBlob20 = RGBBlob2./(255);
Gray2 = rgb2gray(RGBMatlabBlob20);
flipRGB2 = flip(Gray2);
RGB21 = cat(1, Gray2, flipRGB2);
RGBMatlabBlob2 = cat(1, RGB21);
RGBMatlabBlob22 = cat(1, RGBMatlabBlob2, RGBMatlabBlob2);
% Blob3
FramesSaturationBlob3 = [originalCoordinatesv2(:,16), originalCoordinatesv2(:,17),originalCoordinatesv2(:,18)];
RGBBlob3 = table2array(FramesSaturationBlob3);
RGBMatlabBlob30 = RGBBlob3./(255);
Gray3 = rgb2gray(RGBMatlabBlob30);
flipRGB3 = flip(Gray3);
RGB31 = cat(1, Gray3, flipRGB3);
RGBMatlabBlob3 = cat(1, RGB31);
RGBMatlabBlob33 = cat(1, RGBMatlabBlob3, RGBMatlabBlob3);
% Blob4
FramesSaturationBlob4 = [originalCoordinatesv2(:,22), originalCoordinatesv2(:,23),originalCoordinatesv2(:,24)];
RGBBlob4 = table2array(FramesSaturationBlob4);
RGBMatlabBlob40 = RGBBlob4./(255);
Gray4 = rgb2gray(RGBMatlabBlob40);
flipRGB4 = flip(Gray4);
RGB41 = cat(1, Gray4, flipRGB4);
RGBMatlabBlob4 = cat(1, RGB41);
RGBMatlabBlob44 = cat(1, RGBMatlabBlob4, RGBMatlabBlob4);
% Blob5
FramesSaturationBlob5 = [originalCoordinatesv2(:,28), originalCoordinatesv2(:,29),originalCoordinatesv2(:,30)];
RGBBlob5 = table2array(FramesSaturationBlob5);
RGBMatlabBlob50 = RGBBlob5./(255);
Gray5 = rgb2gray(RGBMatlabBlob50);
flipRGB5 = flip(Gray5);
RGB51 = cat(1, Gray5, flipRGB5);
RGBMatlabBlob5 = cat(1, RGB51);
RGBMatlabBlob55 = cat(1, RGBMatlabBlob5, RGBMatlabBlob5);
% Blob6
FramesSaturationBlob6 = [originalCoordinatesv2(:,34), originalCoordinatesv2(:,35),originalCoordinatesv2(:,36)];
RGBBlob6 = table2array(FramesSaturationBlob6);
RGBMatlabBlob60 = RGBBlob6./(255);
Gray6 = rgb2gray(RGBMatlabBlob60);
flipRGB6 = flip(Gray6);
RGB61 = cat(1, Gray6, flipRGB6);
RGBMatlabBlob6 = cat(1, RGB61);
RGBMatlabBlob66 = cat(1, RGBMatlabBlob6, RGBMatlabBlob6);
% Blob7

```

```

FramesSaturationBlob7 = [originalCoordinatesv2(:,40), originalCoordinatesv2(:,41),originalCoordinatesv2(:,42)];
RGBBlob7 = table2array(FramesSaturationBlob7);
RGBMatlabBlob70 = RGBBlob7./(255);
Gray7 = rgb2gray(RGBMatlabBlob70);
flipRGB7 = flip(Gray7);
RGB71 = cat(1,Gray7,flipRGB7);
RGBMatlabBlob7= cat(1, RGB71);
RGBMatlabBlob77 = cat(1,RGBMatlabBlob7, RGBMatlabBlob7);
% PREPARING THE AREA DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Blob1
Area1 = originalCoordinatesv2(:,1);
Area1 = table2array(Area1);
radiusCircle10 = sqrt(Area1/3.14159265359)*0.5; %to calculate the radius, with only knowing the area. Factor of 0.5 used to fit into frame.
% Used for loop:
flip1 = flip(radiusCircle10);
radiusCircle11 = cat(1,radiusCircle10,flip1);
radiusCircle1 = cat(1, radiusCircle11,radiusCircle11);
%Blob2
Area2 = originalCoordinatesv2(:,7);
Area2 = table2array(Area2);
radiusCircle20 = sqrt(Area2/3.14159265359)*0.5;
flip2 = flip(radiusCircle20);
radiusCircle21 = cat(1,radiusCircle20,flip2);
radiusCircle22 = cat(1, radiusCircle21);
radiusCircle2 = cat(1, radiusCircle22,radiusCircle22);
%Blob3
Area3 = originalCoordinatesv2(:,13);
Area3 = table2array(Area3);
radiusCircle30 = sqrt(Area3/3.14159265359)*0.5;
flip3 = flip(radiusCircle30);
radiusCircle31 = cat(1,radiusCircle30,flip3);
radiusCircle33 = cat(1, radiusCircle31);
radiusCircle3 = cat(1, radiusCircle33,radiusCircle33);
%Blob4
Area4 = originalCoordinatesv2(:,19);
Area4 = table2array(Area4);
radiusCircle40 = sqrt(Area4/3.14159265359)*0.5;
flip4 = flip(radiusCircle40);
radiusCircle41 = cat(1,radiusCircle40,flip4);
radiusCircle44 = cat(1, radiusCircle41);
radiusCircle4 = cat(1, radiusCircle44,radiusCircle44);
%Blob5
Area5 = originalCoordinatesv2(:,25);
Area5 = table2array(Area5);
radiusCircle50 = sqrt(Area5/3.14159265359)*0.5;
flip5 = flip(radiusCircle50);
radiusCircle51 = cat(1,radiusCircle50,flip5);
radiusCircle55 = cat(1, radiusCircle51);
radiusCircle5 = cat(1, radiusCircle55,radiusCircle55);
%Blob6
Area6 = originalCoordinatesv2(:,31);
Area6 = table2array(Area6);
radiusCircle60 = sqrt(Area6/3.14159265359)*0.5;
flip6 = flip(radiusCircle60);
radiusCircle61 = cat(1,radiusCircle60,flip6);
radiusCircle66 = cat(1, radiusCircle61);
radiusCircle6 = cat(1, radiusCircle66,radiusCircle66);
%Blob7
Area7 = originalCoordinatesv2(:,37);
Area7 = table2array(Area7);
radiusCircle70 = sqrt(Area7/3.14159265359)*0.5;
flip7 = flip(radiusCircle70);
radiusCircle71 = cat(1,radiusCircle70,flip7);
radiusCircle77 = cat(1, radiusCircle71);
radiusCircle7 = cat(1, radiusCircle77,radiusCircle77);
% PREPARING THE COORDINATES DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%CIRCLE 1
x1coordinates0 = originalCoordinatesv2(:,2); % coordinates x
x1coordinates0 = table2array(x1coordinates0);
y1coordinates0= originalCoordinatesv2(:,3); % coordinates y
y1coordinates0 = table2array(y1coordinates0);
%Used for loops:
flipx1 = flip(x1coordinates0);
flipy1 = flip(y1coordinates0);
x1coordinates1 = cat(1,x1coordinates0,flipx1);
y1coordinates1 = cat(1, y1coordinates0,flipy1);
x1coordinates = cat(1, x1coordinates1,x1coordinates1);
y1coordinates = cat(1, y1coordinates1,y1coordinates1);
x10 = x1coordinates(1,:); % x centre of circle
y10 = y1coordinates(1,:); % y centre of circle
%CIRCLE 2
x2coordinates0 = originalCoordinatesv2(:,8); % coordinates x
x2coordinates0 = table2array(x2coordinates0);
y2coordinates0 = originalCoordinatesv2(:,9); % coordinates y

```

```

y2coordinates0 = table2array(y2coordinates0);
flipx2 = flip(x2coordinates0);
flipy2 = flip(y2coordinates0);
x2coordinates1 = cat(1,x2coordinates0,flipx2);
y2coordinates1 = cat(1,y2coordinates0,flipy2);
x2coordinates = cat(1,x2coordinates1,x2coordinates1);
y2coordinates = cat(1,y2coordinates1,y2coordinates1);
x20 = x2coordinates(1,:); % x centre of circle
y20 = y2coordinates(1,:); % y centre of circle
%CIRCLE 3
x3coordinates0 = originalCoordinatesv2(:,14); % coordinates x
x3coordinates0 = table2array(x3coordinates0);
y3coordinates0= originalCoordinatesv2(:,15); % coordinates y
y3coordinates0 = table2array(y3coordinates0);
flipx3 = flip(x3coordinates0);
flipy3 = flip(y3coordinates0);
x3coordinates1 = cat(1,x3coordinates0,flipx3);
y3coordinates1 = cat(1,y3coordinates0,flipy3);
x3coordinates = cat(1,x3coordinates1,x3coordinates1);
y3coordinates = cat(1,y3coordinates1,y3coordinates1);
x30 = x3coordinates(1,:); % x centre of circle
y30 = y3coordinates(1,:); % y centre of circle
%CIRCLE 4
x4coordinates0 = originalCoordinatesv2(:,20); % coordinates x
x4coordinates0 = table2array(x4coordinates0);
y4coordinates0= originalCoordinatesv2(:,21); % coordinates y
y4coordinates0 = table2array(y4coordinates0);
flipx4 = flip(x4coordinates0);
flipy4 = flip(y4coordinates0);
x4coordinates1 = cat(1,x4coordinates0,flipx4);
y4coordinates1 = cat(1,y4coordinates0,flipy4);
x4coordinates = cat(1,x4coordinates1,x4coordinates1);
y4coordinates = cat(1,y4coordinates1,y4coordinates1);
x40 = x4coordinates(1,:); % x centre of circle
y40 = y4coordinates(1,:); % y centre of circle
%CIRCLE 5
x5coordinates0 = originalCoordinatesv2(:,26); % coordinates x
x5coordinates0 = table2array(x5coordinates0);
y5coordinates0= originalCoordinatesv2(:,27); % coordinates y
y5coordinates0 = table2array(y5coordinates0);
flipx5 = flip(x5coordinates0);
flipy5 = flip(y5coordinates0);
x5coordinates1 = cat(1,x5coordinates0,flipx5);
y5coordinates1 = cat(1,y5coordinates0,flipy5);
x5coordinates = cat(1,x5coordinates1,x5coordinates1);
y5coordinates = cat(1,y5coordinates1,y5coordinates1);
x50 = x5coordinates(1,:); % x centre of circle
y50 = y5coordinates(1,:); % y centre of circle
%CIRCLE 6
x6coordinates0 = originalCoordinatesv2(:,32); % coordinates x
x6coordinates0 = table2array(x6coordinates0);
y6coordinates0= originalCoordinatesv2(:,33); % coordinates y
y6coordinates0 = table2array(y6coordinates0);
flipx6 = flip(x6coordinates0);
flipy6 = flip(y6coordinates0);
x6coordinates1 = cat(1,x6coordinates0,flipx6);
y6coordinates1 = cat(1,y6coordinates0,flipy6);
x6coordinates = cat(1,x6coordinates1,x6coordinates1);
y6coordinates = cat(1,y6coordinates1,y6coordinates1);
x60 = x6coordinates(1,:); % x centre of circle
y60 = y6coordinates(1,:); % y centre of circle
%CIRCLE 7
x7coordinates0 = originalCoordinatesv2(:,38); % coordinates x
x7coordinates0 = table2array(x7coordinates0);
y7coordinates0= originalCoordinatesv2(:,39); % coordinates y
y7coordinates0 = table2array(y7coordinates0);
flipx7 = flip(x7coordinates0);
flipy7 = flip(y7coordinates0);
x7coordinates1 = cat(1,x7coordinates0,flipx7);
y7coordinates1 = cat(1,y7coordinates0,flipy7);
x7coordinates = cat(1,x7coordinates1,x7coordinates1);
y7coordinates = cat(1,y7coordinates1,y7coordinates1);
x70 = x7coordinates(1,:); % x centre of circle
y70 = y7coordinates(1,:); % y centre of circle
N = 100; % number of points used to define circle
radius = 1;
theta = linspace(0,2*pi,N); % create equal length arrays defining a circle in polar coordinates
r = radius * ones(1,N);
area = pi * radius^2;
[x1, y1] = pol2cart(theta, r); % convert polar coordinates to Cartesian coordinates
[x2, y2] = pol2cart(theta, r);
[x3, y3] = pol2cart(theta, r);
[x4, y4] = pol2cart(theta, r);
[x5, y5] = pol2cart(theta, r);
[x6, y6] = pol2cart(theta, r);
[x7, y7] = pol2cart(theta, r);

```

```

x1 = x1 + x10;    % offset the circle so its centre lies at (x0, y0)
y1 = y1 + y10;
x2 = x2 + x20;    % offset the circle so its centre lies at (x0, y0)
y2 = y2 + y20;
x3 = x3 + x30;    % offset the circle so its centre lies at (x0, y0)
y3 = y3 + y30;
x4 = x4 + x40;    % offset the circle so its centre lies at (x0, y0)
y4 = y4 + y40;
x5 = x5 + x50;    % offset the circle so its centre lies at (x0, y0)
y5 = y5 + y50;
x6 = x6 + x60;    % offset the circle so its centre lies at (x0, y0)
y6 = y6 + y60;
x7 = x7 + x70;    % offset the circle so its centre lies at (x0, y0)
y7 = y7 + y70;
% CREATING VIDEO
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
myVideo = VideoWriter('08112022NaturalCoordinates_Area_Saturation_Gray');
myVideo.FrameRate = 28;
open(myVideo)
for i = 1:length(x1coordinates)
    cla()
    set(0,'defaultfigurecolor',[0 0 0])
    set(gca,'color',[0 0 0], 'ydir', 'reverse');
    xlabel('x')    % label axes
    ylabel('y')
    axis equal    % equal axis scaling so our circle looks circular
    xlim([ 50 1000]);    % set plot limits
    ylim([-50 1000]);
    Ax = gca;
    Ax.Color = 'k';
    Ax.XColor = 'none';
    Ax.YColor = 'none';
    % if using radius from existing table instead of default 20, use this: radiusCircle7(i) (adjust number)
    % if using saturation from existing table instead of default 'w', use this: RGBMatlabBlob77(i,:) (adjust number)
    if radiusCircle1(i) > 0    %Draw blob 1
        f = plot(x1coordinates(i), y1coordinates(i), 'o', 'MarkerSize', radiusCircle1(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle2(i) > 0    %Draw blob 2
        g = plot(x2coordinates(i), y2coordinates(i), 'o', 'MarkerSize', radiusCircle2(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');
        hold on;
    end
    if radiusCircle3(i) > 0    %Draw blob 3
        h = plot(x3coordinates(i), y3coordinates(i), 'o', 'MarkerSize', radiusCircle3(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle4(i) > 0    %Draw blob 4
        l = plot(x4coordinates(i), y4coordinates(i), 'o', 'MarkerSize', radiusCircle4(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle5(i) > 0    %Draw blob 5
        j = plot(x5coordinates(i), y5coordinates(i), 'o', 'MarkerSize', radiusCircle5(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle6(i) > 0    %Draw blob 6
        p = plot(x6coordinates(i), y6coordinates(i), 'o', 'MarkerSize', radiusCircle6(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle7(i) > 0    %Draw blob 7
        q = plot(x7coordinates(i), y7coordinates(i), 'o', 'MarkerSize', radiusCircle7(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    axis off
    pause(0.1);
    if i>1    % Start from second frame to avoid problematic first frame
        frame = getframe(gcf); %saveas(gcf, sprintf('./FRAMES/%i.png', i));
        writeVideo(myVideo, frame);
    end
end
close(myVideo)

```



## Appendix K – MATLAB script: Creating table (random) for the non-natural stimulus

```

% CREATING A TABLE WITH RANDOM VALUES BASED ON THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all; close all; clc;
% LOAD THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 42);
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S11", "S12", "S13", "A2", "X2", "Y2", "S21", "S22", "S23", "A3", "X3", "Y3", "S31", "S32", "S33", "A4", "X4",
"Y4", "S41", "S42", "S43", "A5", "X5", "Y5", "S51", "S52", "S53", "A6", "X6", "Y6", "S61", "S62", "S63", "A7", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinatesv2 = readtable("C:\Users\originalCoordinatesv2.csv", opts); % Import the data
originalCoordinatesv2 = table2array(originalCoordinatesv2); % From table to array
clear opts % Clear temporary variables
% CREATE RANDOM COORDINATES
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Update of the distance matrix with the new values from the originalCoordinatesv2 Table.
distanceMatrixUpdated = zeros(369, 7);
for n=1:369
    i=1;
    for b=1:7
        X = [originalCoordinatesv2(n,1+i),originalCoordinatesv2(n,2+i);originalCoordinatesv2(n+1,1+i),originalCoordinatesv2(n+1,2+i)];
        distanceMatrixUpdated(n,b) = pdist(X,'euclidean');
        i = i + 6;
    end
end
NewCol = rand(370,1); %Create a new column
%Add new columns to balance the index
originalCoordinatesv2 = [originalCoordinatesv2(:,1:1) NewCol originalCoordinatesv2(:,1+1:42)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:8) NewCol originalCoordinatesv2(:,8+1:43)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:15) NewCol originalCoordinatesv2(:,15+1:44)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:22) NewCol originalCoordinatesv2(:,22+1:45)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:29) NewCol originalCoordinatesv2(:,29+1:46)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:36) NewCol originalCoordinatesv2(:,36+1:47)];
originalCoordinatesv2 = [originalCoordinatesv2(:,1:43) NewCol originalCoordinatesv2(:,43+1:48)];
coordinateRandomTable= zeros(369,49); % Create an empty table
%Copy first row original values to first row in the random table as a starting point.
coordinateRandomTable(1,:) = originalCoordinatesv2(1,:);
% Use the Euclidean distance to create new positions of the x and y coordinates, in random directions (360 degrees)
for n=1:369
    for b=1:7
        p = 7*b - 4;
        if distanceMatrixUpdated(n,b)<20 % Only if the euclidean distance is smaller than 50, the new coordinate will be calculated with a randomizer
            randomAngle = 360*rand;
            deltax = cos(randomAngle)*distanceMatrixUpdated(n,b);
            disp(deltax);
            deltay = sin(randomAngle)*distanceMatrixUpdated(n,b);
            disp(deltay);
            coordinateRandomTable(n+1,p) = coordinateRandomTable(n,p) + deltax;
            coordinateRandomTable(n+1,p+1) = coordinateRandomTable(n,p+1) + deltay;
            %Use this code if you want to base the coordinates on their original coordinates
            %coordinateRandomTable(n+1,p) = originalCoordinatesv2(n,p) + deltax;
            %coordinateRandomTable(n+1,p+1) = originalCoordinatesv2(n,p+1) + deltay;
            else % if distance is >20 use the original coordinate will be used in that place, because it will be a 0.
                coordinateRandomTable(n+1,p) = originalCoordinatesv2(n+1,p);
                coordinateRandomTable(n+1,p+1) = originalCoordinatesv2(n+1,p+1);
            end
        end
    end
end
% CREATE ORDERED AREAS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
coordinateRandomTable(:,2) = 0;
coordinateRandomTable(:,9) = 0;
coordinateRandomTable(:,16) = 0;
coordinateRandomTable(:,23) = 0;
coordinateRandomTable(:,30) = 0;
coordinateRandomTable(:,37) = 0;
coordinateRandomTable(:,44) = 0;
index = 1;
column = 1;
while column < 44
    for n=1:370
        if n~= 1 && n~= 370
            if originalCoordinatesv2(n,column) == 0 && originalCoordinatesv2(n-1,column) ~= 0
                list = sort(originalCoordinatesv2(index:n-1, column));
                for i=1:length(list)
                    coordinateRandomTable(index+i-1, column) = list(i);
                end
            end
        end
        index = index + 1;
        column = column + 1;
    end
end

```

```

        coordinateRandomTable(n,column) = 0;
    end
end
if originalCoordinatesv2(n,column) ~= 0 && originalCoordinatesv2(n-1,column) == 0
    index = n;
end
if originalCoordinatesv2(n,column) == 0 && originalCoordinatesv2(n-1,column) == 0
    coordinateRandomTable(n,column) = 0;
end
end
if n == 1
    if originalCoordinatesv2(n,column) == 0
        coordinateRandomTable(n,column) = 0;
    end
end
if n == 370
    list = sort(originalCoordinatesv2(index:n, column));
    for i=1:length(list)
        coordinateRandomTable(index+i-1,column) = list(i);
    end
end
end
column = column +7;
index = 1;
end
% CREATE RANDOM AREA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
meansArray = zeros(1,7); %Create some empty arrays
sdArray = zeros(1,7);
minArray = zeros(1,7);
maxArray = zeros(1,7);
%Create different arrays per frame so that we can use the values to create random areas.
for n=1:369
    j = 0;
    for b = 1:7
        cleanArray = nonzeros(originalCoordinatesv2(:,b+j));
        if ~(isempty(cleanArray))
            meansArray(b) = mean(cleanArray); %find the mean of the array
            sdArray(b) = std(cleanArray); %find the standard deviation of the array
            minArray(b) = min(cleanArray); %find the minimal value of the array
            maxArray(b) = max(cleanArray); %find the maximal value of the array
        end
        j = j+6;
    end
    %Create random areas based on the values in the loop before (1 Area array with values according to a normal %distribution, 1 Area according to a uniform
distribution of values)
    for l=2:369
        j = 1;
        for b=1:7
            if originalCoordinatesv2(1,b+j) ~= 0
                coordinateRandomTable(1,b+j)= normrnd(meansArray(b), sdArray(b)); % use the normal distribution of the values
%coordinateRandomTable(1,b+j+1)= unifrnd(minArray(b), maxArray(b)); % use a uniform distribution of the values
            end
            j = j+6;
        end
    end
end
end
% CREATE ORDERED SATURATION
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Transform saturation data into gray scale values
column=5;
while column < 49
    for n=1:369
        coordinateRandomTable(n,column) = (0.2989 * originalCoordinatesv2(n,column) + 0.5870 * originalCoordinatesv2(n,column+1)+ 0.1140 *
originalCoordinatesv2(n,column+2));
        coordinateRandomTable(n,column+1) = (0.2989 * originalCoordinatesv2(n,column) + 0.5870 * originalCoordinatesv2(n,column+1)+ 0.1140 *
originalCoordinatesv2(n,column+2));
        coordinateRandomTable(n,column+2) = (0.2989 * originalCoordinatesv2(n,column) + 0.5870 * originalCoordinatesv2(n,column+1)+ 0.1140 *
originalCoordinatesv2(n,column+2));
    end
    column = column +7;
end
end
%Only show saturation when circle is visible
column = 1;
while column < 49
    for n=1:369
        if originalCoordinatesv2(n,column) == 0
            coordinateRandomTable(n,column+4) = 0;
            coordinateRandomTable(n,column+5) = 0;
            coordinateRandomTable(n,column+6) = 0;
        end
        coordinateRandomTable(n,column+4) = coordinateRandomTable(n,column+4);
        coordinateRandomTable(n,column+5) = coordinateRandomTable(n,column+5);
        coordinateRandomTable(n,column+6) = coordinateRandomTable(n,column+6);
    end
end
end

```

```

    column = column +7;
end
%Order the data per section from small values to larger values (for first saturation column)
index = 1;
column = 5;
while column < 48
    for n=1:370
        if n~= 1 && n~= 370
            if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) ~= 0
                list = sort(coordinateRandomTable(index:n-1, column));
                for i=1:length(list)
                    coordinateRandomTable(index+i-1,column) = list(i);
                    coordinateRandomTable(n,column) = 0;
                end
            end
            if coordinateRandomTable(n,column) ~= 0 && coordinateRandomTable(n-1,column) == 0
                index = n;
            end
            if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) == 0
                coordinateRandomTable(n,column) = 0;
            end
        end
        if n == 1
            if coordinateRandomTable(n,column) == 0
                coordinateRandomTable(n,column) = 0;
            end
        end
        if n == 370 %last frame
            disp(index)
            list = sort(coordinateRandomTable(index:n, column));
            for i=1:length(list)
                coordinateRandomTable(index+i-1,column) = list(i);
            end
        end
    end
    column = column +7;
    index = 1;
end
%Order the data per section from small values to larger values (for second saturation column)
index = 1;
column = 6;
while column < 49
    for n=1:370
        if n~= 1 && n~=370
            if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) ~= 0
                list = sort(coordinateRandomTable(index:n-1, column));
                for i=1:length(list)
                    coordinateRandomTable(index+i-1,column) = list(i);
                    coordinateRandomTable(n,column) = 0;
                end
            end
            if coordinateRandomTable(n,column) ~= 0 && coordinateRandomTable(n-1,column) == 0
                index = n;
            end
            if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) == 0
                coordinateRandomTable(n,column) = 0;
            end
        end
        if n==1
            if coordinateRandomTable(n,column) == 0
                coordinateRandomTable(n,column) = 0;
            end
        end
        if n == 370
            list = sort(coordinateRandomTable(index:n, column));
            for i=1:length(list)
                coordinateRandomTable(index+i-1,column) = list(i);
            end
        end
    end
    column = column +7;
    index=1;
end
%Order the data per section from small values to larger values (for third saturation column)
index = 1;
column = 7;
while column < 50
    for n=1:370
        if n~= 1 && n~=370
            if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) ~= 0
                list = sort(coordinateRandomTable(index:n-1, column));
                for i=1:length(list)
                    coordinateRandomTable(index+i-1,column) = list(i);
                    coordinateRandomTable(n,column) = 0;
                end
            end
        end
    end
end

```

```

end
if coordinateRandomTable(n,column) ~= 0 && coordinateRandomTable(n-1,column) == 0
    index = n;
end
if coordinateRandomTable(n,column) == 0 && coordinateRandomTable(n-1,column) == 0
    coordinateRandomTable(n,column) = 0;
end
end
if n==1
    if coordinateRandomTable(n,column) == 0
        coordinateRandomTable(n,column) = 0;
    end
end
if n == 370 %last frame
    list = sort(coordinateRandomTable(index:n, column));
    for i=1:length(list)
        coordinateRandomTable(index+i-1,column) = list(i);
    end
end
end
column = column +7;
index=1;
end
%% CREATE RANDOM SATURATION
%% %%%%%%%%%%%
%% Create a vertical list of all saturation values in the movie
% saturationLong1 = vertcat(originalCoordinatesv2(:,5), originalCoordinatesv2(:,12), originalCoordinatesv2(:,19), originalCoordinatesv2(:,26),
originalCoordinatesv2(:,33), originalCoordinatesv2(:,40));
% saturationLong2 = vertcat(originalCoordinatesv2(:,6), originalCoordinatesv2(:,13), originalCoordinatesv2(:,20), originalCoordinatesv2(:,27),
originalCoordinatesv2(:,34), originalCoordinatesv2(:,41));
% saturationLong3 = vertcat(originalCoordinatesv2(:,7), originalCoordinatesv2(:,14), originalCoordinatesv2(:,21), originalCoordinatesv2(:,28),
originalCoordinatesv2(:,35), originalCoordinatesv2(:,42));
%% Create a final table of all saturation values
% saturationtotal = [saturationLong1 saturationLong2 saturationLong3];
%% Remove rows with 0's
% saturationtotalwithoutzeros = saturationtotal(all(saturationtotal,2).:);
%% Use a random index to fill in saturation in the table in a random way
% for l=2:369
%     j = 4;
%     for b=1:7
%         randomIndex1 = randsample(1534,1);
%         disp(randomIndex1);
%         if originalCoordinatesv2(1,b+j) ~= 0
%             coordinateRandomTable(1,b+j)= saturationtotalwithoutzeros(randomIndex1,1);
%             coordinateRandomTable(1,b+j+1)= saturationtotalwithoutzeros(randomIndex1,2);
%             coordinateRandomTable(1,b+j+2)= saturationtotalwithoutzeros(randomIndex1,3);
%         end
%         j = j+6;
%     end
% end
tableNew = array2table(coordinateRandomTable,... %Create new table
    'VariableNames',{'A1ordered', 'A1normdistrnd', 'X1','Y1','S11','S12','S13','A12ordered', 'A2normdistrnd', 'X2','Y2','S21','S22','S23','A3ordered',
'A3normdistrnd', 'X3','Y3','S31','S32','S33','A4ordered', 'A4normdistrnd', 'X4','Y4','S41','S42','S43','A5ordered', 'A5normdistrnd',
'X5','Y5','S51','S52','S53','A6ordered', 'A6normdistrnd', 'X6','Y6','S61','S62','S63','A7ordered', 'A7normdistrnd', 'X7','Y7','S71','S72','S73'});
writetable(tableNew,'coordinateRandomTable.csv'); % Save table as CSV
save("100FramesTrackingBlobs.mat","T"); %Save table as .mat

```

## Appendix L – MATLAB script: Creating the video for the non-natural stimulus

```

% RECREATING NON-NATURAL MOVEMENTS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear; close all;
% LOAD THE COORDINATE RANDOM TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 49);
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1ordered", "A1normdistrnd", "X1", "Y1", "S11", "S12", "S13", "A12ordered", "A2normdistrnd",
"X2", "Y2", "S21", "S22", "S23", "A3ordered", "A3normdistrnd", "X3", "Y3", "S31", "S32", "S33", "A4ordered", "A4normdistrnd",
"X4", "Y4", "S41", "S42", "S43", "A5ordered", "A5normdistrnd", "X5", "Y5", "S51", "S52", "S53", "A6ordered", "A6normdistrnd",
"X6", "Y6", "S61", "S62", "S63", "A7ordered", "A7normdistrnd", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
coordinateRandomTable = readtable("coordinateRandomTable.csv", opts); % Import the data
clear opts % Clear temporary variables
% LOAD THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 42);
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S11", "S12", "S13", "A2", "X2", "Y2", "S21", "S22", "S23", "A3", "X3", "Y3", "S31", "S32", "S33", "A4", "X4",
"Y4", "S41", "S42", "S43", "A5", "X5", "Y5", "S51", "S52", "S53", "A6", "X6", "Y6", "S61", "S62", "S63", "A7", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinatesv2 = readtable("originalCoordinatesv2.csv", opts); % Import the data depending on which variable %from which table to use, adapt in code
below. Note that the originalCoordinatesv2 table has more columns than the %coordinate random table, so next to the name of the table in the code, the index
needs to be adapted as well.
% PREPARING THE SATURATION DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Blob1
FramesSaturationBlob1 = [coordinateRandomTable(:,5), coordinateRandomTable(:,6),coordinateRandomTable(:,7)];
RGBBlob1 = table2array(FramesSaturationBlob1); %set from table to array
RGBMatlabBlob10 = RGBBlob1./(255); %so that Matlab understands the colors
Gray1 = rgb2gray(RGBMatlabBlob10); %set colors to gray
%This code is used to loop:
%flipRGB1 = flip(Gray1);
%RGB11 = cat(1,Gray1,flipRGB1);
RGB11 = cat(1,Gray1,Gray1);
RGBMatlabBlob1= cat(1, RGB11);
RGBMatlabBlob11 = cat(1,RGBMatlabBlob1, RGBMatlabBlob1);
%Blob2
FramesSaturationBlob2 = [coordinateRandomTable(:,12), coordinateRandomTable(:,13),coordinateRandomTable(:,14)];
RGBBlob2 = table2array(FramesSaturationBlob2);
RGBMatlabBlob20 = RGBBlob2./(255);
Gray2 = rgb2gray(RGBMatlabBlob20);
RGB21 = cat(1,Gray2,Gray2);
RGBMatlabBlob2= cat(1, RGB21);
RGBMatlabBlob22 = cat(1,RGBMatlabBlob2, RGBMatlabBlob2);
%Blob3
FramesSaturationBlob3 = [coordinateRandomTable(:,19), coordinateRandomTable(:,20),coordinateRandomTable(:,21)];
RGBBlob3 = table2array(FramesSaturationBlob3);
RGBMatlabBlob30 = RGBBlob3./(255);
Gray3 = rgb2gray(RGBMatlabBlob30);
RGB31 = cat(1,Gray3,Gray3);
RGBMatlabBlob3= cat(1, RGB31);
RGBMatlabBlob33 = cat(1,RGBMatlabBlob3, RGBMatlabBlob3);
%Blob4
FramesSaturationBlob4 = [coordinateRandomTable(:,26), coordinateRandomTable(:,27),coordinateRandomTable(:,28)];
RGBBlob4 = table2array(FramesSaturationBlob4);
RGBMatlabBlob40 = RGBBlob4./(255);
Gray4 = rgb2gray(RGBMatlabBlob40);
RGB41 = cat(1,Gray4,Gray4);
RGBMatlabBlob4= cat(1, RGB41);
RGBMatlabBlob44 = cat(1,RGBMatlabBlob4, RGBMatlabBlob4);
%Blob5
FramesSaturationBlob5 = [coordinateRandomTable(:,33), coordinateRandomTable(:,34),coordinateRandomTable(:,35)];
RGBBlob5 = table2array(FramesSaturationBlob5);
RGBMatlabBlob50 = RGBBlob5./(255);
Gray5 = rgb2gray(RGBMatlabBlob50);
RGB51 = cat(1,Gray5,Gray5);
RGBMatlabBlob5= cat(1, RGB51);

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RGBMatlabBlob55 = cat(1,RGBMatlabBlob5, RGBMatlabBlob5);
%Blob6
FramesSaturationBlob6 = [coordinateRandomTable(:,40), coordinateRandomTable(:,41),coordinateRandomTable(:,42)];
RGBBlob6 = table2array(FramesSaturationBlob6);
RGBMatlabBlob60 = RGBBlob6./(255);
Gray6 = rgb2gray(RGBMatlabBlob60);
RGB61 = cat(1,Gray6,Gray6);
RGBMatlabBlob6= cat(1, RGB61);
RGBMatlabBlob66 = cat(1,RGBMatlabBlob6, RGBMatlabBlob6);
%Blob7
FramesSaturationBlob7 = [coordinateRandomTable(:,47), coordinateRandomTable(:,48),coordinateRandomTable(:,49)];
RGBBlob7 = table2array(FramesSaturationBlob7);
RGBMatlabBlob70 = RGBBlob7./(255);
Gray7 = rgb2gray(RGBMatlabBlob70);
RGB71 = cat(1,Gray7,Gray7);
RGBMatlabBlob7= cat(1, RGB71);
RGBMatlabBlob77 = cat(1,RGBMatlabBlob7, RGBMatlabBlob7);
% PREPARING THE AREA DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Blob1
Area1 = coordinateRandomTable(:,1);
Area1 = table2array(Area1);
radiusCircle10 = sqrt(Area1/3.14159265359)*0.5; %to calculate the radius, with only knowing the area. Factor of 0.5 used to fit into frame.
% Used for loop:
%flip1 = flip(radiusCircle10);
radiusCircle11 = cat(1,radiusCircle10,radiusCircle10);
radiusCircle1 = cat(1, radiusCircle11,radiusCircle11);
%Blo2
Area2 = coordinateRandomTable(:,8);
Area2 = table2array(Area2);
radiusCircle20 = sqrt(Area2/3.14159265359)*0.5;
radiusCircle21 = cat(1,radiusCircle20,radiusCircle20);
radiusCircle2 = cat(1, radiusCircle21,radiusCircle21);
%Blo3
Area3 = coordinateRandomTable(:,15);
Area3 = table2array(Area3);
radiusCircle30 = sqrt(Area3/3.14159265359)*0.5;
radiusCircle31 = cat(1,radiusCircle30,radiusCircle30);
radiusCircle3 = cat(1, radiusCircle31,radiusCircle31);
%Blo4
Area4 = coordinateRandomTable(:,22);
Area4 = table2array(Area4);
radiusCircle40 = sqrt(Area4/3.14159265359)*0.5;
radiusCircle41 = cat(1,radiusCircle40,radiusCircle40);
radiusCircle4 = cat(1, radiusCircle41,radiusCircle41);
%Blo5
Area5 = coordinateRandomTable(:,29);
Area5 = table2array(Area5);
radiusCircle50 = sqrt(Area5/3.14159265359)*0.5;
radiusCircle51 = cat(1,radiusCircle50,radiusCircle50);
radiusCircle5 = cat(1, radiusCircle51,radiusCircle51);
%Blo6
Area6 = coordinateRandomTable(:,36);
Area6 = table2array(Area6);
radiusCircle60 = sqrt(Area6/3.14159265359)*0.5;
radiusCircle61 = cat(1,radiusCircle60,radiusCircle60);
radiusCircle6 = cat(1, radiusCircle61,radiusCircle61);
%Blob7
Area7 = coordinateRandomTable(:,43);
Area7 = table2array(Area7);
radiusCircle70 = sqrt(Area7/3.14159265359)*0.5;
radiusCircle71 = cat(1,radiusCircle70,radiusCircle70);
radiusCircle7 = cat(1, radiusCircle71,radiusCircle71);
% PREPARING THE COORDINATES DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% CIRCLE 1
x1coordinates0 = coordinateRandomTable(:,3); % coordinates x
x1coordinates0 = table2array(x1coordinates0);
y1coordinates0= coordinateRandomTable(:,4); % coordinates y
y1coordinates0 = table2array(y1coordinates0);
%Used for loop:
flipx1 = flip(x1coordinates0);
flipy1 = flip(y1coordinates0);
x1coordinates1 = cat(1,x1coordinates0,flipx1);
y1coordinates1 = cat(1, y1coordinates0,flipy1);
x1coordinates = cat(1, x1coordinates1,x1coordinates1);
y1coordinates = cat(1, y1coordinates1,y1coordinates1);
x10 = x1coordinates(1,:); % x centre of circle
y10 = y1coordinates(1,:); % y centre of circle
% CIRCLE 2
x2coordinates0 = coordinateRandomTable(:,10); % coordinates x
x2coordinates0 = table2array(x2coordinates0);
y2coordinates0 = coordinateRandomTable(:,11); % coordinates y
y2coordinates0 = table2array(y2coordinates0);
flipx2 = flip(x2coordinates0);
flipy2 = flip(y2coordinates0);

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x2coordinates1 = cat(1,x2coordinates0,flipx2);
y2coordinates1 = cat(1, y2coordinates0,flipy2);
x2coordinates = cat(1, x2coordinates1,x2coordinates1);
y2coordinates = cat(1, y2coordinates1,y2coordinates1);
x20 = x2coordinates(1,:);    % x centre of circle
y20 = y2coordinates(1,:);    % y centre of circle
%CIRCLE 3
x3coordinates0 = coordinateRandomTable(:,17); % coordinates x
x3coordinates0 = table2array(x3coordinates0);
y3coordinates0= coordinateRandomTable(:,18); % coordinates y
y3coordinates0 = table2array(y3coordinates0);
flipx3 = flip(x3coordinates0);
flipy3 = flip(y3coordinates0);
x3coordinates1 = cat(1,x3coordinates0,flipx3);
y3coordinates1 = cat(1,y3coordinates0,flipy3);
x3coordinates = cat(1, x3coordinates1,x3coordinates1);
y3coordinates = cat(1, y3coordinates1,y3coordinates1);
x30 = x3coordinates(1,:);    % x centre of circle
y30 = y3coordinates(1,:);    % y centre of circle
%CIRCLE 4
x4coordinates0 = coordinateRandomTable(:,24); % coordinates x
x4coordinates0 = table2array(x4coordinates0);
y4coordinates0= coordinateRandomTable(:,25); % coordinates y
y4coordinates0 = table2array(y4coordinates0);
flipx4 = flip(x4coordinates0);
flipy4 = flip(y4coordinates0);
x4coordinates1 = cat(1,x4coordinates0,flipx4);
y4coordinates1 = cat(1, y4coordinates0,flipy4);
x4coordinates = cat(1, x4coordinates1,x4coordinates1);
y4coordinates = cat(1, y4coordinates1,y4coordinates1);
x40 = x4coordinates(1,:);    % x centre of circle
y40 = y4coordinates(1,:);    % y centre of circle
%CIRCLE 5
x5coordinates0 = coordinateRandomTable(:,31); % coordinates x
x5coordinates0 = table2array(x5coordinates0);
y5coordinates0= coordinateRandomTable(:,32); % coordinates y
y5coordinates0 = table2array(y5coordinates0);
flipx5 = flip(x5coordinates0);
flipy5 = flip(y5coordinates0);
x5coordinates1 = cat(1,x5coordinates0,flipx5);
y5coordinates1 = cat(1, y5coordinates0,flipy5);
x5coordinates = cat(1, x5coordinates1,x5coordinates1);
y5coordinates = cat(1, y5coordinates1,y5coordinates1);
x50 = x5coordinates(1,:);    % x centre of circle
y50 = y5coordinates(1,:);    % y centre of circle
%CIRCLE 6
x6coordinates0 = coordinateRandomTable(:,38); % coordinates x
x6coordinates0 = table2array(x6coordinates0);
y6coordinates0= coordinateRandomTable(:,39); % coordinates y
y6coordinates0 = table2array(y6coordinates0);
flipx6 = flip(x6coordinates0);
flipy6 = flip(y6coordinates0);
x6coordinates1 = cat(1,x6coordinates0,flipx6);
y6coordinates1 = cat(1, y6coordinates0,flipy6);
x6coordinates = cat(1, x6coordinates1,x6coordinates1);
y6coordinates = cat(1, y6coordinates1,y6coordinates1);
x60 = x6coordinates(1,:);    % x centre of circle
y60 = y6coordinates(1,:);    % y centre of circle
%CIRCLE 7
x7coordinates0 = coordinateRandomTable(:,45); % coordinates x
x7coordinates0 = table2array(x7coordinates0);
y7coordinates0= coordinateRandomTable(:,46); % coordinates y
y7coordinates0 = table2array(y7coordinates0);
flipx7 = flip(x7coordinates0);
flipy7 = flip(y7coordinates0);
x7coordinates1 = cat(1,x7coordinates0,flipx7);
y7coordinates1 = cat(1, y7coordinates0,flipy7);
x7coordinates = cat(1, x7coordinates1,x7coordinates1);
y7coordinates = cat(1, y7coordinates1,y7coordinates1);
x70 = x7coordinates(1,:);    % x centre of circle
y70 = y7coordinates(1,:);    % y centre of circle
N = 100;    % number of points used to define circle
radius = 1;
theta = linspace(0,2*pi,N); % create equal length arrays defining a circle in polar coordinates
r = radius * ones(1,N);
area = pi * radius^2;
[x1, y1] = pol2cart(theta, r); % convert polar coordinates to Cartesian coordinates
[x2, y2] = pol2cart(theta, r);
[x3, y3] = pol2cart(theta, r);
[x4, y4] = pol2cart(theta, r);
[x5, y5] = pol2cart(theta, r);
[x6, y6] = pol2cart(theta, r);
[x7, y7] = pol2cart(theta, r);
x1 = x1 + x10;    % offset the circle so its centre lies at (x0, y0)
y1 = y1 + y10;
x2 = x2 + x20;    % offset the circle so its centre lies at (x0, y0)

```

```

y2 = y2 + y20;
x3 = x3 + x30;    % offset the circle so its centre lies at (x0, y0)
y3 = y3 + y30;
x4 = x4 + x40;    % offset the circle so its centre lies at (x0, y0)
y4 = y4 + y40;
x5 = x5 + x50;    % offset the circle so its centre lies at (x0, y0)
y5 = y5 + y50;
x6 = x6 + x60;    % offset the circle so its centre lies at (x0, y0)
y6 = y6 + y60;
x7 = x7 + x70;    % offset the circle so its centre lies at (x0, y0)
y7 = y7 + y70;
% CREATING VIDEO
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
myVideo = VideoWriter('SunLightBlobsWithAreaColorBrightnessFaster');
myVideo.FrameRate = 28;
open(myVideo)
for i = 1:length(x1coordinates)
    cla()
    set(0,'defaultfigurecolor',[0 0 0])
    set(gca,'color',[0 0 0], 'ydir', 'reverse');
    xlabel('x')    % label axes
    ylabel('y')
    axis equal    % equal axis scaling so our circle looks circular
    xlim([ 50 1000]);    % set plot limits
    ylim([-50 1000]);
    Ax = gca;
    Ax.Color = 'k';
    Ax.XColor = 'none';
    Ax.YColor = 'none';
    %set(gca,'color',[0 0 0]);
    % if using radius from existing table instead of default 20, use this: radiusCircle7(i) (adjust number)
    % if using saturation from existing table instead of default 'w', use this: RGBMatlabBlob77(i,:) (adjust number)
    if radiusCircle1(i) > 0 %Draw blob 1
        f = plot(x1coordinates(i), y1coordinates(i),'o','MarkerSize', radiusCircle1(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w'); % plot as circle
        hold on;
    end
    if radiusCircle2(i) > 0 %Draw blob 2
        g = plot(x2coordinates(i), y2coordinates(i),'o','MarkerSize', radiusCircle2(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor','w'); %plot as circle
        hold on;
    end
    if radiusCircle3(i) > 0 %Draw blob 3
        h = plot(x3coordinates(i), y3coordinates(i),'o','MarkerSize', radiusCircle3(i), 'MarkerFaceColor','w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle4(i) > 0 %Draw blob 4
        l = plot(x4coordinates(i), y4coordinates(i),'o','MarkerSize', radiusCircle4(i), 'MarkerFaceColor','w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle5(i) > 0 %Draw blob 5
        j = plot(x5coordinates(i), y5coordinates(i),'o','MarkerSize', radiusCircle5(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle6(i) > 0 %Draw blob 6
        p = plot(x6coordinates(i), y6coordinates(i),'o','MarkerSize', radiusCircle6(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle7(i) > 0 %Draw blob 7
        q = plot(x7coordinates(i), y7coordinates(i),'o','MarkerSize', radiusCircle7(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    axis off
    pause(0.1);
    if i>1 % Start from second frame to avoid problematic first frame
        frame = getframe(gcf);    % saveas(gcf,sprintf('/FRAMES_UNNATURAL/%i.png',i));
        writeVideo(myVideo,frame);
    end
end
close(myVideo)

```



## Appendix M – MATLAB script: Calculating the mean area of light patches

```

% CALCULATING MEAN BLOB AREA & NUMBER AND SELECTING THE CLOSEST FRAME
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear; close all;
% LOAD THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 42);
opts.DataLines = [2, Inf]; % Specify range
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S11", "S12", "S13", "A2", "X2", "Y2", "S21", "S22", "S23", "A3", "X3", "Y3", "S31", "S32", "S33", "A4", "X4",
"Y4", "S41", "S42", "S43", "A5", "X5", "Y5", "S51", "S52", "S53", "A6", "X6", "Y6", "S61", "S62", "S63", "A7", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinatesv2 = readtable("originalCoordinatesv2.csv", opts); % Import the data
% Add the total area of blobs per frame in the table
originalCoordinatesv2.total_area = originalCoordinatesv2.A1 + originalCoordinatesv2.A2 + originalCoordinatesv2.A3 + originalCoordinatesv2.A4 +
originalCoordinatesv2.A5 + originalCoordinatesv2.A6 + originalCoordinatesv2.A7;
% Calculate mean, max, min, median of total area of all blobs per frame
mean_total_area_all_blobs = mean(originalCoordinatesv2.total_area);
max_total_area_all_blobs = max(originalCoordinatesv2.total_area);
min_total_area_all_blobs = min(originalCoordinatesv2.total_area);
median_total_area_all_blobs = median(originalCoordinatesv2.total_area);
% Calculate number of blobs with non-zero area (= visible blobs) per frame and add to table
for i=1:height(originalCoordinatesv2)
originalCoordinatesv2.n_blobs(i) = nnz([originalCoordinatesv2.A1(i) originalCoordinatesv2.A2(i) originalCoordinatesv2.A3(i) originalCoordinatesv2.A4(i)
originalCoordinatesv2.A5(i) originalCoordinatesv2.A6(i) originalCoordinatesv2.A7(i)]);
end
% Calculate mean, max, min, median number of blobs per frame and round it (integer)
mean_number_all_blobs = round(mean(originalCoordinatesv2.n_blobs), 0);
max_number_all_blobs = round(max(originalCoordinatesv2.n_blobs), 0);
min_number_all_blobs = round(min(originalCoordinatesv2.n_blobs), 0);
median_number_all_blobs = round(median(originalCoordinatesv2.n_blobs), 0);
% Find table element with the closest total area to the mean total area
[minValue,closestIndex] = min(abs(originalCoordinatesv2.total_area(:) - mean_total_area_all_blobs));
originalCoordinatesv2.n_blobs(closestIndex) % Find number of blobs for that table element (frame 358)

```

## Appendix N – MATLAB script: Creating the static stimulus

```

clear; close all;
% LOAD THE ORIGINAL COORDINATES V2 TABLE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
control_frame = 358;
% Set up the Import Options and import the data
opts = delimitedTextImportOptions("NumVariables", 42);
opts.DataLines = [2, Inf]; % Specify range and delimiter
opts.Delimiter = ","; % Specify delimiter
% Specify column names and types
opts.VariableNames = ["A1", "X1", "Y1", "S11", "S12", "S13", "A2", "X2", "Y2", "S21", "S22", "S23", "A3", "X3", "Y3", "S31", "S32", "S33", "A4", "X4",
"Y4", "S41", "S42", "S43", "A5", "X5", "Y5", "S51", "S52", "S53", "A6", "X6", "Y6", "S61", "S62", "S63", "A7", "X7", "Y7", "S71", "S72", "S73"];
opts.VariableTypes = ["double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double",
"double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double", "double"];
opts.ExtraColumnsRule = "ignore"; % Specify file level properties
opts.EmptyLineRule = "read";
originalCoordinatesv2 = readtable("originalCoordinatesv2.csv", opts); % Import the data
clear opts % Clear temporary variables
% PREPARING THE SATURATION DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Blob1
FramesSaturationBlob1 = [originalCoordinatesv2(:,4), originalCoordinatesv2(:,5),originalCoordinatesv2(:,6)];
RGBBlob1 = table2array(FramesSaturationBlob1); %set from table to array
RGBMatlabBlob10 = RGBBlob1./(255); %so that Matlab understands the colors
Gray1 = rgb2gray(RGBMatlabBlob10); %set colors to gray
%To create the loop
flipRGB1 = flip(Gray1);
RGB11 = cat(1,Gray1,flipRGB1);
RGBMatlabBlob1= cat(1, RGB11);
RGBMatlabBlob11 = cat(1,RGBMatlabBlob1, RGBMatlabBlob1);
%Blob2
FramesSaturationBlob2 = [originalCoordinatesv2(:,10), originalCoordinatesv2(:,11),originalCoordinatesv2(:,12)];
RGBBlob2 = table2array(FramesSaturationBlob2);
RGBMatlabBlob20 = RGBBlob2./(255);
Gray2 = rgb2gray(RGBMatlabBlob20);
%To create the loop
flipRGB2 = flip(Gray2);
RGB21 = cat(1,Gray2,flipRGB2);
RGBMatlabBlob2= cat(1, RGB21);
RGBMatlabBlob22 = cat(1,RGBMatlabBlob2, RGBMatlabBlob2);
%Blob3
FramesSaturationBlob3 = [originalCoordinatesv2(:,16), originalCoordinatesv2(:,17),originalCoordinatesv2(:,18)];
RGBBlob3 = table2array(FramesSaturationBlob3);
RGBMatlabBlob30 = RGBBlob3./(255);
Gray3 = rgb2gray(RGBMatlabBlob30);
flipRGB3 = flip(Gray3);
RGB31 = cat(1,Gray3,flipRGB3);
RGBMatlabBlob3= cat(1, RGB31);
RGBMatlabBlob33 = cat(1,RGBMatlabBlob3, RGBMatlabBlob3);
%Blob4
FramesSaturationBlob4 = [originalCoordinatesv2(:,22), originalCoordinatesv2(:,23),originalCoordinatesv2(:,24)];
RGBBlob4 = table2array(FramesSaturationBlob4);
RGBMatlabBlob40 = RGBBlob4./(255);
Gray4 = rgb2gray(RGBMatlabBlob40);
flipRGB4 = flip(Gray4);
RGB41 = cat(1,Gray4,flipRGB4);
RGBMatlabBlob4= cat(1, RGB41);
RGBMatlabBlob44 = cat(1,RGBMatlabBlob4, RGBMatlabBlob4);
%Blob5
FramesSaturationBlob5 = [originalCoordinatesv2(:,28), originalCoordinatesv2(:,29),originalCoordinatesv2(:,30)];
RGBBlob5 = table2array(FramesSaturationBlob5);
RGBMatlabBlob50 = RGBBlob5./(255);
Gray5 = rgb2gray(RGBMatlabBlob50);
flipRGB5 = flip(Gray5);
RGB51 = cat(1,Gray5,flipRGB5);
RGBMatlabBlob5= cat(1, RGB51);
RGBMatlabBlob55 = cat(1,RGBMatlabBlob5, RGBMatlabBlob5);
%Blob6
FramesSaturationBlob6 = [originalCoordinatesv2(:,34), originalCoordinatesv2(:,35),originalCoordinatesv2(:,36)];
RGBBlob6 = table2array(FramesSaturationBlob6);
RGBMatlabBlob60 = RGBBlob6./(255);
Gray6 = rgb2gray(RGBMatlabBlob60);
flipRGB6 = flip(Gray6);
RGB61 = cat(1,Gray6,flipRGB6);
RGBMatlabBlob6= cat(1, RGB61);
RGBMatlabBlob66 = cat(1,RGBMatlabBlob6, RGBMatlabBlob6);
%Blob7
FramesSaturationBlob7 = [originalCoordinatesv2(:,40), originalCoordinatesv2(:,41),originalCoordinatesv2(:,42)];
RGBBlob7 = table2array(FramesSaturationBlob7);
RGBMatlabBlob70 = RGBBlob7./(255);
Gray7 = rgb2gray(RGBMatlabBlob70);
flipRGB7 = flip(Gray7);
RGB71 = cat(1,Gray7,flipRGB7);

```

```

RGBMatlabBlob7= cat(1, RGB71);
RGBMatlabBlob77 = cat(1,RGBMatlabBlob7, RGBMatlabBlob7);
% PREPARING THE AREA DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Blob1
Area1 = originalCoordinatesv2(:,1);
Area1 = table2array(Area1);
radiusCircle10 = sqrt((Area1/3.14159265359)*0.5); %to calculate the radius, with only knowing the area. Factor of 0.5 used to fit into frame.
% Used for loop:
flip1 = flip(radiusCircle10);
radiusCircle11 = cat(1,radiusCircle10,flip1);
radiusCircle1 = cat(1, radiusCircle11,radiusCircle11);
%Blob2
Area2 = originalCoordinatesv2(:,7);
Area2 = table2array(Area2);
radiusCircle20 = sqrt((Area2/3.14159265359)*0.5);
flip2 = flip(radiusCircle20);
radiusCircle21 = cat(1,radiusCircle20,flip2);
radiusCircle22 = cat(1, radiusCircle21);
radiusCircle2 = cat(1, radiusCircle22,radiusCircle22);
%Blob3
Area3 = originalCoordinatesv2(:,13);
Area3 = table2array(Area3);
radiusCircle30 = sqrt((Area3/3.14159265359)*0.5);
flip3 = flip(radiusCircle30);
radiusCircle31 = cat(1,radiusCircle30,flip3);
radiusCircle33 = cat(1, radiusCircle31);
radiusCircle3 = cat(1, radiusCircle33,radiusCircle33);
%Blob4
Area4 = originalCoordinatesv2(:,19);
Area4 = table2array(Area4);
radiusCircle40 = sqrt((Area4/3.14159265359)*0.5);
flip4 = flip(radiusCircle40);
radiusCircle41 = cat(1,radiusCircle40,flip4);
radiusCircle44 = cat(1, radiusCircle41);
radiusCircle4 = cat(1, radiusCircle44,radiusCircle44);
%Blob5
Area5 = originalCoordinatesv2(:,25);
Area5 = table2array(Area5);
radiusCircle50 = sqrt((Area5/3.14159265359)*0.5);
flip5 = flip(radiusCircle50);
radiusCircle51 = cat(1,radiusCircle50,flip5);
radiusCircle55 = cat(1, radiusCircle51);
radiusCircle5 = cat(1, radiusCircle55,radiusCircle55);
%Blob6
Area6 = originalCoordinatesv2(:,31);
Area6 = table2array(Area6);
radiusCircle60 = sqrt((Area6/3.14159265359)*0.5);
flip6 = flip(radiusCircle60);
radiusCircle61 = cat(1,radiusCircle60,flip6);
radiusCircle66 = cat(1, radiusCircle61);
radiusCircle6 = cat(1, radiusCircle66,radiusCircle66);
%Blob7
Area7 = originalCoordinatesv2(:,37);
Area7 = table2array(Area7);
radiusCircle70 = sqrt((Area7/3.14159265359)*0.5);
flip7 = flip(radiusCircle70);
radiusCircle71 = cat(1,radiusCircle70,flip7);
radiusCircle77 = cat(1, radiusCircle71);
radiusCircle7 = cat(1, radiusCircle77,radiusCircle77);
% PREPARING THE COORDINATES DATA
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%CIRCLE 1
x1coordinates0 = originalCoordinatesv2(:,2); % coordinates x
x1coordinates0 = table2array(x1coordinates0);
y1coordinates0= originalCoordinatesv2(:,3); % coordinates y
y1coordinates0 = table2array(y1coordinates0);
%Used for loops:
flipx1 = flip(x1coordinates0);
flipy1 = flip(y1coordinates0);
x1coordinates1 = cat(1,x1coordinates0,flipx1);
y1coordinates1 = cat(1, y1coordinates0,flipy1);
x1coordinates = cat(1, x1coordinates1,x1coordinates1);
y1coordinates = cat(1, y1coordinates1,y1coordinates1);
x10 = x1coordinates(1,:); % x centre of circle
y10 = y1coordinates(1,:); % y centre of circle
%CIRCLE 2
x2coordinates0 = originalCoordinatesv2(:,8); % coordinates x
x2coordinates0 = table2array(x2coordinates0);
y2coordinates0 = originalCoordinatesv2(:,9); % coordinates y
y2coordinates0 = table2array(y2coordinates0);
flipx2 = flip(x2coordinates0);
flipy2 = flip(y2coordinates0);
x2coordinates1 = cat(1,x2coordinates0,flipx2);
y2coordinates1 = cat(1, y2coordinates0,flipy2);
x2coordinates = cat(1, x2coordinates1,x2coordinates1);

```

```

y2coordinates = cat(1, y2coordinates1, y2coordinates1);
x20 = x2coordinates(1,:); % x centre of circle
y20 = y2coordinates(1,:); % y centre of circle
% CIRCLE 3
x3coordinates0 = originalCoordinatesv2(:,14); % coordinates x
x3coordinates0 = table2array(x3coordinates0);
y3coordinates0 = originalCoordinatesv2(:,15); % coordinates y
y3coordinates0 = table2array(y3coordinates0);
flipx3 = flip(x3coordinates0);
flipy3 = flip(y3coordinates0);
x3coordinates1 = cat(1, x3coordinates0, flipx3);
y3coordinates1 = cat(1, y3coordinates0, flipy3);
x3coordinates = cat(1, x3coordinates1, x3coordinates1);
y3coordinates = cat(1, y3coordinates1, y3coordinates1);
x30 = x3coordinates(1,:); % x centre of circle
y30 = y3coordinates(1,:); % y centre of circle
% CIRCLE 4
x4coordinates0 = originalCoordinatesv2(:,20); % coordinates x
x4coordinates0 = table2array(x4coordinates0);
y4coordinates0 = originalCoordinatesv2(:,21); % coordinates y
y4coordinates0 = table2array(y4coordinates0);
flipx4 = flip(x4coordinates0);
flipy4 = flip(y4coordinates0);
x4coordinates1 = cat(1, x4coordinates0, flipx4);
y4coordinates1 = cat(1, y4coordinates0, flipy4);
x4coordinates = cat(1, x4coordinates1, x4coordinates1);
y4coordinates = cat(1, y4coordinates1, y4coordinates1);
x40 = x4coordinates(1,:); % x centre of circle
y40 = y4coordinates(1,:); % y centre of circle
% CIRCLE 5
x5coordinates0 = originalCoordinatesv2(:,26); % coordinates x
x5coordinates0 = table2array(x5coordinates0);
y5coordinates0 = originalCoordinatesv2(:,27); % coordinates y
y5coordinates0 = table2array(y5coordinates0);
flipx5 = flip(x5coordinates0);
flipy5 = flip(y5coordinates0);
x5coordinates1 = cat(1, x5coordinates0, flipx5);
y5coordinates1 = cat(1, y5coordinates0, flipy5);
x5coordinates = cat(1, x5coordinates1, x5coordinates1);
y5coordinates = cat(1, y5coordinates1, y5coordinates1);
x50 = x5coordinates(1,:); % x centre of circle
y50 = y5coordinates(1,:); % y centre of circle
% CIRCLE 6
x6coordinates0 = originalCoordinatesv2(:,32); % coordinates x
x6coordinates0 = table2array(x6coordinates0);
y6coordinates0 = originalCoordinatesv2(:,33); % coordinates y
y6coordinates0 = table2array(y6coordinates0);
flipx6 = flip(x6coordinates0);
flipy6 = flip(y6coordinates0);
x6coordinates1 = cat(1, x6coordinates0, flipx6);
y6coordinates1 = cat(1, y6coordinates0, flipy6);
x6coordinates = cat(1, x6coordinates1, x6coordinates1);
y6coordinates = cat(1, y6coordinates1, y6coordinates1);
x60 = x6coordinates(1,:); % x centre of circle
y60 = y6coordinates(1,:); % y centre of circle
% CIRCLE 7
x7coordinates0 = originalCoordinatesv2(:,38); % coordinates x
x7coordinates0 = table2array(x7coordinates0);
y7coordinates0 = originalCoordinatesv2(:,39); % coordinates y
y7coordinates0 = table2array(y7coordinates0);
flipx7 = flip(x7coordinates0);
flipy7 = flip(y7coordinates0);
x7coordinates1 = cat(1, x7coordinates0, flipx7);
y7coordinates1 = cat(1, y7coordinates0, flipy7);
x7coordinates = cat(1, x7coordinates1, x7coordinates1);
y7coordinates = cat(1, y7coordinates1, y7coordinates1);
x70 = x7coordinates(1,:); % x centre of circle
y70 = y7coordinates(1,:); % y centre of circle
N = 100; % number of points used to define circle
radius = 1;
theta = linspace(0, 2*pi, N); % create equal length arrays defining a circle in polar coordinates
r = radius * ones(1, N);
area = pi * radius^2;
[x1, y1] = pol2cart(theta, r); % convert polar coordinates to Cartesian coordinates
[x2, y2] = pol2cart(theta, r);
[x3, y3] = pol2cart(theta, r);
[x4, y4] = pol2cart(theta, r);
[x5, y5] = pol2cart(theta, r);
[x6, y6] = pol2cart(theta, r);
[x7, y7] = pol2cart(theta, r);
x1 = x1 + x10; % offset the circle so its centre lies at (x0, y0)
y1 = y1 + y10;
x2 = x2 + x20; % offset the circle so its centre lies at (x0, y0)
y2 = y2 + y20;
x3 = x3 + x30; % offset the circle so its centre lies at (x0, y0)
y3 = y3 + y30;

```

```

x4 = x4 + x40;    % offset the circle so its centre lies at (x0, y0)
y4 = y4 + y40;
x5 = x5 + x50;    % offset the circle so its centre lies at (x0, y0)
y5 = y5 + y50;
x6 = x6 + x60;    % offset the circle so its centre lies at (x0, y0)
y6 = y6 + y60;
x7 = x7 + x70;    % offset the circle so its centre lies at (x0, y0)
y7 = y7 + y70;
% CREATE IMAGE FOR CONTROL CONDITION
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i = 356:control_frame
    cla()
    set(gca,'color',[0 0 0], 'ydir', 'reverse');
    set(0,'defaultfigurecolor',[0 0 0])
    xlabel('x')    % label axes
    ylabel('y')
    axis equal    % equal axis scaling so our circle looks circular
    xlim([ 50 1000]);    % set plot limits
    ylim([-50 1000]);
    Ax = gca;
    Ax.Color = 'k';
    Ax.XColor = 'none';
    Ax.YColor = 'none';
    % set(gca,'color',[0 0 0]);
    % if using radius from existing table instead of default 20, use this:
    % radiusCircle7(i) (adjust number)
    % if using saturation from existing table instead of default 'w', use
    % this: RGBMatlabBlob77(i,:) (adjust number)
    if radiusCircle1(i) > 0    %Draw blob 1
        f = plot(x1coordinates(i), y1coordinates(i),'o','MarkerSize', radiusCircle1(i), 'MarkerFaceColor','w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle2(i) > 0    %Draw blob 2
        g = plot(x2coordinates(i), y2coordinates(i),'o','MarkerSize', radiusCircle2(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');
        hold on;
    end
    if radiusCircle3(i) > 0    %Draw blob 3
        h = plot(x3coordinates(i), y3coordinates(i),'o','MarkerSize', radiusCircle3(i), 'MarkerFaceColor','w', 'MarkerEdgeColor','w');    % plot as circle
        hold on;
    end
    if radiusCircle4(i) > 0    %Draw blob 4
        l = plot(x4coordinates(i), y4coordinates(i),'o','MarkerSize', radiusCircle4(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle5(i) > 0    %Draw blob 5
        j = plot(x5coordinates(i), y5coordinates(i),'o','MarkerSize', radiusCircle5(i), 'MarkerFaceColor','w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle6(i) > 0    %Draw blob 6
        p = plot(x6coordinates(i), y6coordinates(i),'o','MarkerSize', radiusCircle6(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    if radiusCircle7(i) > 0    %Draw blob 7
        q = plot(x7coordinates(i), y7coordinates(i),'o','MarkerSize', radiusCircle7(i), 'MarkerFaceColor', 'w', 'MarkerEdgeColor', 'w');    % plot as circle
        hold on;
    end
    axis off
    saveas(gcf, sprintf('%i.png',i));
end

```

### Appendix O – Reflection factor of objects in laboratory

<b>Location</b>	<b>Reflection Factor</b>
Desk	65.73%
Right Wall (from participants' perspective)	82.43%
Left Wall (from participants' perspective)	84.14%
Floor	26.50%
Chair	11.38%
Curtain	83.70%
Ceiling	88.56%
Laptop screen (during baseline measurements)	1.04%
Laptop screen (when turned off)	2.03%
Light patch on the wall during static condition (projector turned on)	84.80%

*Table O1. Reflection factor of the objects in area B of the laboratory. Note that the projector was turned off during the measurements, unless stated otherwise.*

## Appendix P – Final Questionnaire

Concept	Item	Answer
Stressfulness	<i>The projected light is stressful.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Excitement	<i>The projected light is exciting.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Preference	<i>I liked the projected light.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Fascination	<i>The project light is fascinating.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Relaxation	<i>The projected light is relaxing.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Distraction	<i>The projected light is distracting.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Interest	<i>The projected light is interesting.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Complexity	<i>The projected light is complex.</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Association with nature	<i>The projected light reminds me of nature</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Association with sunlight	<i>The projected light reminds me of sunlight</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Work environment	<i>It would be pleasant to have this projected light in my work environment</i>	Likert scale: 0 (Not at all) – 10 (Very much)
Demographics	<i>Gender</i>	Choice: male, female, non-binary
	<i>Age (in years)</i>	Open question
Final remarks	<i>Do you have additional remarks about the experiment?</i>	Open question

*Table P1. Summary of subjective measures in the final questionnaire. Note that the concepts ‘association with nature’ and ‘fascination’ in the final questionnaire are part of the main focus of this study. The other concepts were used for exploratory analysis.*