MSc Interaction Technology Thesis

Exploring the mediation of emotional state on the influence of ambient light on eating behaviour

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Contents

Abstract

Supporting healthy eating is a topic that has great social relevance. As eating behaviour has been proven to be influenced by physical environment and ambient light, this field is widely researched. The process behind the influence of light on eating behaviour is widely hypothesized to be caused by a mediating or moderating effect of emotional state, but this has not been confirmed by many studies. The current study researched the extent to which emotional state mediated the influence of ambient light on eating behaviour of healthy and unhealthy snacks. To do so, two studies were designed. In Study 1, 120 online participants rated photographs of healthy and unhealthy snacks illuminated by light varying in illuminance level (35 lx versus 300 lx) and colour temperature (2700K versus 6000K). A mediating and moderating effect of valence of emotional state was found on the influence of illuminance level on liking of appearance of snacks. This effect was researched more in depth in Study 2, in which 40 participants rated and ate an unhealthy snack in both bright (300 lx) and dim (35 lx) light. From this, only a moderating effect of valence of emotional state on the influence of illuminance level on liking of appearance was found. The nature of these mediations and moderations, as well as the difference between the two studies, might be due to differences in study design, participants (unbeknownst to the researcher) might be either emotional eaters or not, and a difference might exist between healthy and unhealthy snacks. For a better understanding of the effect, research with long-term exposure with higher ecological validity and a manipulation of emotional state is recommended.

Acknowledgements

Before you lies the thesis “Exploring the mediation of emotional state on the influence of ambient light on eating behaviour”, a piece that attempts to enrich the field of eating behaviour research and support healthy eating. This thesis is the final piece of my master’s, Interaction Technology, at the University of Twente. For the past half year, I have been researching and writing this thesis. This has been challenging at times, especially considering the global pandemic that started in 2020. Not only did it limit the practical possibilities of research, but it especially limited the social contact with my supervisors and peers. I am however proud of the outcome of this research: the topic has captured and motivated me to such an extent that it overcame most of the difficulties of social distancing.

This thesis could not have been completed, or even started, without the exceptional guidance and contribution of many different people. First, I would like to thank my supervisors, Juliet Haarman and Roelof de Vries. You have always motivated and guided me with such positivity, that it would have been impossible not to enjoy doing this research. Your feedback and help during our weekly meetings motivated me to keep pushing forward and your knowledge and expertise greatly contributed to the final thesis. I am not exaggerating when I say that your supervision exceeds all others (and I have been supervised a lot!). I also want to express my gratitude towards Dirk Heylen and Cristina Zaga, who have agreed to join my examination committee. A big thanks to all 160 participants of both my studies: without you, this research would not have been possible. Finally, I would like to thank my parents, Yolande Kanbier and Emil Tutuarima, my sister, Madelief Kanbier, and my partner, Dani Verhaar, who always knew it was going to be fine, even if I doubted myself. They have always supported me along the way.

1. Introduction

1.1. Motivation

The World Health Organization reports that in 2018, 39% of adults were overweight and 13% were obese, while 41 million children younger than five years were overweight or obese and even 340 million at the age of 5-19 were overweight or obese (2018). Overweight and a too high BMI lead to an array of health risks and should thus be avoided if possible. One way to facilitate this is through healthy eating (Nicklas et al., 2001), e.g., following a consistent pattern of eating a variety of foods that provide nutrition necessary for maintaining health and feeling good and energetic. Researching eating behaviour and promoting healthy eating has thus been an important area for researchers. While some people try to achieve healthy eating by following guidelines, changes in eating behaviour are not easy to achieve. To promote healthy eating behaviour, many different intervention possibilities for different demographics have been investigated, from policy changes (such as promoting a plenary healthy eating program in a certain environment, Korwanich et al., 2008; Woynarowska et al., 2011) to gamification (e.g., smartphone apps rewarding healthy eating with prizes and competing in leader boards, Edwards et al., 2016).

Eating behaviour is the whole process from seeing food to digesting it, or in other words: the process between the sensory perception of food and the nutritional status (e.g., the physiological state of an individual resulting from the intake, absorption and use of nutrition (Maastricht UMC+, n.d.)) (Drewnowski, 1997). This process of eating behaviour is mediated by many different other processes, namely: sensory perception (seeing the food and perceiving its visual properties, such as food colour), hedonic response (the liking or disliking of a food), food preferences (attitudinal and behavioural measures, often learned associations), food choice (the selection of food), food intake (the act of eating a specific quantity of the chosen food) and finally nutritional status (the long term result of the previous steps, determining the status of the body) (Drewnowski, A., 1997). This sequential chain of eating behaviour is visualised in Figure 1.

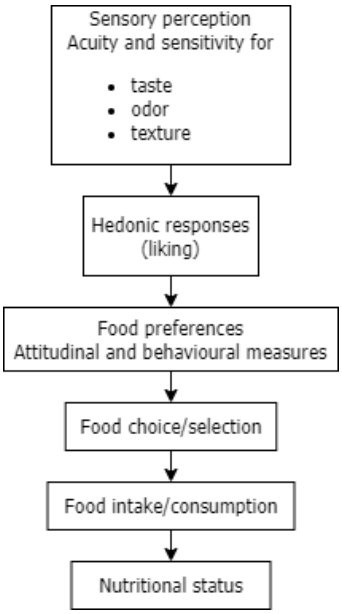

Figure 1. *Variables Mediating Eating Behaviour. This figure depicts the flowchart of variables intervening between taste function and food intake. The domain of eating behaviour is a chain consisting of these variables and processes. Adapted to clarify wording from Drewnowski, A. (1997).*

If one of these variables or processes can be controlled, this effect would trickle down this chain. The further up the chain this happens, the more processes are influenced. The first process in the chain, sensory perception, is thus full of potential. Even more so, as the visual properties of a food might be the easiest of all processes to have an external influence on. The sequential chain of eating behaviour is mediated by a person's physiology, psychology, genetics, culture, socio-economic status, and environment (Emilien & Hollis, 2017). Of all the variables influencing the processes involved with eating behaviour, a person's environment is relatively easy to control. By altering one's environment, the sensory perception of food also changes. Therefore, this possibility of changing one's environment, has a lot of potential for changing a person's eating behaviour and nudging them towards a healthy nutritional status. The first step towards promoting healthy eating through environmental changes is understanding how exactly a person's environment influences the different processes and variables enveloping eating behaviour.

The physical environment is a complex one. A person is affected by everything they see, hear, smell, taste, or touch. They are influenced by architecture, ambient sounds and music, smells much more. A plethora of literature exists on the influence of one's (ambient) environment on eating behaviour. For example, it has been found that in a fast-food restaurant setting, environmental cues such as lighting and music strongly bias eating behaviour. For example, a study by Wansink and Van Ittersum[1] (2012) suggests that soft lighting and music lead to people eating less and rating food as more enjoyable. In a supermarket environment however, customers tend to make significantly healthier choices in a brighter environment compared to a dim environment (Biswas et al., 2017). The same goes for general (non- fast food) diners

[1] A lot of research by Wansink was retracted due to him being accused of scientific fraud (Kotlikoff, 2018). This must be considered while consulting his literature. His theories only serve as a source of inspiration for future research.

(Murray, 2017). A person's environment, specifically ambient light, thus veritably seems to influence their eating behaviour.

Many researchers have speculated on the nature of these effects. Especially since the mention of interpersonal differences occurs frequently in studies on the influence of ambient factors. Results of existing literature vary amongst participants. Some participants react more strongly to the effects of lighting than others, who might not even react at all. Many studies hypothesize the mediating effect of some variable, often emotional state, as it is known that mood is influenced by ambient light and influences eating behaviour, but no conclusive answer has been found as to why the interpersonal differences are found so remarkably frequent.

1.2. Research questions

The state of the art is the main reason for this study and the motivation for the research question. By exploring and clarifying the relationship between ambient light, emotional state and eating behaviour, it will be easier to explain interpersonal differences between the influence of ambient light on eating behaviour. This will eventually expand the field of eating behaviour research and might support healthy eating.

The research question of this study is:

Main RQ:

"To what extent, if any, is the influence of ambient light on eating behaviour mediated by emotional state?"

The structure of the hypothesized effect is visualised in figure 2.

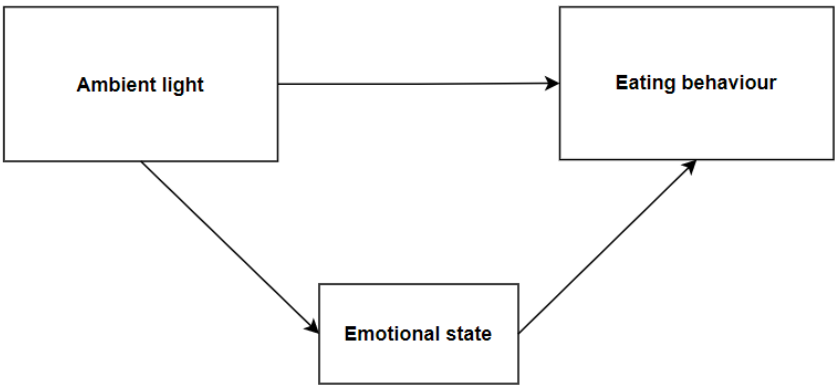

Figure 2. *The causal diagram of the main hypothesis.*

The hypothesis and the background of the research question and hypothesis are given in section 2.

To answer the research question, the study is divided in three parts. The first part has as a main goal to explore the topics of the research question as thoroughly as possible. To do so, an exploratory study (Study 1) with the exploratory research question was designed:

Main RQ Study 1:

"To what extent, if any, does emotional state and other factors influence the effect of ambient light on eating behaviour?"

To make answering the question easier, the research question of Study 1 is divided into several exploratory sub-questions. The background of the sub-questions is elaborated upon in the relevant sections. The exploratory sub-questions are as follows.

- RQ1.1. Does ambient light directly influence eating behaviour of healthy and unhealthy snacks?
- RQ.1.2. Is eating behaviour of healthy and unhealthy snacks directly influenced by emotional state?
- RQ.1.3. Is emotional state directly influenced by ambient light?
- RQ.1.4. Is eating behaviour of healthy and unhealthy snacks directly influenced by mental awareness?
- RQ.1.5. Is eating behaviour of healthy and unhealthy snacks directly influenced by other personal factors?
- RQ1.6. Does emotional state have a mediating or moderating effect on the influence of ambient light on eating behaviour?

Based on the findings of Study 1, a follow-up study was designed, which zoomed in on particularly interesting findings of Study 2. The main research question of Study 2 is:

"To what extent, if any, does the illuminance level of ambient light influence the hedonic response and/or food intake of an unhealthy snack, and to what extent (if any) does emotional valence affect this relationship?"

To make answering easier, the research question of Study 2 is also divided into several sub-questions.

The sub-questions of this study are:

- RQ2.1. Does illuminance level directly influence hedonic response to and/or food intake of an unhealthy snack?
- RQ2.2. Does illuminance level directly influence valence of emotional state?
- RQ2.3. Does valence of emotional state directly influence hedonic response to and or/food intake of an unhealthy snack?
- RQ2.4. Does valence of emotional state have a mediating or moderating effect on the influence of illuminance level on hedonic response to and/or food intake of an unhealthy snack?
- RQ2.5. Is hedonic response to and/or food intake of an unhealthy snack influenced by other personal factors?

Finally, the answers to all research questions are combined to answer the main research question.

1.3. Report organization

To ensure a good reading experience, the report is structured into different sections.

Section 2, the background, delves further into the existing literature surrounding the research questions. This section also includes a hypothesis for the main research question.

Section 3, which describes Study 1, is about the exploratory study that examines the different factors of the main research question. Different exploratory sub-questions are formulated to

structure the exploration. An online survey was designed in which 120 participants rated photographs of different types of food in eight light conditions, varying in illuminance level and colour temperature. This section directly discusses the results and limitations to the specific study design of Study 1 and gives recommendations for the follow-up study.

Section 4 describes Study 2, the follow-up study of Study 1. Here, the most interesting findings of Study 1 are researched more in depth in an experimental setting. Like Section 3, different sub-questions are formulated to structure the exploration. 40 people participated in a lab study where they ate and rated an unhealthy snack, illuminated with either dim or bright light. This section directly discusses the results of this study and limitations to the specific study design of Study 2.

Section 5 is the general discussion section. In this section, findings of Study 1 and 2 are considered in unison and combined into one general discussion. Section 5 also includes limitations of the study and recommendations for future work.

Finally, in section 6, the conclusion of the study is presented.

2. Background

To get an understanding of how different environmental aspects influence eating behaviour, a preparatory literature research on the influence of ambient light and other environmental factors was performed. Based on a plethora of previous studies, "eating behaviour" was defined as a sequential chain of variables and processes that influence the final state: nutritional status. It was found that these different variables and processes can be influenced by the environment in different ways. This is visualised in figure 3. Food colour and the colour of peripherals such as dinnerware and tablecloth influence the taste perception of food. This process is hypothesized to be caused mainly via learned associations and expectations about food colour. Ambient light also influences eating behaviour, on many different levels (e.g., taste perception, liking, food choice and food intake). Researchers in many instances hypothesize that the process behind the influence of ambient light on eating behaviour can be explained through a person's emotional state and/or physiological arousal. Background music and sound also influence eating behaviour, through a similar process.

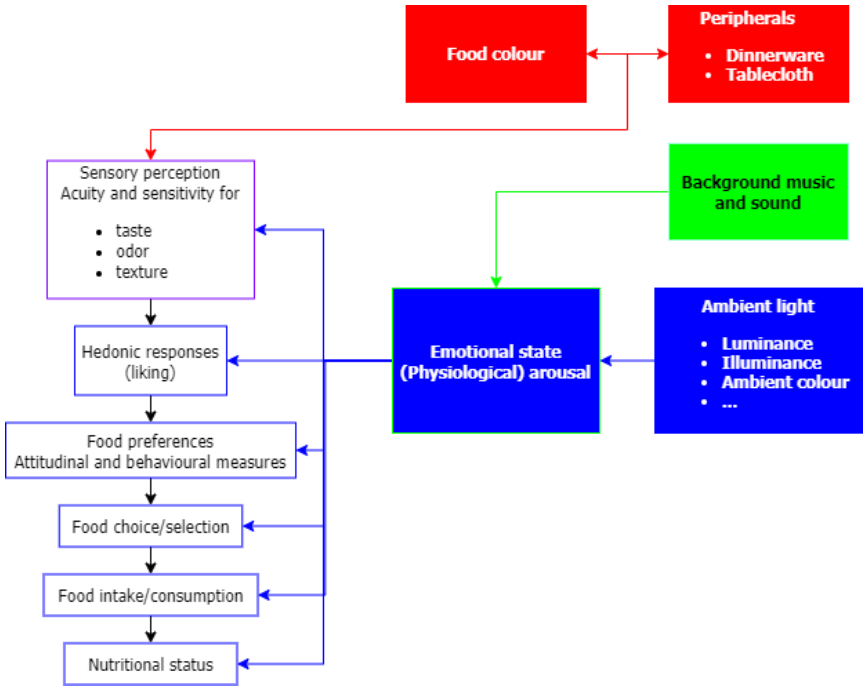

Figure 3. *The Effect of Food Colour, Ambient Light, and Other Ambient Factors on Variables Mediating Eating Behaviour. This figure depicts the influences of all the considered ambient factors on the chain of variables intervening between taste function and food intake, as shown by research. Adapted from Drewnowski (1997).*

2.1. The influence of ambient light on eating behaviour

In literature, the two main aspects of ambient light that are applied to influence eating behaviour are illuminance and light colour.

2.1.1. The influence of colour temperature on eating behaviour

Colour temperature indicates warmness of light and is defined in Kelvin, often ranging from 2700K, which is warm, reddish light, to 4000K, which is cold, blueish light.

When it comes to light colour, the main aspect that is researched is the actual colour of lighting, often RGB. For example, Suk, Park & Kim (2012) found that yellow light stimulated appetite, while red and blue light discouraged appetite. Moreover, when the colour of the food and the light are similar, appetite is stimulated, whereas when the colours are dissimilar, appetite is discouraged. This effect is hypothesized to be due to incongruent colours distorting the natural colours of the food, leading to hesitation in eating.

However, light colour should not be confused with colour temperature, which indicates warmth of the light. The effect of warmth on eating behaviour is not at all widely researched. Research by Wansink[1] (2004) and Gal et al. (2007) suggests that people stay longer and eat more in a restaurant with warm lighting, compared to cold lighting. However, more research in this field is necessary to establish which effect colour temperature has on eating behaviour.

2.1.2. The influence on illuminance on eating behaviour

Illuminance, simply put, is the measure of the amount of incident light that illuminates a surface. The impact of illuminance on eating behaviour has been the topic of interest of many researchers.

Rebollar et al. (2017) studied flavour perception of yoghurt under high illuminance levels versus low illuminance levels. The yoghurt was rated as healthier under the low illuminance condition. Moreover, female participants rated the yoghurt as sweeter under the high illuminance condition. Another study, by Katsuura et al. (2005), analysed the threshold for different basic tastes under two illuminance levels. They found reduced thresholds for bitter and sweet tastes under high illuminance conditions, indicating a higher level of taste sensitivity in brighter environments with a high colour temperature, approximating daylight. A study by Ross (1974) found that a bowl of nuts which was illuminated brightly induced obese people to eat more, but also led to decrease how long people stayed in the environment and with it their overall alcohol- and food intake.

Another study by Hasenbeck et al. (2014), presented green, red, and blue bell peppers under differently coloured lighting, while participants indicated their willingness to eat the bell pepper as well as their liking of the appearance of the food. They found that yellow and blue lighting increased liking of appearance for red, green, and yellow bell peppers. Yellow lighting improved willingness to eat, while blue lighting decreased willingness to eat. Additionally, low illuminance levels led to a decreased liking of appearance and willingness to eat as compared to high illuminance levels. Congruent colouring of food and light led to increased liking of appearance and willingness to eat. Hasenbeck et al. hypothesize that under yellow lighting as well as bright lighting, food appears clearer and more natural, while under harsh incongruent lighting as well as dim lighting, food appears unnatural, increasing hesitation and decreasing and willingness to eat.

Generally, these effects of illuminance on ambient light are hypothesized to be caused by multiple things. The increase in taste sensitivity in bright environments is proposed by Katsuura et al. (2005) to be caused by humans being omnivorous, causing us to need nutrients from a large variety of food and thus needing to judge through our taste whether food contains energy (sweet) and minerals (salty), whether it's toxic (bitter) or rotten (sour). Moreover, we are diurnal animals (meaning we wake during the day and sleep during the night), which causes our senses to be more sensitive under bright environmental conditions. The effect of ambient light on taste perception is also mediated by physiological processes, as underlined by a study by Srivastava et al. (2013). They exposed 14 subjects briefly (30 minutes) to bright light (10.000 lux) and found a reduction in the threshold for tasting sweetness, but not for tasting saltiness. This effect is thought to be caused by the alteration of the levels of circulating serotonin, a neurotransmitter associated with mood regulation, through bright light exposure. Mood, in turn, is known to influence taste perception, as well as liking and food choice (Noel & Dando, 2006; Gibson, 2006).

Other than these evolutional and physiological explanations, there is a third hypothesis: the mediating effect of emotional state.

2.2. The influence of emotional state on eating behaviour

The relation between emotional state and food choice and intake is widely acknowledged. Emotions are generally classified in two dimensions: valence (positive or negative) and arousal (activated or deactivated) (Russell, 1980). Emotions differing in valence and arousal have been found to influence eating behaviour. An extensive research review on emotional eating-literature by Macht (2008) states that emotions, both specific emotions such as anger and joy and more diffuse and long-term emotions, have been found to affect many processes in the sequential chain of eating behaviour, such as eating motivation, hedonic response, food choice, food intake and even metabolism and digestion. More specifically, research has found that high arousal appears to increase negative emotion and decrease food intake, whereas low-to-moderate emotions increase food intake (Robbins & Fray, 1980).

More specifically, research has found people in an emotional state with positive valence (in other words, with a higher level of pleasure), tend to rate food as more pleasant (e.g., Bongers et al., 2013) and tend to increase their intake (Evers et al., 2013). At the other hand, negative emotion leads to an increase in appetite and food intake for some, but a decrease in appetite and food intake for others (Macht, 2008).

2.3. The influence of light on emotional state

The relation between (ambient) light and emotional and physiological state is well-established. Emotional arousal induces physiological arousal, a measure of alertness and an affective response to emotional stimuli. Physiological arousal is increased by lighting with higher illuminance (e.g., Cajochen, 2007; Smolders, De Kort & Cluitmans, 2012). Affective (emotional) states have also been found to be influenced by (coloured) light (Hedge, 2000; Küller et al., 2006). Colour temperature also has been found to influence emotional state and mood, but the direction of this effect appears to be dependent on gender and setting (Park et al., 2010; Knez & Enmarker, 1998; McCloughan, Aspinall & Webb, 1999).

Effects are strong especially for long-term (30+ minutes) exposure to bright light (Smolders & De Kort, 2014; Leichtfried et al., 2015). These studies mostly focus on the non-image forming (NIF) effects of illuminance on alertness and mood. In the effects of light on humans, a distinction can be made between image forming and non-image forming effects (Boyce, 2003). Here, image-forming (IF) effects refers to the activation of the visual system, which enables us to see the world around us. For this, the light enters the eye, and through the retina signals are sent towards the different brain regions that are involved in vision such as the Lateral Geniculate Nucleus (LGN). Light however also affects our physiology and psychology and it does so through non-image forming effects (NIF). For this, light also travels from the eye (via the retina) to the brain, but signals are sent to brain areas involved in physiology, mood, and behaviour.

NIF effect are often not acute and involve a long-term exposure to light. Acute NIF effects of ambient light on emotional state are not widely researched, but some studies (Li et al., 2021; Souman et al., 2018) have confirmed the acute effects of illuminance and colour temperature on emotional state.

2.4. Interpersonal differences and the mediating effect of emotional state on eating behaviour

As the effects of ambient light on emotional state and eating behaviour as well as the effects of emotional state on eating behaviour are well-established, it is hypothesized by some researchers, such as Hasenbeck et al. (2014) and Katsuura et al. (2005) that emotional state plays a mediating role in the effect of ambient light on eating behaviour.

Colour temperature and brightness influence emotional state and physiological arousal (Cajochen, 2007), which in turn influences food choice and intake (Macht, 2008). This causality is a returning proposition amongst literature. Through this effect, the emotion caused by the light condition may have a mediating effect on the liking of appearance and willingness to eat. For example, cold, bright light induces heightened arousal and alertness levels (Cajochen, 2007), which might modulate the willingness to eat food.

Moreover, throughout the preparatory literature review, the mention of interpersonal differences occurs frequently in studies on the influence of ambient factors. Results of existing literature vary amongst participants. Some participants react more strongly to the effects of lighting than others, who might not even react at all. Many studies hypothesize the mediating effect of some variable, often physiological arousal, but no conclusive answer has been found as to why the interpersonal differences are found so remarkably frequent.

This phenomenon seems neglectable, and many studies come to the same conclusion. In many studies, the interpersonal differences are noted as a limitation, but do not largely influence the conclusion of the research. Results are generalized over participants to formulate a certain conclusion. This however can have serious ramifications.

Research on the influence of varying factors (such as ambient light) is carried out with a certain goal in mind. Perhaps the findings will be implemented in an intervention to support healthy eating. However, for a successful intervention to be designed, it must be clear which processes are influenced by what variables. Moreover, it is important to be able to target your specific demographic. Interpersonal differences make this difficult. An intervention based on generalized findings might for one person, but not for another.

It is important to be able to control for this variable. If the emotional state of a person is well established and controlled for, results of research on the influence of ambient light on eating behaviour will be more cohesive. A study on this was already done by Oberfeld et al. (2009), who hypothesized that the effect of food and beverage colour on taste perception could be mediated by an emotional process, and if food colour can influence emotional state, the ambient colour of the environment should too. They did find an effect of ambient light colour on hedonic response towards wine but could not find a correlation between emotional response (valence and arousal) to a colour and global liking of the wine. They only conducted the experiment for ambient light colour, and not for illuminance levels, which might be a more interesting area, as high illuminance has been proven to influence arousal levels.

Of course, emotional state is not the only factor that accounts for interpersonal differences. Some other factors are proposed and shortly discussed in literature, such as the influence of gender. Male and females tend to have differently significant results amongst different studies, especially in the domains of taste perception and food intake. The difference in gender might be based in differences in neural responses to visual cues, for example women having increased brain activity in regions involving inhibition control when presented with food-related visual cues (Cornier et al., 2010). Associations and expectations are also a probable cause of interpersonal differences, especially in the domain of taste perception. This has been researched in context the effect of food colour on taste perception, but this notion might also translate to more environmental light colour. This might correspond with age group, as adults have more learned associations than children. Even other mediating factors might exist.

Both the influence of illuminance and colour temperature on eating behaviour, and the extent to which emotional state and physiological arousal have a mediating effect, will be considered in this research. Based on the literature, it is hypothesized that emotional state will have a larger mediating effect for different illuminance-levels than for different light colours, as the effect of light colour might be rooted more in different explanations such as food recognition than in emotional state. However, to understand interpersonal differences better and be able to account for these differences in future studies, considering and understanding emotional state as a mediating factor might be important.

3. Study 1: Exploring the influence of ambient light on eating behaviour

To try to answer the research question, conducting a real-life experiment would be very fitting. However, both eating behaviour and ambient light are complex domains with many different settings. To explore the domain of eating behaviour, an exploratory study was performed.

3.1. Background

The general background of this study is provided in section 2. However, as this study acted as an exploratory study to investigate as much of the main research question as possible, some additional points of interest were added, which will be discussed in this section.

3.1.1. Simplifying the setting

The main research question of this study mostly stemmed from the gap in the literature that became apparent from the conducted literature review. That gap is the interpersonal differences that are prevalent in research on ambient light and eating behaviour. To fill that gap is to mostly enhance the current research domain. Although very important, real-life implications are not only more interesting, but also follow naturally from such a human-focused domain. The main scope of the study is the effect of ambient light on eating behaviour. To make this less abstract and more practical, a goal must be defined. The question that was asked was: "In what setting should this study solve a problem?" In other words: "How could the findings of this research be implemented to actually support people with eating healthily?"

To do so, different settings were explored in the literature, such as supporting healthy eating during a meal such as breakfast, lunch, or dinner. Such a setting immediately makes the scope of the study more concrete. One could hypothesize that ambient light might influence eating behaviour during a meal, and that this effect is mediated by one's emotional state.

However, considering such a setting would complicate a study design. A meal is often eaten with other people present. This must thus be included in the study design for ecological validity. However, the presence of other people influences emotional state and eating behaviour on completely different levels.

The setting should thus be kept as simple as possible, while still providing real-life value. To do so, the setting that was chosen is that of snacking, comparing eating behaviour of healthy snacks with eating behaviour of unhealthy snacks. The purpose is to support healthy eating, which would translate to motivating eating healthy snacks or demotivating eating unhealthy snacks.

3.1.2. (Mindless) snacking as a scope

Mindless eating behaviour, such as eating in front of a TV has been linked to greater unhealthy snack food consumption in both children and adolescents (Snoek et al., 2006).

Mindless eating (for example while watching television) has been associated with unhealthy eating behaviour (snacking energy-dense food, increased food intake, etc.) (Snoek et al., 2006). Mindless eating behaviour is also associated with a higher BMI (Lemoine & McCarthy, 2008). It is thought that people are less alert about their food choices and food intake when they are distracted by something else.

Supporting mindful eating might thus also support healthy eating, by reducing unhealthy snacking behaviour. Because of this, mindless snacking was considered as the setting of the exploratory study.

Mindless eating behaviour research requires some form of inducing a mindless state, for example by watching a video while. Research on ambient light and eating behaviour, especially when dependent variables are factors like taste perception and hedonic response, often is designed in a way that a participant is eating mindfully. Their main task is to eat food. Because of this (and because of time restraints in conducting the study) instead of inducing a mindless state, the extent to which ambient light influences alertness, and how that in turn influences eating behaviour, is investigated.

Ambient light does influence alertness in several ways. A decrease in mental alertness tends to lead to greater preference for unhealthy options (Dhar and Wertenbroch, 2012; Shiv and Fedorikhin, 1999). Moreover, research also shows that reduced mental alertness leads to mindless decisions (Janssen et al., 2008) and mindless decisions tend to lead to unhealthy behaviour (Wansink, Just, and Payne, 2009).

So instead of trying to induce a mindful or mindless state, which is hard to do consistently to begin with, it is interesting to consider to what extent ambient light influences alertness and how that in turn influences eating behaviour.

Information about mental alertness might also help explaining more interpersonal differences in data, which adds to the main goal of this study.

3.1.3. Research questions

The main exploratory research question of this study is:

Main RQ Study 1:

"To what extent, if any, does emotional state and other factors influence the effect of ambient light on eating behaviour?"

To make answering easier, the research question is divided into several sub-questions and hypotheses.

- RQ1.1. Does ambient light directly influence eating behaviour of healthy and unhealthy snacks, and if yes, to what extent?
    - H1.1: Ambient light will directly influence eating behaviour of healthy and unhealthy snacks. Higher level and a warm colour temperature will positively increase hedonic response, appetite satisfaction and food intake.
- RQ.1.2. Is eating behaviour of healthy and unhealthy snacks directly influenced by emotional state, and if yes, to what extent?
    - H1.2: Emotional state will directly influence eating behaviour of healthy and unhealthy snacks. A high level of valence and a high level of arousal will positively increase hedonic response, appetite satisfaction and food intake.
- RQ.1.3. Is emotional state directly influenced by ambient light, and if yes, to what extent?
    - H1.3: Ambient light will directly influence emotional state. Bright light as well as a warm colour temperature will increase valence and arousal.

- RQ.1.4. Is eating behaviour of healthy and unhealthy snacks directly influenced by mental alertness, and if yes, to what extent?
    - H1.4: Mental alertness will directly influence eating behaviour of healthy and unhealthy snacks. A high alertness will improve hedonic response to healthy snacks and decrease food intake of unhealthy snacks.
- RQ.1.5. Is eating behaviour of healthy and unhealthy snacks directly influenced by other personal factors, and if yes, to what extent?
    - H1.5: Eating behaviour is influenced by hungriness, healthiness, liking of raisins, liking of M&Ms, age, and gender.
- RQ1.6. Does emotional state have a mediating or moderating effect on the influence of ambient light on eating behaviour, and if yes, to what extent?
    - H1.6: Valence and arousal of emotional state will have a moderating effect on the influence of ambient on hedonic response and food intake.

3.2. Methodology

To answer the research questions, an online survey was designed.

3.2.1. Study design

To ensure validity of the findings, which is important for an exploratory study, as many participants need to be recruited as possible. However, time is limited, and deadlines have to be considered. To collect as much data as possible, different study designs (such as a physical experimental lab study or a VR study) were considered. While a lab study would lead to the highest ecological validity, this would drastically decrease the number of participants that would be needed for the exploration of many different measures in different conditions. Based on this, it was decided that data collection through an online survey with photographs of food under different light conditions was the best option. It should be noted that in lighting research, images do not necessarily evoke a realistic psychological response (Chen, Cui and Hao, 2019). Also, food intake and taste perception cannot be directly measured, only visual perception and hedonic qualities. These things should be kept in mind while analysing the results of this study, and this study should thus mainly serve as an exploratory study for a study with high ecological validity.

An online survey was designed in Qualtrics™ (Qualtrics, Provo, UT). In this survey, participants were shown images of a healthy snack (raisins) and an unhealthy snack (brown chocolate M&Ms). Food types were chosen based on previous research on food choice (Salerno, Laran & Janiszewski, 2014; Biswas et al., 2017). The images were taken under 4 different lighting conditions (see figure 4 and 5). The light conditions had a varying illuminance and colour temperature. Most non-professional cameras cannot accurately capture illuminance and colour temperature exactly the same as the naked eye would see it. To accurately portray the light conditions on photographs, the conditions were thus first prepared in real life, presenting the plates with snacks in either dim (35 lx) or bright (300 lx) light and different colour temperatures (either warm (2700K) or cold (6000K). A base picture in neutral light was taken and was visually matched to these light conditions.

Figure 4. *A plate of raisins in four different light conditions. From left to right: Bright Cold, Dim Cold, Bright Warm, Dim Warm.*

Figure 5. *A plate of chocolate M&Ms in four different light conditions. From left to right: Bright Cold, Dim Cold, Bright Warm, Dim Warm.*

The independent variables are thus:

- Illuminance (lx) (35 lx vs 300 lx)
- Colour temperature (K) (2700 K vs 5000 K)
- Snack type (healthy vs unhealthy)

The study used a within-participants design, meaning all participants were exposed to all conditions. Conditions were randomized over participants to balance the study design and prevent fatigue- or response biases.

Participants were asked to imagine that they were to eat this food. Based on that, for each picture, the following dependent variables were measured:

- their current emotional state;
- their level of sleepiness;
- their hedonic response:
    - willingness to eat (How willing are you to eat this snack?);
    - liking of appearance (How much do you like how this snack looks?);
    - expected liking (How much do you think you will like this snack?);
- a prediction of appetite satisfaction (How much do you think this food will satisfy your appetite?);
- an estimate of their intake (How much quantities of this food would you eat?).

Participants were also presented with photographs of both a plate of raisins and a plate of M&Ms, in four different ambient light-conditions (Dim Warm, Dim Cold, Bright Warm and Bright Cold), see figure 6.

Figure 6. *Two plates of raisins (left) chocolate M&Ms (right) in four different light conditions. From left to right: Dim Warm, Dim Cold, Bright Warm and Bright Cold.*

For each photo, participants were asked to choose whether they would rather eat the raisins (left) or the M&Ms (right). Thus, the following additional dependent variable was measured:

- food choice.

The following possible covariates were measured as well:

- current level of hungriness;
- extent to which a participant focuses on healthy eating;
- some demographics (age, gender).

Emotional state was measured with two concepts: valence and arousal. Valence is the extent to which an emotion is positive or negative, whereas arousal is the level of intensity of the emotion (Citron et al., 2014). The measure that was used was the Affective slider, designed by Betella and Verschure (2016) to enhance usability in digital surveys (see figure 7). On this slider, participants can visually match their emotional state to the emoticons. This results in a number ranging from 0 to 100.

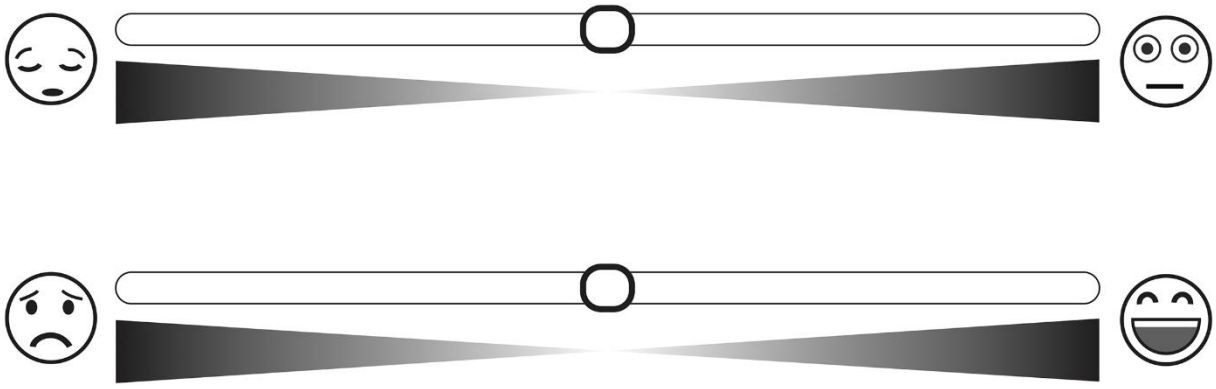

Figure 7. *The Affective slider designed by Betella and Verschure (2016).*

As stated in Section 3.1.2., state mindfulness is hard to measure and would be better used as a condition (manipulated state mindfulness). As this is not easy in a survey, where it is important to keep length limited to improve response rate, mental alertness is used as a predictor for state mindfulness. To reflect the current level of mental alertness, level of sleepiness was measured on the Karolinska Sleepiness Scale (KSS), which is a 9-point Likert scale ranging from 1 = Extremely alert to 10 = Very sleepy, great effort to keep alert, fighting sleep (Åkerstedt & Gillberg, 1990). The KSS is an often-used index of self-reported level of alertness and sleepiness (e.g., Putilov & Donskaya, 2013; Basner et al., 2019).

Hedonic response and predicted appetite satisfaction were measured on appropriately labelled (e.g., 1 = won't like at all – 7 = will like extremely) 7-point Likert scales, based on combined similar research (Liem, Aydin & Zandstra, 2012; Hasenbeck et al., 2014).

Estimated intake was measured on a slides scale ranging from 0 = nothing at all to 100 = everything.

The study design was approved by the UTwente Ethics Commission under the reference number RP 2021-150.

3.2.2. Participants

Participants were recruited through the online platform Prolific. In total, 120 participants completed the survey, of which 39 male, 79 female and 2 who identified as an "Other" gender. The mean age of the participants was 40,31. Upon completion of the survey, participants received a monetary compensation. Because this survey acted as an exploratory study for further research in a Dutch lab, it would have been ideal to recruit Dutch participants for the survey as well. However, the database of active participants with a Dutch nationality was relatively small. Due to the time constraints of the research and the following need of fast data collection, participants were recruited from the database of active participants with a British nationality, as this database was significantly larger and has a similar (Western) cultural background.

3.2.3. Data analysis

The variables were coded as follows in table 1:

Variable name	**Variable description**
Independent variable	
Healthy	One of the independent variables used in the LMM, healthiness of a snack. Healthy = 1 refers to the healthy snack (raisins), Healthy = 2 refers to the unhealthy snack (M&Ms).
Bright	One of the independent variables used in the LMM analysis, illuminance level. Bright = 1 refers to the Bright condition (300lx), Bright = 0 refers to the Dim condition (35lx).
Warm	One of the independent variables used in the LMM analysis, colour temperature. Warm = 1 refers to the Warm condition (2700K), Warm = 0 refers to the Cold condition (6000K).
Covariate, hypothesized as mediating variable	
Pleasure	The level of Pleasure measured from 0 to 100. Indicates the positivity of the current emotional state.
Arousal	The level of Arousal measured from 0 to 100. Indicates the strength of the current emotional state.
Sleepiness	The level of sleepiness measured on the 10-point Karolinska Sleepiness Scale. Indicates the current level of sleepiness and conversely mental alertness.
Dependent variables	
Willingness to eat	Willingness to eat the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).

Liking of appearance	Liking of appearance of the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).
Perceived appetite satisfaction	Perceived appetite satisfaction of the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).
Predicted food intake	The predicted amount of food that a participant imagines they would eat, measured from 0 to 100.
Food choice Dim Warm	The choice between Raisins (option 1) and M&Ms (option 2) in the Dim Warm light condition.
Food choice Dim Cold	The choice between Raisins (option 1) and M&Ms (option 2) in the Dim Cold light condition.
Food choice Bright Warm	The choice between Raisins (option 1) and M&Ms (option 2) in the Bright Warm light condition.
Food choice Bright Cold	The choice between Raisins (option 1) and M&Ms (option 2) in the Bright Cold light condition.
Covariates	
Hungriness	Current level of hungriness, measured on a 7-point Likert scale (also see Section 3.2.1.).
Healthiness	General focus on healthy eating, measured on a 7-point Likert scale (also see Section 3.2.1.).
Liking_of_raisins	General liking of M&Ms, measured on a 7-point Likert scale (also see Section 3.2.1.).
Liking_of_M&Ms	General liking of M&Ms, measured on a 7-point Likert scale (also see Section 3.2.1.).
Age	Current age in years.
Gender	Gender (1=male, 2=female, 3=other).

Table 1. *The variables that were measured and coded for the analysis, including a description of the variables.*

For analysis of the data, a linear mixed model (LMM) was chosen, due to the repeated measurements of the different eating behaviours over for 8 different conditions over time. To do so, the data was restructured to a long format.

Participant ID was used to define the subjects in the LMM, as the correlation between the repeated measurements per subject is to be modelled. The repeated variables are the dummy variables representing the different conditions: Healthy (0=unhealthy i.e. M&Ms, 1=healthy i.e. raisins), Bright (0=dim i.e. 35 lx, 1=bright i.e. 300 lx) and Warm (0=cold i.e. 6000K, 1=warm i.e. 2700K). These variables were also set as the factors of the model.

The dependent variables that were defined as the covariates were: Sleepiness, Pleasure, Arousal. It was also checked whether Hungriness, Healthiness, Liking of Raisins, Liking of M&Ms, Age and Gender influenced the dependent variable by adding them as a covariate in the model. Categorical variables were treated as fixed effects in the model, while continuous variables were treated as random effects.

It is hypothesized that emotional state mediates or moderates the influence of ambient light on eating behaviour. Mediation analysis on data with repeated measures in 8 conditions is very complex and not attempted for the current study. As this survey acted as an exploratory study, interaction effects and moderating effects are researched. The follow-up study will include mediation analysis of the found interaction effects. In addition to these direct effects, the interaction effects between the following interaction effects were investigated:

- Bright*Pleasure
- Bright*Arousal

- Warm*Pleasure
- Warm*Arousal

It is important to note that an interaction effect reflects a moderation effect (see figure 8), not a mediating effect. A significant interaction effect does not always mean that there is a significant mediation effect, as an interaction does not imply a causal sequence. Repeated measures are generally difficult for standard mediation analysis.

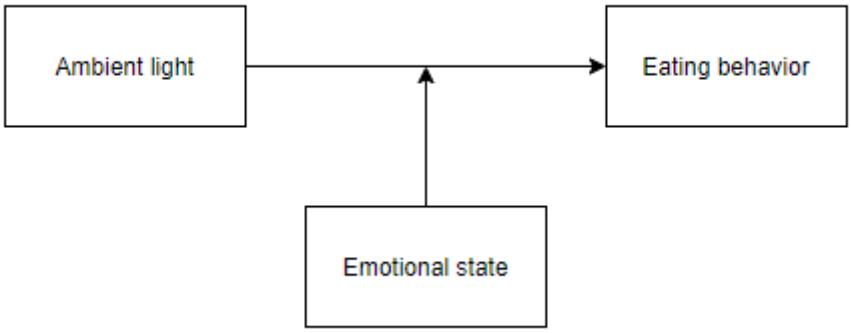

Figure 8. *A schematic overview of a moderation effect.*

The residuals were structured by using compound symmetry structure as variances and covariances of the subjects' residuals are homogeneous, meaning that there is a correlation between two separate measurements (due to the measurements being very close in time), but it is assumed that the correlation is constant regardless of how far apart the measurements are. Subject (participant ID) was added as a random intercept to indicate the clustering of the data.

The dataset was also split into two using Healthy as the identifier, to examine the responses for both the unhealthy and healthy condition apart. For both datasets, a LMM with the same compound structure, dependent variables, and random intercepts as in the full dataset was implemented.

For all final LMM's, the significance table of all included variables will be shown. The direction and strength of the effect will be visualised in graphs.

To compare the food choice under the different lighting conditions, a McNemar Test was carried out for the Food Choice responses under the different conditions.

The power of the study was calculated using the G*Power software. As a within-subject design is used with a linear mixed model, with 120 participants, a significance level 0.05 and a small hypothesised effect size, the calculated power is 80%. This means that there is an 80% chance of findings significant results if an effect exists in a population.

3.3. Results

Table 2 shows the descriptives of all dependent variables.

	Mean	Std. Deviation
Pleasure	57	30.603
Arousal	41	28.166
Sleepiness	3	1.648
Liking of appearance	4	1.763
Willingness to eat	4	1.886
Perceived appetite satisfaction	3	1.720
Predicted food intake	59	37.934
Food choice Dim Warm	2	0.433
Food choice Dim Cold	2	0.423
Food choice Bright Warm	2	0.462
Food choice Bright Cold	2	0.462
Current hungriness	4	1.307
Focused on healthy eating	5	1.300
General liking of raisins	4	1.804
General liking of M&Ms	5	1.439
Gender	2	0.497
Age	40	14.873

Table 2. *The mean and standard deviation of all measured variables.*

3.3.1. Willingness to eat

The significance table of the final LMM with Willingness to eat as dependent variable is shown in table 3.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	133.200	20.029	0.000
Healthy	1	828.736	0.013	0.908
Bright	1	838.384	0.015	0.903
Warm	1	833.258	0.465	0.495
sleepiness	1	199.542	0.389	0.533
pleasure	1	886.590	1200.391	0.000
arousal	1	663.421	3.064	0.081
Bright * pleasure	1	838.116	1.929	0.165
Bright * arousal	1	839.772	2.061	0.151
Warm * pleasure	1	834.815	0.709	0.400
Warm * arousal	1	835.502	4.044	0.045
Healthy * Liking_of_raisins	2	206.608	10.268	0.000
Healthy * Liking_of_M_Ms	2	206.643	2.808	0.063

Table 3. *The significance table of the final LMM with Willingness to eat as dependent variable. Significant effects are highlighted in green.*

The model revealed a significant effect of Pleasure on Willingness to eat, where a higher level of pleasure leads to a higher Willingness to eat. This is visualised in figure 9.

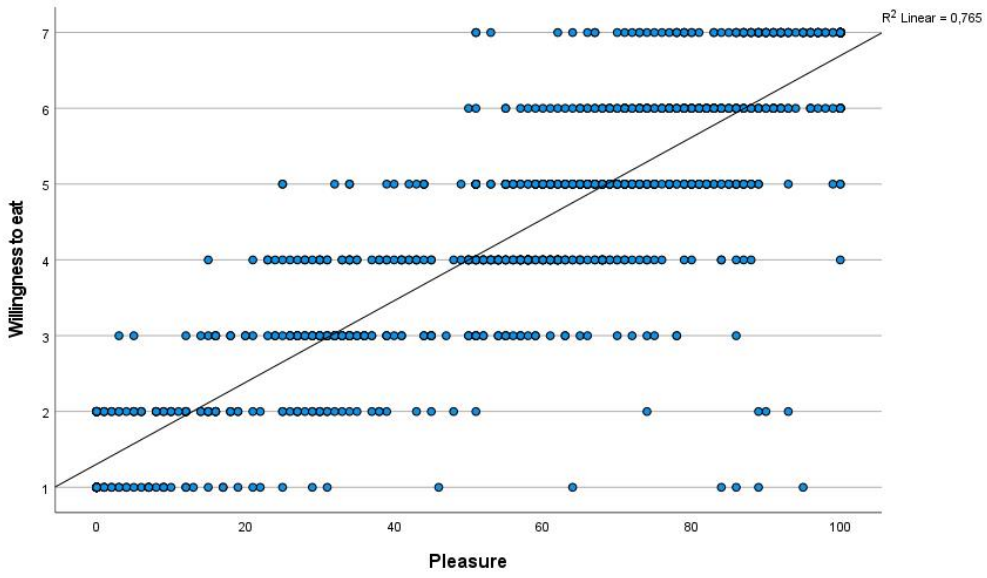

Figure 9. *A scatterplot with Pleasure on the x-axis and Willingness to eat on the y-axis. The effect is visualised with the fitted line through the data-points.*

Following the Type III Tests of Fixed Effects, the interaction between Warm and Arousal was significant, indicating that the arousal effect was greater in the warm condition than in the cold condition. However, when examining the Estimates of Fixed Effects, it becomes apparent that the interaction between Warm and Arousal is not significant for both conditions. This is reflected in figure 11.

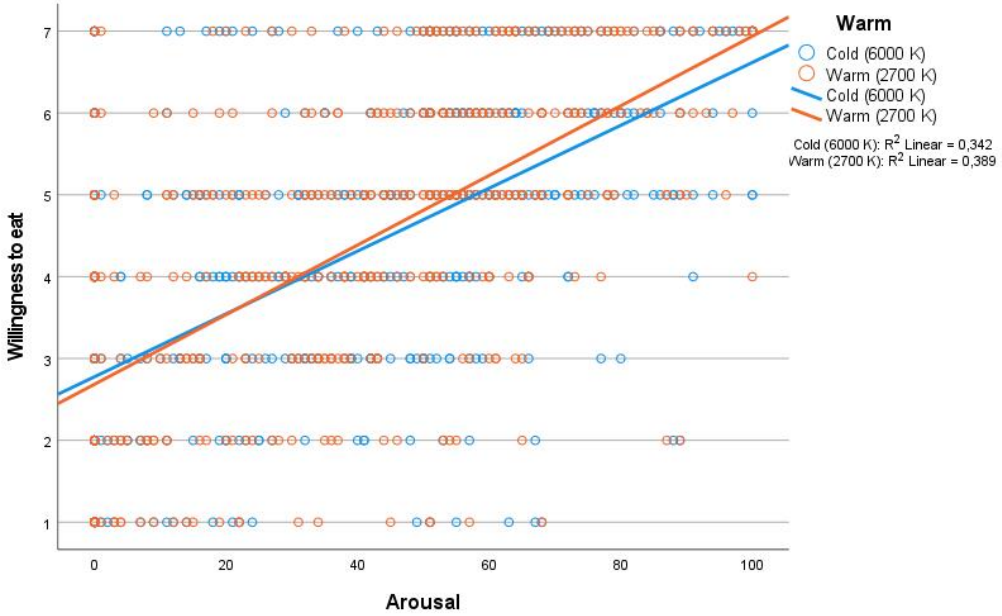

Figure 11. *A scatterplot with Arousal on the x-axis and Willingness to eat on the y-axis. The data-points are marked by the Warm condition, with the blue colour marking the Cold condition and the orange colour marking the Warm condition. The effect is visualised with the fitted lines through the data-points.*

Moreover, the interaction between Healthy and Liking of raisins was significant, indicating that the effect of Liking of raisins on willingness to eat was greater in the Healthy condition than in the Unhealthy condition (see figure 12). A similar yet reversed effect showed a trend towards significance for Liking of M&Ms (see figure 13).

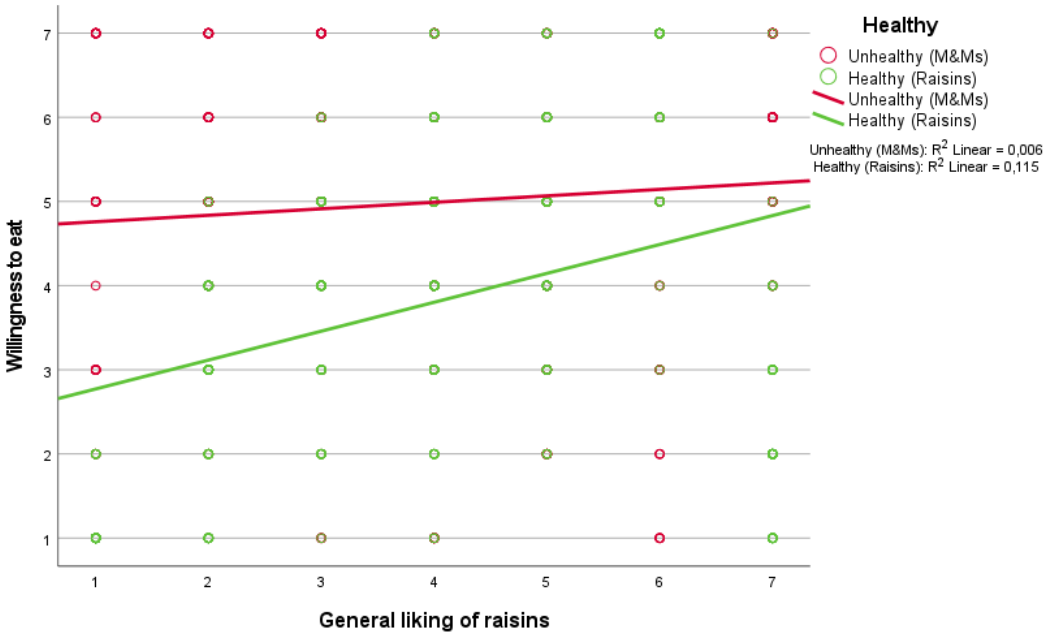

Figure 12. *A scatterplot with General liking of raisins on the x-axis and Willingness to eat on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

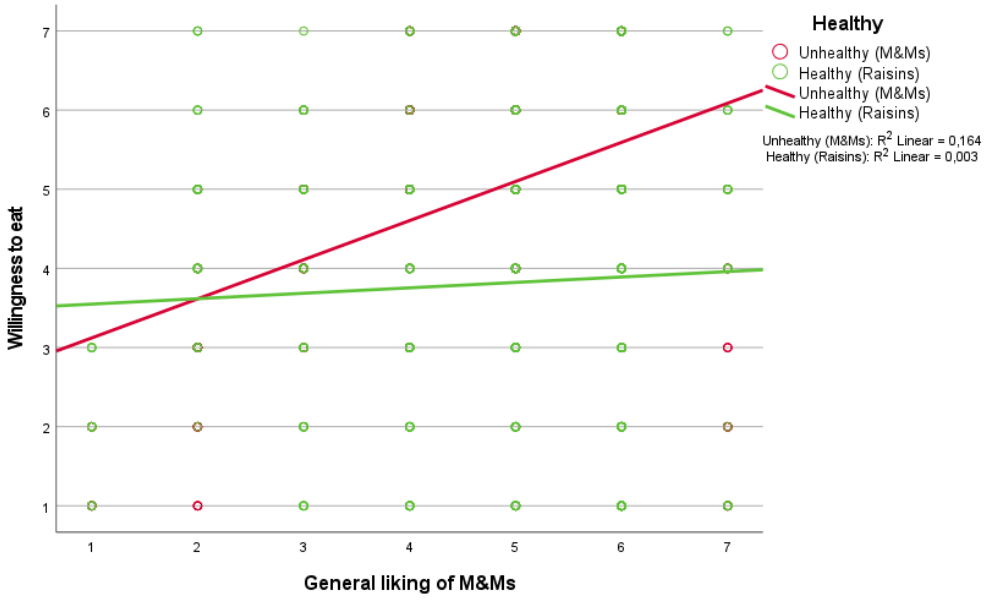

Figure 13. *A scatterplot with General liking of M&Ms on the x-axis and Willingness to eat on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

3.3.1.1. Willingness to eat in Healthy condition

The significance table of the final LMM with Willingness to eat as dependent variable including only the data of the Healthy condition is shown in figure 4.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	131.418	45.023	0.000
Bright	1	347.720	0.047	0.828
Warm	1	340.550	0.179	0.672
sleepiness	1	183.567	0.077	0.782
pleasure	1	293.363	507.780	0.000
arousal	1	340.595	0.957	0.329
Bright * pleasure	1	343.960	0.000	0.990
Bright * arousal	1	345.444	3.268	0.072
Warm * pleasure	1	340.437	0.462	0.497
Warm * arousal	1	341.821	3.092	0.080
Liking_of_raisins	1	108.308	6.830	0.010

Table 4. *The significance table of the final LMM with Willingness to eat as dependent variable. This model only contains data from the Healthy condition. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange.*

Considering only the Healthy condition, the effect of pleasure on Willingness to eat is similar to the main effect found.

Interaction effects between Bright and Warm and pleasure and arousal were not significant.

Willingness to eat also significantly increases with a higher general liking of raisins.

3.3.1.2. Willingness to eat in Unhealthy condition

The significance table of the final LMM with Willingness to eat as dependent variable including only the data of the Unhealthy condition is shown in table 5.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	135.249	13.993	0.000
Bright	1	357.257	1.503	0.221
Warm	1	346.478	0.527	0.468
sleepiness	1	223.344	0.344	0.558
pleasure	1	451.484	189.266	0.000
arousal	1	422.735	3.281	0.071
Bright * pleasure	1	349.852	2.328	0.128
Bright * arousal	1	348.146	9.165	0.003
Warm * pleasure	1	347.316	0.007	0.935
Warm * arousal	1	346.339	1.609	0.205
Liking_of_M_Ms	1	121.738	7.930	0.006

Table 5. *The significance table of the final LMM with Willingness to eat as dependent variable. This model only contains data from the Unhealthy condition. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange*

Considering only the Unhealthy condition, Willingness to eat also significantly increases with a higher level of pleasure, similar to the complete dataset.

The interaction effect between Arousal and Bright is significant, indicating that the effect of Arousal on Willingness to eat was greater in the Dim condition than in the Bright condition, however, the effect is very small (see figure 16).

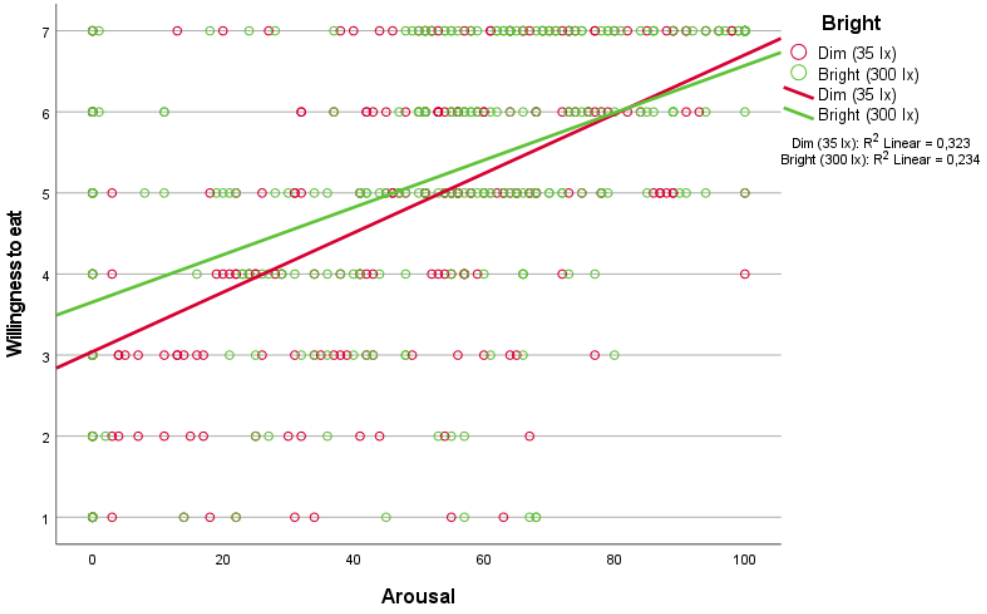

Figure 16. *A scatterplot of data in the Unhealthy condition with Arousal on the x-axis and Willingness to eat on the y-axis. The data-points are marked by the Bright condition, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

Again, liking of M&Ms led to a higher willingness to eat in the Unhealthy condition.

3.3.2. Liking of appearance

The significance table of the final LMM with Willingness to eat as dependent variable is shown in table 5.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	10.290	34.408	0.000
Healthy	1	1711.378	0.483	0.487
Bright	1	1720.021	129.486	0.000
Warm	1	1716.691	90.850	0.000
sleepiness	1	19.265	3.211	0.089
Bright * pleasure	1	1719.352	123.392	0.000
Warm * arousal	1	1718.051	0.281	0.596
Warm * pleasure	1	1717.323	8.119	0.004
Bright * arousal	1	1720.002	0.998	0.318
Healthy * Liking_of_M_Ms	1	15.680	0.423	0.662
Healthy * Liking_of_raisins	1	15.679	0.531	0.598

Table 5. *The significance table of the final LMM with Liking of appearance as dependent variable. Significant effects are highlighted in green.*

The model revealed a significant effect of Bright on Liking of appearance, showing a higher Liking of appearance in the Bright condition (see figure 17).

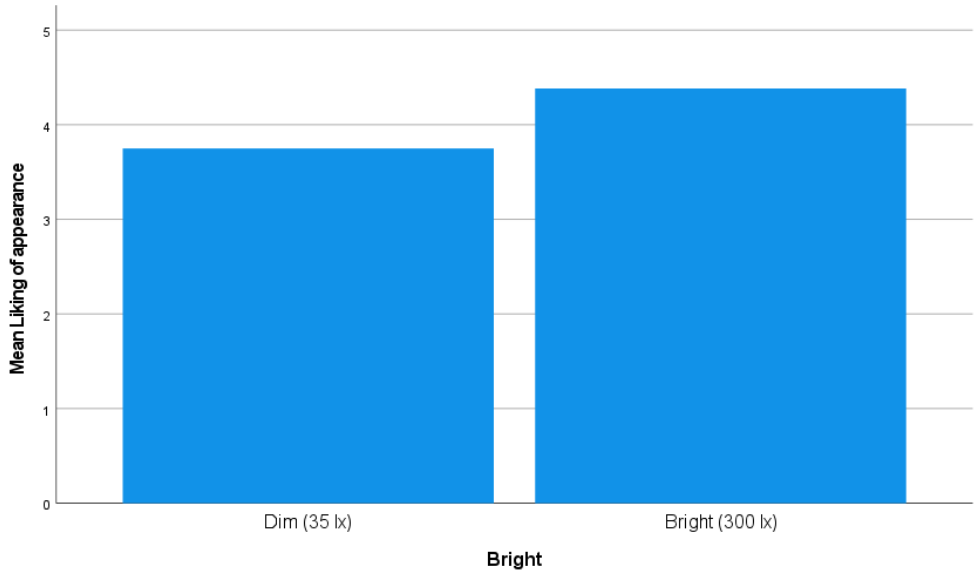

Figure 17. *A bar chart with Bright on the x-axis and mean Liking of appearance on the y-axis.*

The effect of Warm on Liking of appearance was significant as well, showing a higher Liking of appearance in the Cold condition (see figure 18).

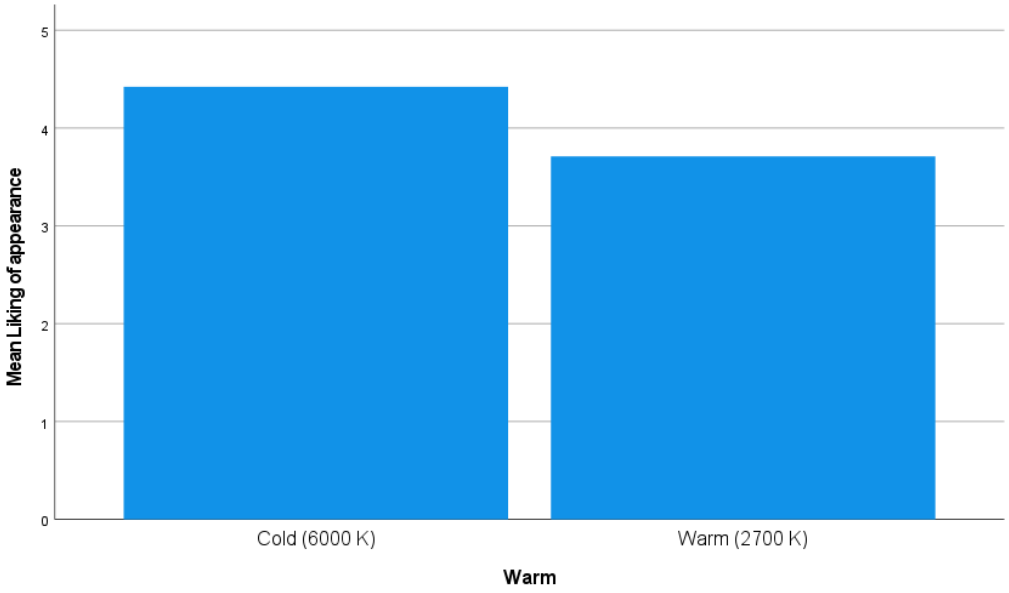

Figure 18. *A bar chart with Warm on the x-axis and mean Liking of appearance on the y-axis.*

The addition of Pleasure and Arousal as singular terms led to the model not achieving convergence. The final model thus dropped these terms from the equation. However, when examined without the interaction effects, Pleasure is found to have a significant effect on Liking of Appearance ($F(1,569) = 175.251$, $p = 0.000$). The effect of Arousal is also significant ($F(1,322) = 6.274$, $p = 0.013$). The direction of the effect is positive, as visualised in figures 19 and 20.

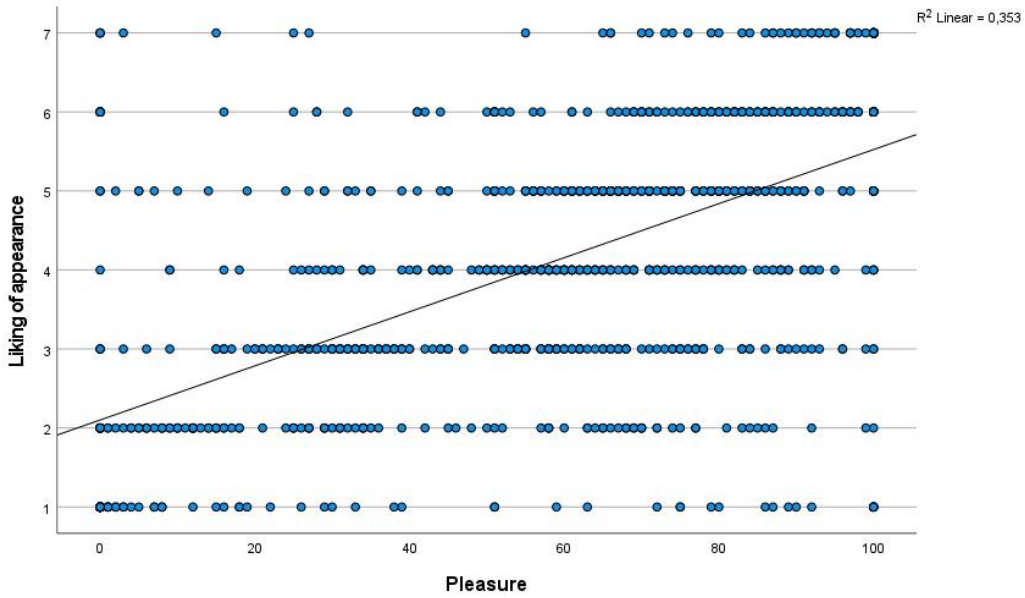

Figure 19. *A scatterplot with Pleasure on the x-axis and Liking of appearance on the y-axis. The effect is visualised with the fitted line through the data-points.*

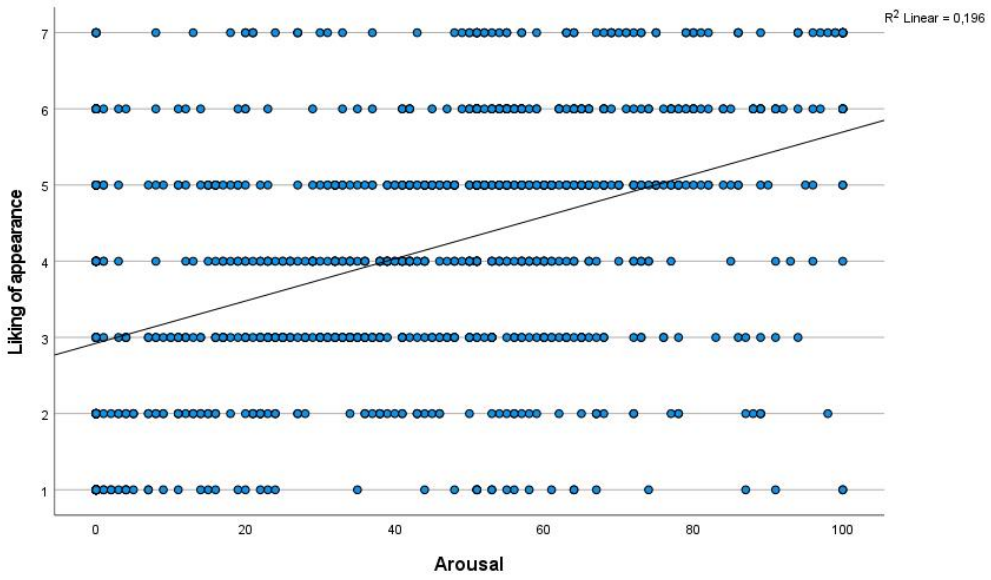

Figure 20. *A scatterplot with Arousal on the x-axis and Liking of appearance on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction between Bright and Pleasure was significant, indicating that the pleasure effect was greater in the bright condition than in the dim condition (see figure 21).

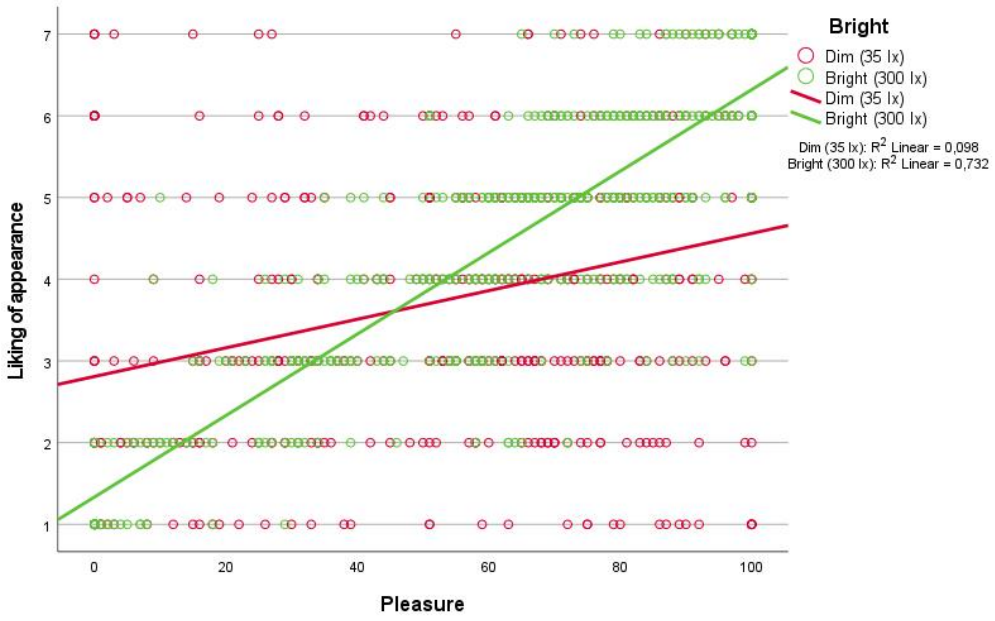

Figure 21. *A scatterplot with Pleasure on the x-axis and Liking of appearance on the y-axis. The data-points are marked by the Bright condition, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

The interaction between Warm and Pleasure was significant as well, however with a much weaker effect, as seen in figure 22.

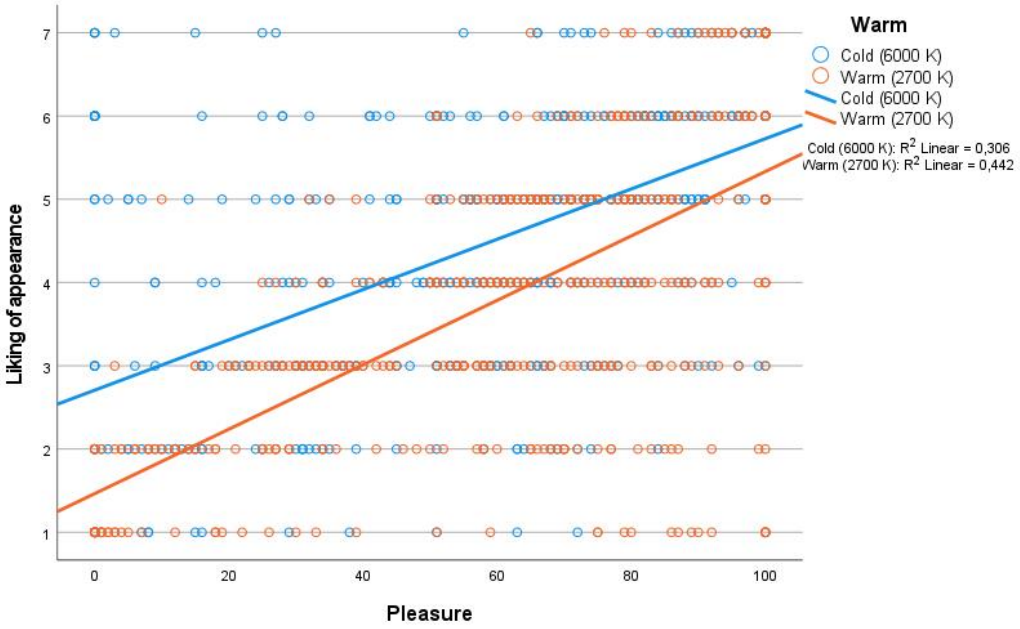

Figure 22. *A scatterplot with Pleasure on the x-axis and Liking of appearance on the y-axis. The data-points are marked by the Warm condition, with the blue colour marking the Cold condition and the orange colour marking the Warm condition. The effect is visualised with the fitted lines through the data-points.*

3.3.2.1. Liking of appearance in Healthy condition

The significance table of the final LMM with Liking of appearance as dependent variable including only the data of the Healthy condition is shown in table 6.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	12.844	83.549	0.000
Bright	1	699.245	98.560	0.000
Warm	1	697.834	148.662	0.000
sleepiness	1	15.061	2.372	0.144
pleasure	1	21.156	104.834	0.000
arousal	1	24.618	1.654	0.210
Bright * pleasure	1	698.760	44.685	0.000
Bright * arousal	1	697.132	0.201	0.654
Warm * pleasure	1	698.780	20.041	0.000
Warm * arousal	1	699.745	8.081	0.005
Liking_of_raisins	1	11.649	0.299	0.595

Table 6. *The significance table of the final LMM with Liking of appearance as dependent variable. This model only contains data from the Healthy condition. Significant effects are highlighted in green.*

In the Healthy condition, similar effects from Bright, Warm, the interaction between Bright and Pleasure and the interaction between Warm and Pleasure were found.

Other than in the general findings, the interaction between Warm and Arousal was significant in the Healthy condition. The effect of arousal was stronger in the Warm condition than in the Cold condition (see figure 23).

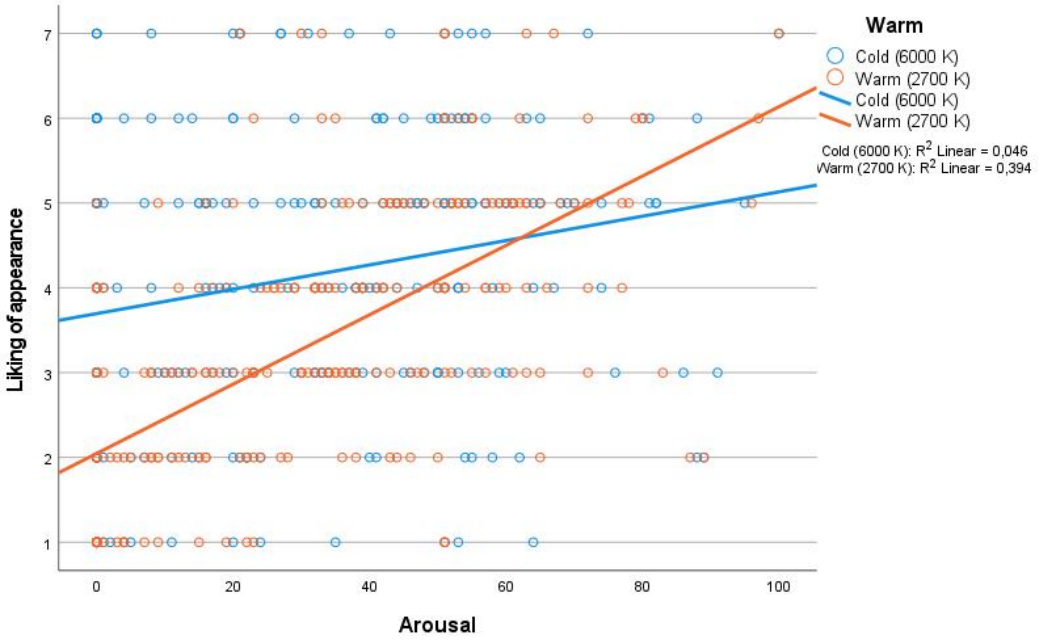

Figure 23. *A scatterplot of data in the Healthy condition with Arousal on the x-axis and Liking of appearance on the y-axis. The data-points are marked by the Warm condition, with the blue colour marking the Cold condition and the orange colour marking the Warm condition. The effect is visualised with the fitted lines through the data-points.*

3.3.2.2. Liking of appearance in Unhealthy condition

The significance table of the final LMM with Liking of appearance as dependent variable including only the data of the Unhealthy condition is shown in table 7.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	127.531	40.740	0.000
Bright	1	375.858	4.166	0.042
Warm	1	364.609	0.000	0.990
sleepiness	1	138.509	3.098	0.081
pleasure	1	220.147	87.156	0.000
arousal	1	197.820	3.608	0.059
Bright * pleasure	1	370.914	22.026	0.000
Bright * arousal	1	370.821	0.060	0.806
Warm * pleasure	1	370.269	2.567	0.110
Warm * arousal	1	365.486	0.333	0.564
Liking_of_M_Ms	1	126.741	0.006	0.937

Table 7. *The significance table of the final LMM with Liking of appearance as dependent variable. This model only contains data from the Unhealthy condition. Significant effects are highlighted in green.*

In the Unhealthy condition, similar effects from Pleasure and the interaction between Bright and Pleasure were found. The effect of Bright on Liking of appearance was similar to the effect found in the general dataset. The effect of Warm was insignificant. The other interaction effects found over all conditions and in the Healthy condition were insignificant in the Unhealthy condition.

3.3.3. Perceived appetite satisfaction

The significance table of the final LMM with Perceived appetite satisfaction as dependent variable is shown in table 8.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	129.807	1.081	0.300
Healthy	1	830.565	14.817	0.000
Bright	1	832.365	0.000	0.990
Warm	1	829.554	0.586	0.444
sleepiness	1	352.516	0.053	0.818
Bright * pleasure	1	830.323	0.515	0.473
Warm * arousal	1	829.687	0.898	0.344
Warm * pleasure	1	829.181	0.043	0.835
Bright * arousal	1	831.164	1.427	0.233
Healthy * Liking_of_M_Ms	2	202.770	0.846	0.431
Healthy * Liking_of_raisins	2	202.420	10.219	0.000
Healthiness	1	114.082	0.720	0.398
Healthy * Healthiness	1	830.485	19.087	0.000

Table 8. *The significance table of the final LMM with Perceived appetite satisfaction as dependent variable. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange.*

The model revealed a significant effect of Healthy. Perceived appetite satisfaction was higher for the Unhealthy condition (see figure 25).

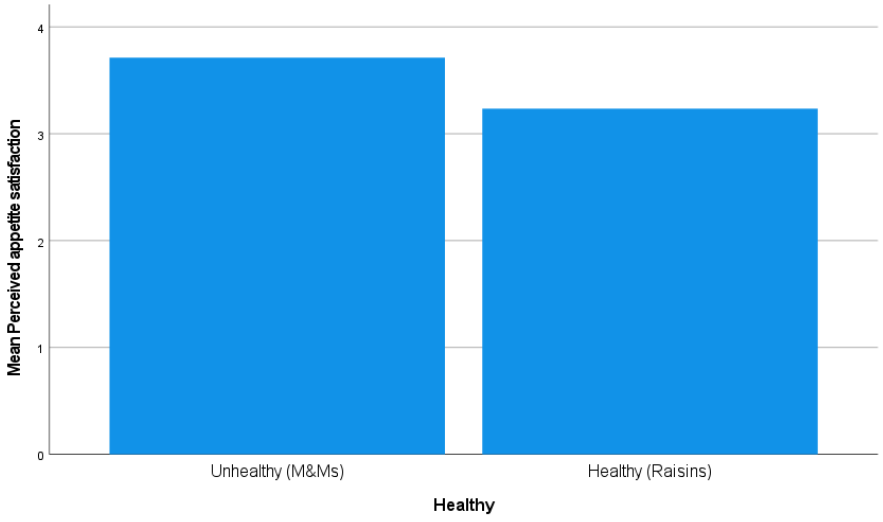

Figure 25. *A bar chart with Healthy on the x-axis and mean Perceived appetite satisfaction on the y-axis.*

Similar to the LMM on Willingness to eat, the addition of Pleasure and Arousal as singular terms led to the model not achieving convergence. The final model thus dropped these terms from the equation. However, when examined without the interaction effects, Pleasure is found to have a significant effect on Liking of Appearance ($F(1,944) = 288.254$, $p = 0.000$). The effect

of Arousal is also significant (F(1,928) = 23.308, p = 0.000). The direction of the effect is positive, as visualised in figures 26 and 27.

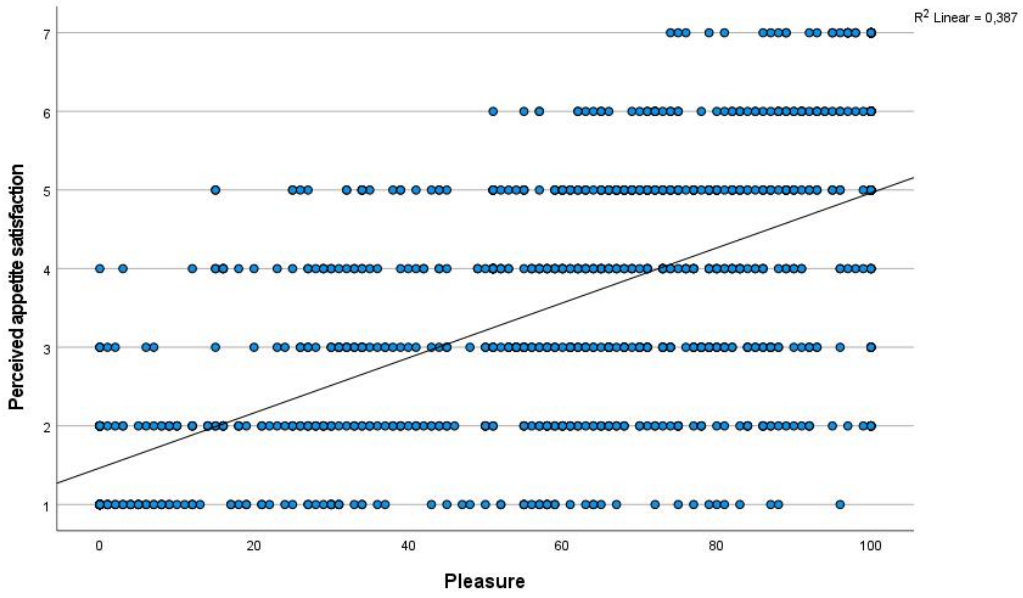

Figure 26. *A scatterplot with Pleasure on the x-axis and Perceived appetite satisfaction on the y-axis. The effect is visualised with the fitted line through the data-points.*

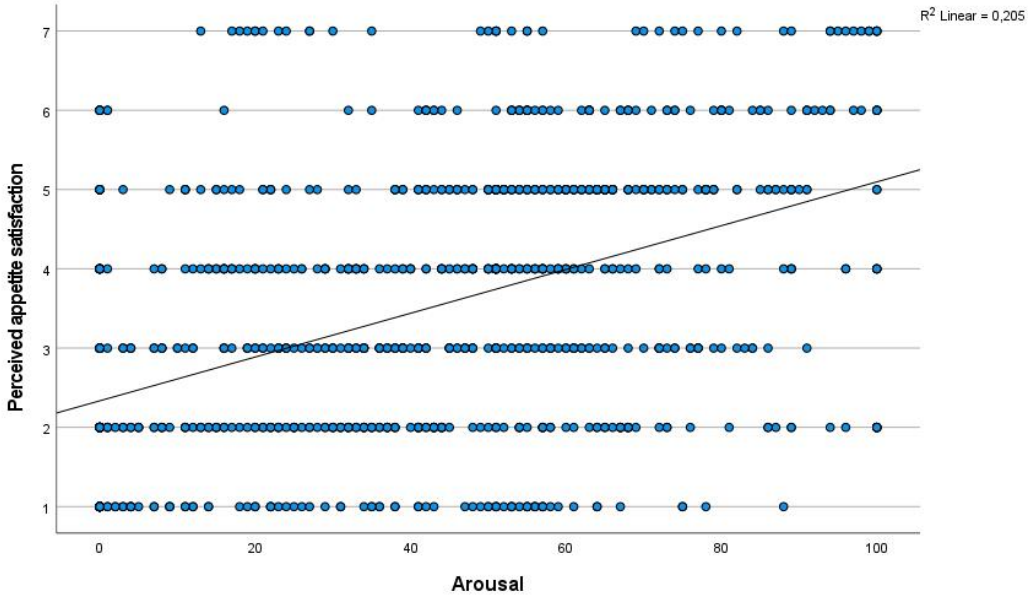

Figure 27. *A scatterplot with Arousal on the x-axis and Perceived appetite satisfaction on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction between Healthy and Liking of raisins was significant as well: the effect of Liking of raisins was somewhat stronger in the Healthy condition than in the Unhealthy condition. This effect is very small, as also indicated by the low Goodness of Fit of the fitted lines (R^2 = 0.0006 and 0.121) (see figure 28).

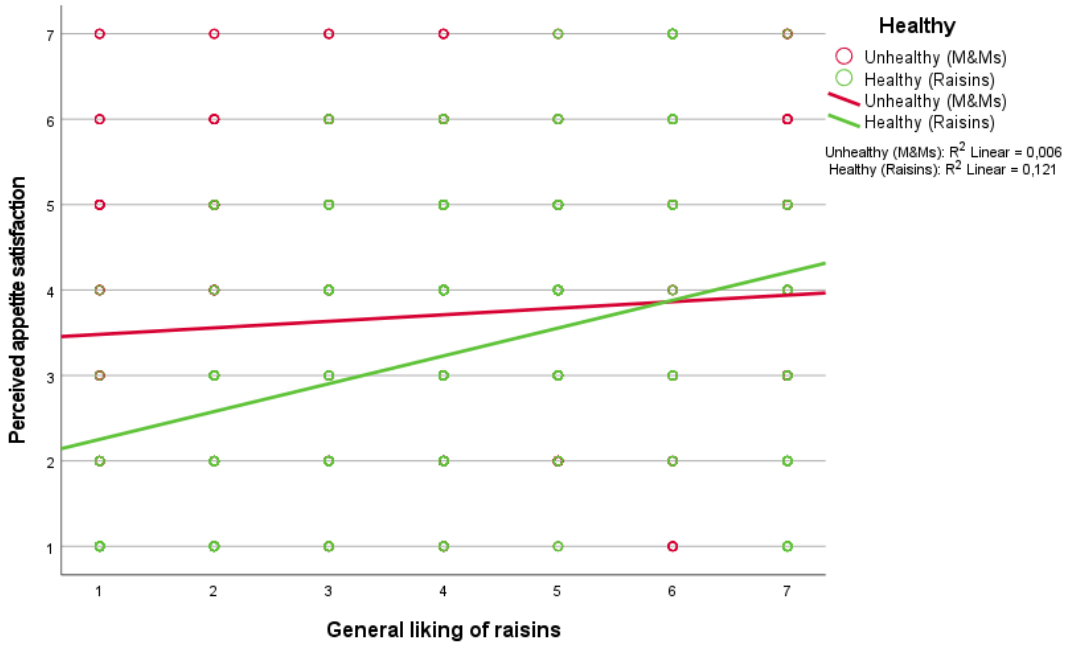

Figure 28. *A scatterplot with General liking of raisins on the x-axis and Perceived appetite satisfaction on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

A small significant effect was found for the interaction between Healthy and Healthiness (the extent to which a participant generally focuses on healthy eating), where Healthiness has a stronger effect on Perceived appetite satisfaction in the Healthy condition than in the Unhealthy condition (see figure 29).

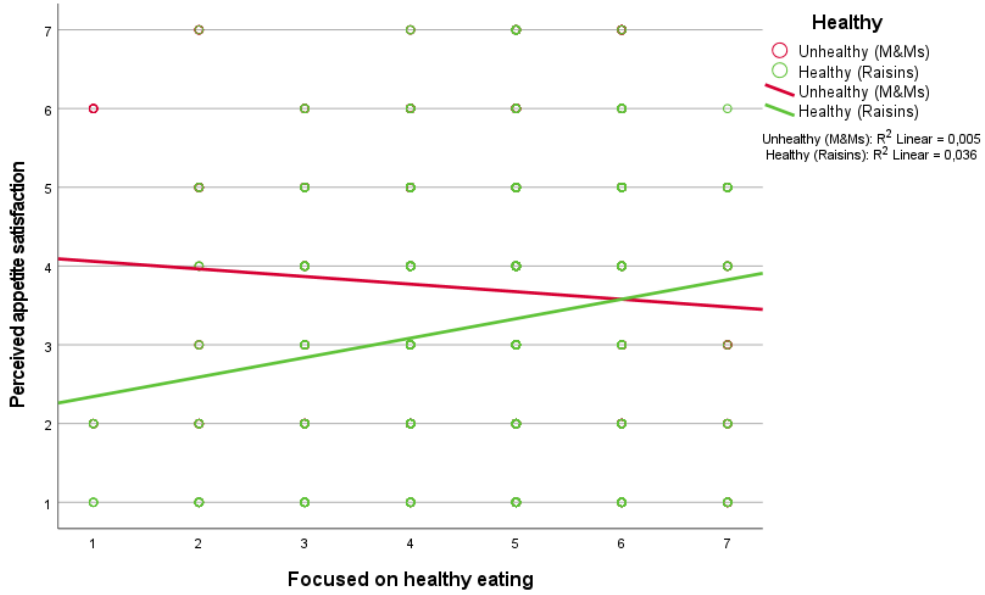

Figure 29. *A scatterplot with Healthiness on the x-axis and Perceived appetite satisfaction on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

3.3.3.1. Perceived appetite satisfaction in Healthy condition

The significance table of the final LMM with Perceived appetite satisfaction as dependent variable including only the data of the Healthy condition is shown in table 9.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	133.520	1.309	0.255
Bright	1	355.644	2.911	0.089
Warm	1	351.364	0.284	0.594
sleepiness	1	358.516	2.035	0.155
pleasure	1	463.851	70.750	0.000
arousal	1	467.901	29.785	0.000
Bright * pleasure	1	351.366	0.037	0.847
Bright * arousal	1	352.261	1.653	0.199
Warm * pleasure	1	350.322	1.094	0.296
Warm * arousal	1	350.767	2.539	0.112
Liking_of_raisins	1	119.880	5.680	0.019
Healthiness	1	114.465	3.927	0.050

Table 9. *The significance table of the final LMM with Perceived appetite satisfaction as dependent variable. This model only contains data from the Healthy condition. Significant effects are highlighted in green.*

In the Healthy condition, significant effects similar to the combined dataset were found, with the addition of a trend towards significance of Bright on Perceived appetite satisfaction. The direction of this trend is towards the Bright condition, as visualised in figure 30.

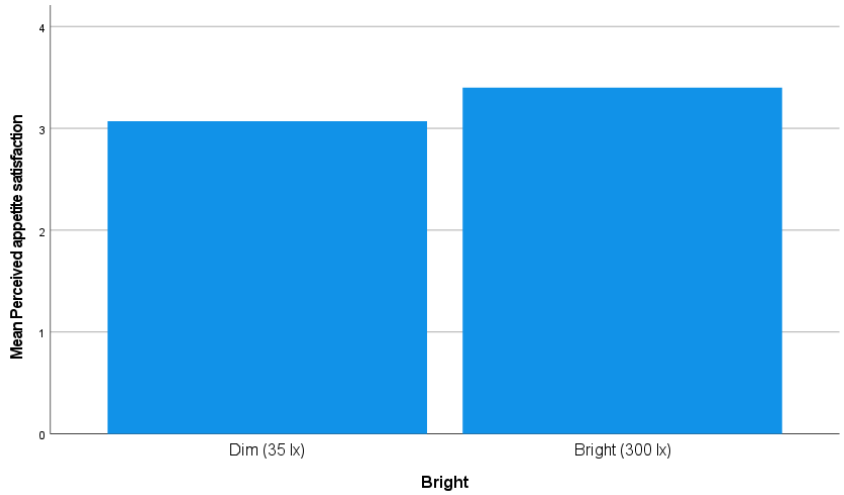

Figure 30. *A bar chart of data in the Healthy condition with Bright on the x-axis and mean Perceived appetite satisfaction on the y-axis.*

3.3.3.2. Perceived appetite satisfaction in Unhealthy condition

The significance table of the final LMM with Perceived appetite satisfaction as dependent variable including only the data of the Unhealthy condition is shown in table 10.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	122.859	8.300	0.005
Bright	1	357.433	1.020	0.313
Warm	1	351.362	1.570	0.211
pleasure	1	458.141	48.037	0.000
arousal	1	467.341	5.579	0.019
Bright * pleasure	1	353.407	2.084	0.150
Bright * arousal	1	352.234	1.826	0.177
Warm * pleasure	1	351.779	1.682	0.196
Warm * arousal	1	351.152	0.079	0.779
Liking_of_M_Ms	1	124.910	2.375	0.126

Table 10. *The significance table of the final LMM with Perceived appetite satisfaction as dependent variable. This model only contains data from the Unhealthy condition. Significant effects are highlighted in green.*

The Unhealthy condition shows similar significant effects for Pleasure and Arousal, but not for the Healthiness or Liking of raisins.

3.3.4. Predicted food intake

The significance table of the final LMM with Predicted food intake as dependent is shown in table 11.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	137.271	6.347	0.013
Healthy	1	828.661	0.155	0.694
Bright	1	834.876	1.340	0.247
Warm	1	831.370	0.214	0.644
sleepiness	1	271.349	1.561	0.213
Bright * pleasure	1	833.351	3.251	0.072
Warm * arousal	1	832.184	0.901	0.343
Warm * pleasure	1	831.553	0.118	0.731
Bright * arousal	1	834.424	3.939	0.047
Healthy * Liking_of_M_Ms	2	205.001	4.702	0.010
Healthy * Liking_of_raisins	2	204.616	3.976	0.020

Table 11. *The significance table of the final LMM with Predicted food intake as dependent variable. Significant effects are highlighted in green.*

Similar to the LMM on Willingness to eat and Perceived appetite satisfaction, the addition of Pleasure and Arousal as singular terms led to the model not achieving convergence. The final model thus dropped these terms from the equation. However, when examined without the interaction effects, Pleasure is found to have a significant effect on Liking of Appearance ($F(1,947) = 897.116$, $p = 0.000$). The effect of Arousal is also significant ($F(1,888) = 8.101$, $p = 0.005$). The direction of the effect is positive, as visualised in figures 31 and 32.

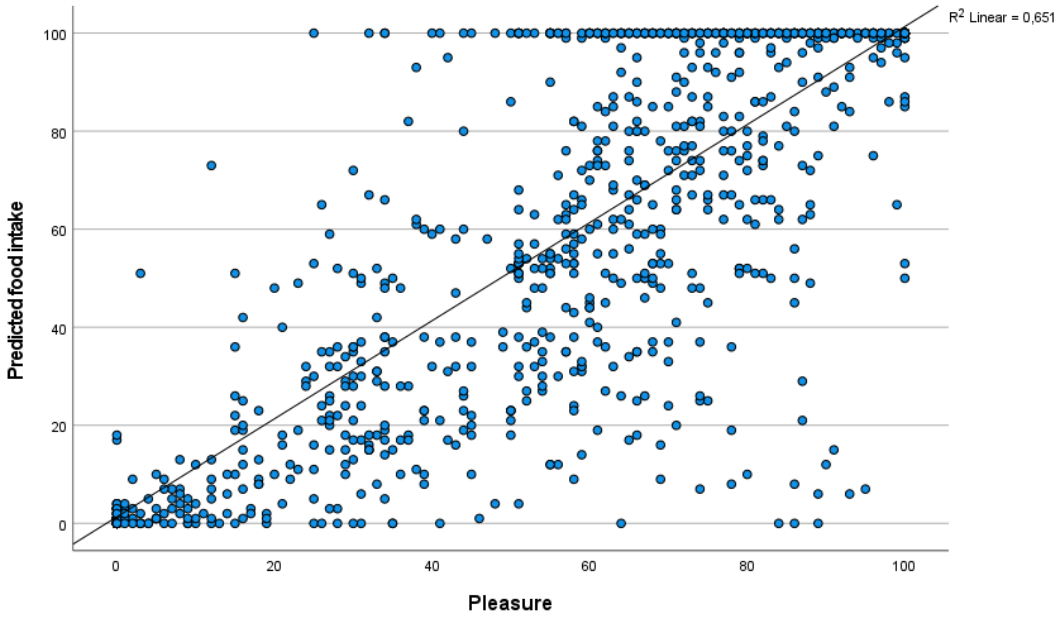

Figure 31. *A scatterplot with Pleasure on the x-axis and Predicted food intake on the y-axis. The effect is visualised with the fitted line through the data-points.*

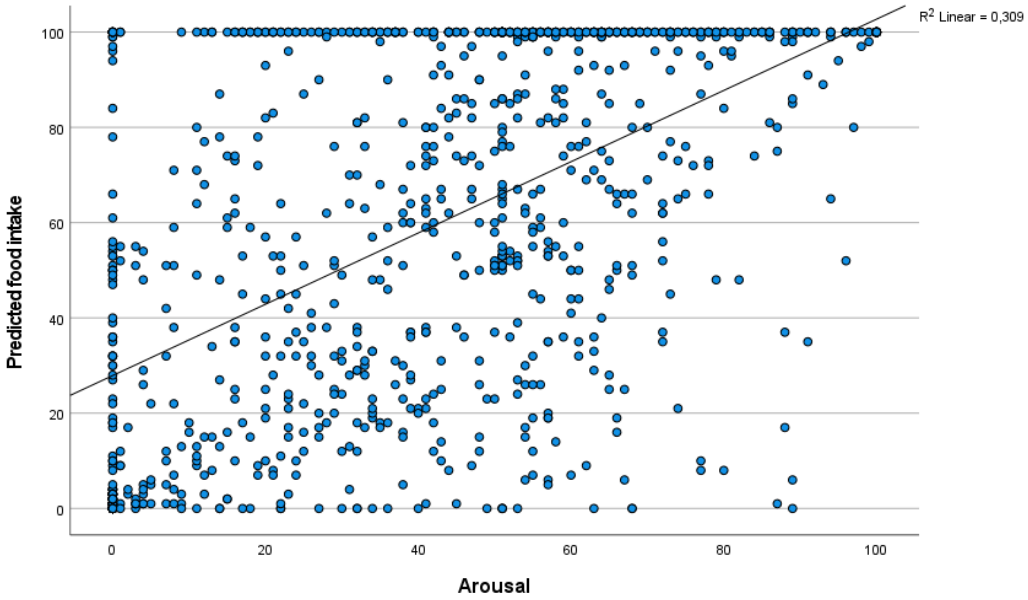

Figure 32. *A scatterplot with Arousal on the x-axis and Predicted food intake on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction between Bright and Arousal is significant: the effect of Arousal on Predicted food intake is slightly stronger in the Dim condition, as seen in figure 33.

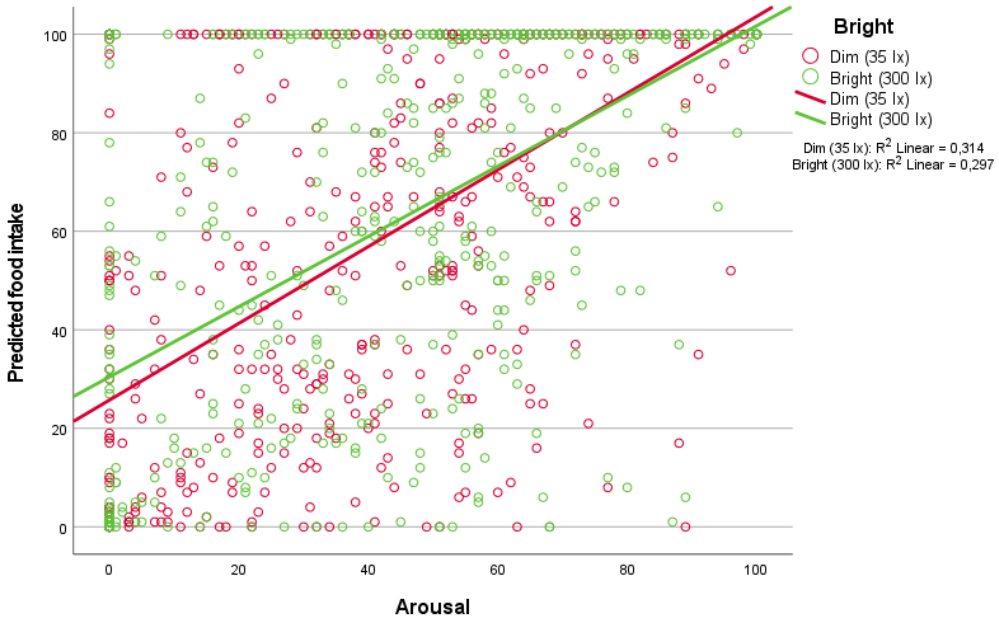

Figure 33. *A scatterplot with Arousal on the x-axis and Predicted food intake on the y-axis. The data-points are marked by the Bright condition, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

Again, the interaction between Healthy and Liking of raisins was significant, as well as the interaction between Healthy and Liking of M&Ms (see figure 34 and 35). Predicted food intake was higher for the unhealthy condition in all cases, but the Liking of raisins effect on Predicted food intake was stronger in the Healthy condition than in the Unhealthy condition. The Liking of M&Ms effect was stronger in the Unhealthy condition than in the Healthy condition.

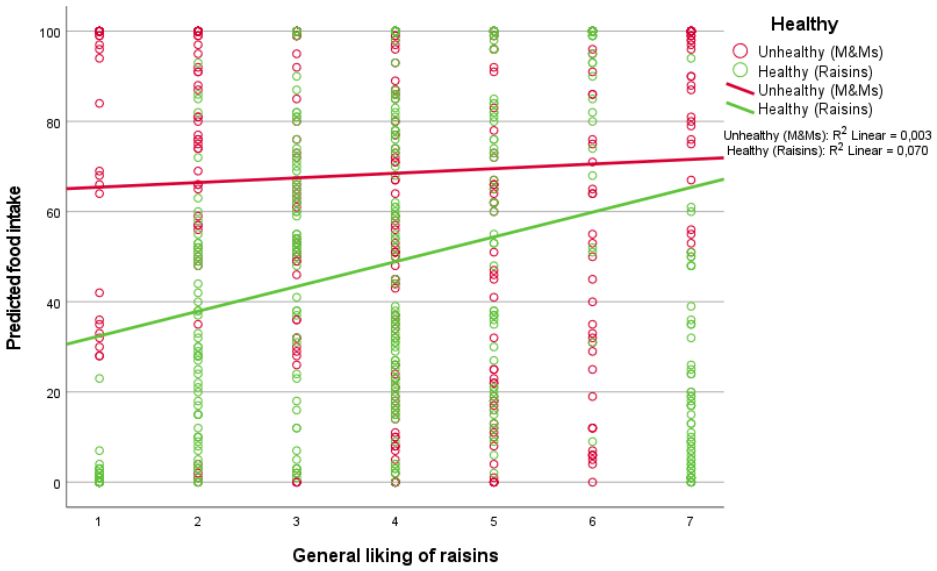

Figure 34. *A scatterplot with General liking of raisins on the x-axis and Predicted food intake on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

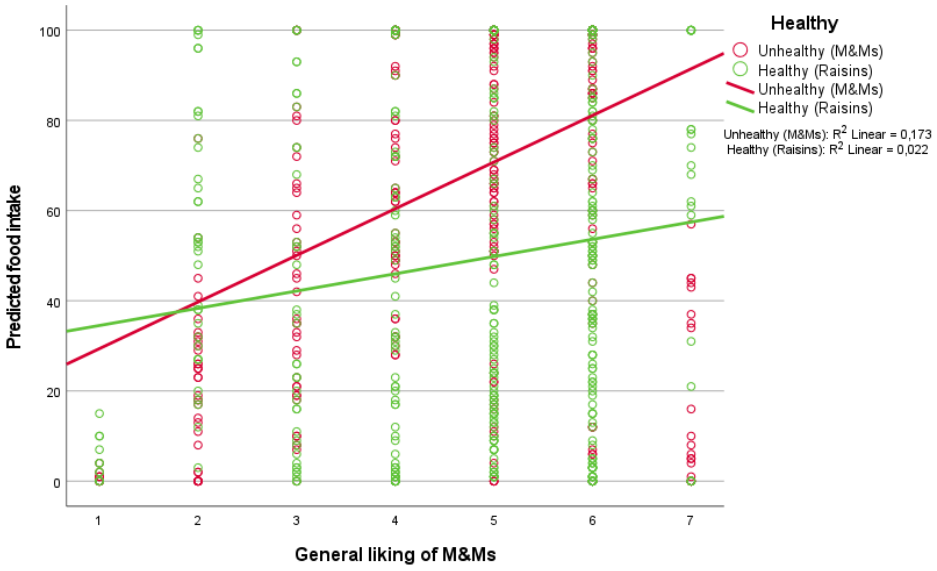

Figure 35. *A scatterplot with General liking of M&Ms on the x-axis and Predicted food intake on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

3.3.4.1. Predicted food intake in Healthy condition

The significance table of the final LMM with Predicted food intake as dependent variable including only the data of the Healthy condition is shown in table 12.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	155.662	1.011	0.316
Bright	1	344.953	0.076	0.783
Warm	1	340.596	0.034	0.854
sleepiness	1	372.018	0.425	0.515
pleasure	1	468.001	197.905	0.000
arousal	1	466.611	8.527	0.004
Bright * pleasure	1	340.455	0.984	0.322
Bright * arousal	1	341.324	0.000	0.983
Warm * pleasure	1	339.448	0.396	0.530
Warm * arousal	1	339.898	2.775	0.097
Liking_of_raisins	1	110.146	1.530	0.219

Table 12. *The significance table of the final LMM with Predicted food intake as dependent variable. This model only contains data from the Healthy condition. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange.*

In the Healthy condition, significant effects similar to the combined dataset were found.

3.3.4.2. Predicted food intake in Unhealthy condition

The significance table of the final LMM with Predicted food intake as dependent variable including only the data of the Unhealthy condition is shown in table 13.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	119.379	0.265	0.607
Bright	1	354.082	0.099	0.753
Warm	1	347.904	1.382	0.241
pleasure	1	457.541	146.988	0.000
arousal	1	467.155	4.611	0.032
Bright * pleasure	1	349.984	3.980	0.047
Bright * arousal	1	348.790	7.043	0.008
Warm * pleasure	1	348.327	1.220	0.270
Warm * arousal	1	347.690	0.040	0.842
Liking_of_M_Ms	1	121.389	12.068	0.001

Table 13. *The significance table of the final LMM with Predicted food intake as dependent variable. This model only contains data from the Unhealthy condition. Significant effects are highlighted in green.*

In the Healthy condition, significant effects similar to the combined dataset were found. The interaction between Bright and Pleasure is significant in the Unhealthy condition, where the Pleasure effect is stronger in the Bright condition, however, this effect is very small (see figure 36).

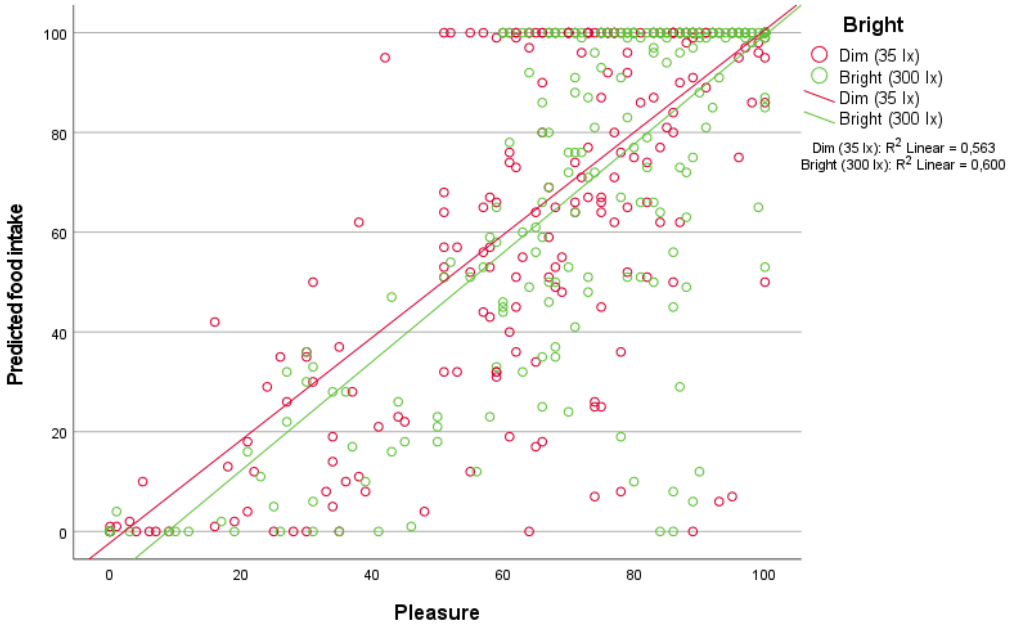

Figure 36. *A scatterplot of data in the Unhealthy condition with Pleasure on the x-axis and Predicted food intake on the y-axis. The data-points are marked by the Bright condition, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

3.3.5. Food choice

A McNemar test showed that the two food choices were different between all dim and bright warm-conditions, p = .001 (2 sided). Participants tend to choose food choice option 2 (M&Ms) in all conditions but show a stronger tendency towards option 2 in both the Dim Warm (M = 1.72, SD = 0.45) and the Dim Cold (M = 1.74, SD = 0.44) conditions, compared to the Bright Warm (M = 1.66, SD = 0.47) and the Bright Cold (M = 1.66, SD = 0.47) conditions.

3.3.6. Correlations between eating behaviour measures

A correlation matrix (table 14) shows that all dependent variables of eating behaviour are significantly correlated (correlation is significant at the 0.01 level, 2-tailed), varying from moderately (0.5 > r < 0.7) to strongly (r > 0.7). The strongest correlation exists between Willingness to eat and Predicted food intake (r = 0.86).

		Liking of appearance	Willingness to eat	Perceived appetite satisfaction	Predicted food intake
Liking of appearance	Pearson Correlation	1	.602**	.521**	.502**
	Sig. (2-tailed)		0.000	0.000	0.000
	N	960	960	960	960
Willingness to eat	Pearson Correlation	.602**	1	.684**	.862**
	Sig. (2-tailed)	0.000		0.000	0.000
	N	960	960	960	960
Perceived appetite satisfaction	Pearson Correlation	.521**	.684**	1	.618**
	Sig. (2-tailed)	0.000	0.000		0.000

	N	960	960	960	960
Predicted food intake	Pearson Correlation	.502**	.862**	.618**	1
	Sig. (2-tailed)	0.000	0.000	0.000	
	N	960	960	960	960

Table 14. *The correlation matrix of all dependent variables of eating behaviour. Significant effects (two-tailed) are highlighted in green.*

3.3.7. Effects on Pleasure, Arousal and Sleepiness

In the main models, Pleasure was found to be mostly influenced by Bright and sometimes by Warm. The influence of other possible variables was examined as well.

The Pearson Correlation between Pleasure and Arousal was somewhat strong (r=0.68) and significant (p=0.000, 2-tailed).

3.3.7.1. Effects on Pleasure

Table 15 shows the significance table of the LMM with Pleasure as dependent variable.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	117.000	18.193	0.000
Healthy	1	835.000	0.455	0.500
Bright	1	835.000	31.997	0.000
Warm	1	835.000	0.894	0.345
Liking_of_raisins	1	117.000	17.105	0.000
Liking_of_M_Ms	1	117.000	10.028	0.002
Healthy * Liking_of_raisins	1	835.000	18.737	0.000
Healthy * Liking_of_M_Ms	1	835.000	61.630	0.000

Table 15. *The significance table of the final LMM with Pleasure as dependent variable. Significant effects are highlighted in green.*

Healthy and Warm are not significant. Bright is significant and has a positive effect on Pleasure, as seen in figure 37.

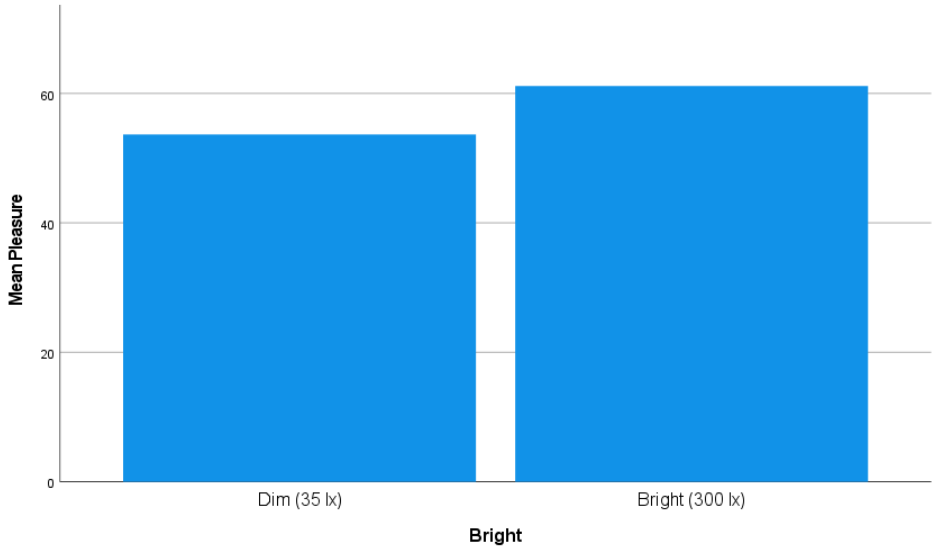

Figure 37. *A bar chart with Bright on the x-axis and mean Pleasure on the y-axis.*

Liking of raisins and Liking of M&Ms both have a positive, significant effect on Pleasure (see Figure 38 and 39).

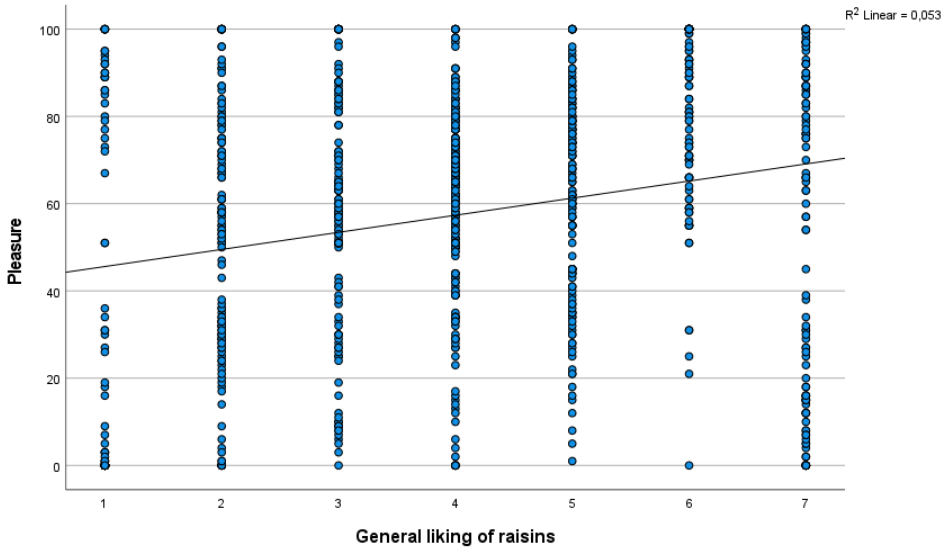

Figure 38. *A scatterplot with General liking of raisins on the x-axis and Pleasure on the y-axis. The effect is visualised with the fitted line through the data-points.*

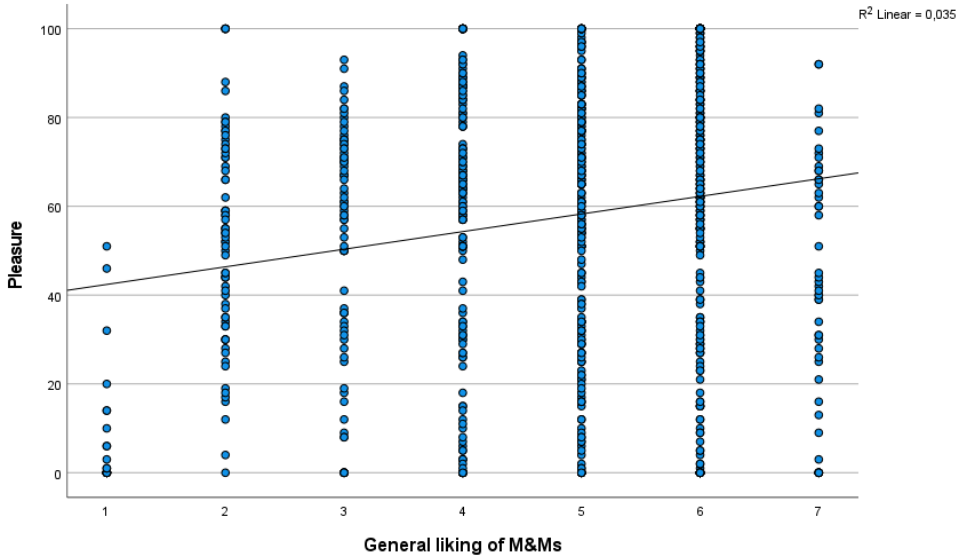

Figure 39. *A scatterplot with General liking of M&Ms on the x-axis and Pleasure on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction effect between Healthy and Liking of raisins on Pleasure is also significant: Pleasure is generally lower in the Healthy condition than in the Unhealthy condition, but the effect of Liking of raisins is stronger in the Healthy condition than in the Unhealthy condition (see figure 40).

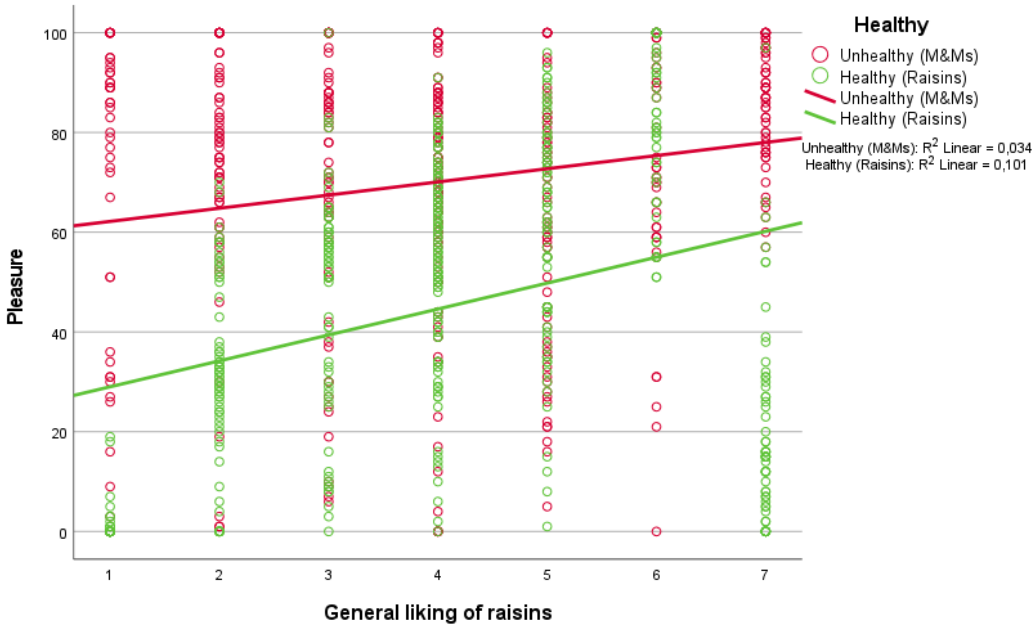

Figure 40. *A scatterplot with General liking of raisins on the x-axis and Pleasure on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

The interaction effect between Healthy and Liking of M&Ms on Pleasure is significant as well: Pleasure is generally higher in the Unhealthy condition than in the Healthy condition. The effect of Liking of M&Ms is stronger in the Unhealthy condition than in the Healthy condition (see figure 41).

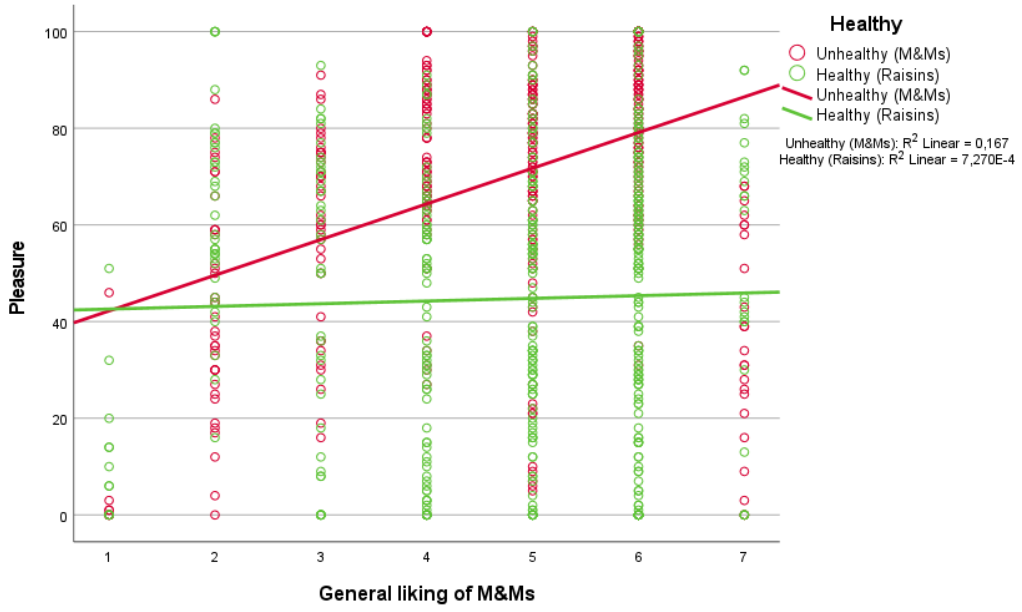

Figure 41. *A scatterplot with General liking of M&Ms on the x-axis and Pleasure on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

3.3.7.2. Effects on Arousal

Table 16 shows the significance table of the LMM with Arousal as dependent variable.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	128.588	13.985	0.000
Healthy	1	826.540	0.067	0.796
Bright	1	847.485	20.441	0.000
Warm	1	824.778	0.052	0.820
sleepiness	1	408.637	19.667	0.000
Liking_of_raisins	1	107.788	2.017	0.158
Healthy * Liking_of_raisins	1	827.122	45.588	0.000
Liking_of_M_Ms	1	107.965	6.370	0.013
Healthy * Liking_of_M_Ms	1	824.791	88.047	0.000

Table 16. *The significance table of the final LMM with Arousal as dependent variable. Significant effects are highlighted in green.*

Healthy and Warm are again not significant.

Bright is significant and has a positive effect on Arousal, as seen in figure 42.

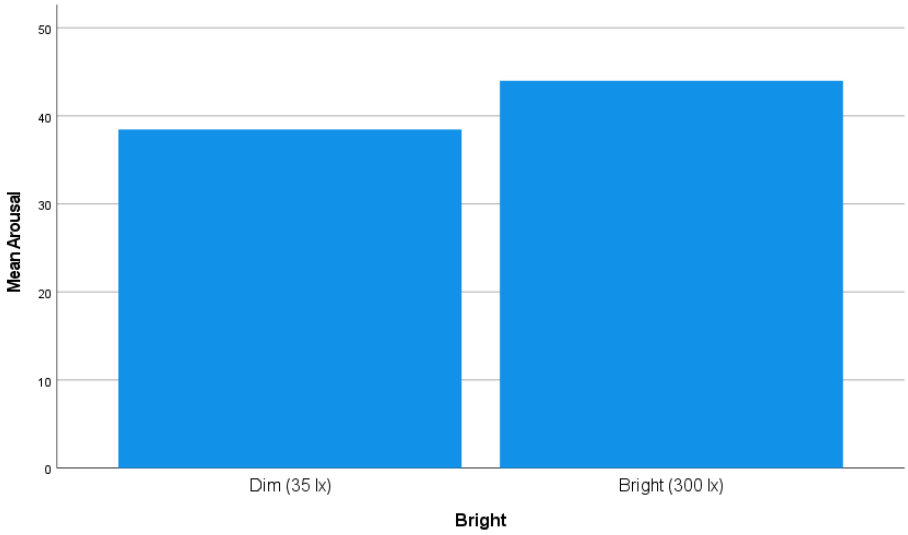

Figure 42. *A bar chart with Bright on the x-axis and mean Arousal on the y-axis.*

Sleepiness has a significant effect on Arousal in the negative direction (see figure 43).

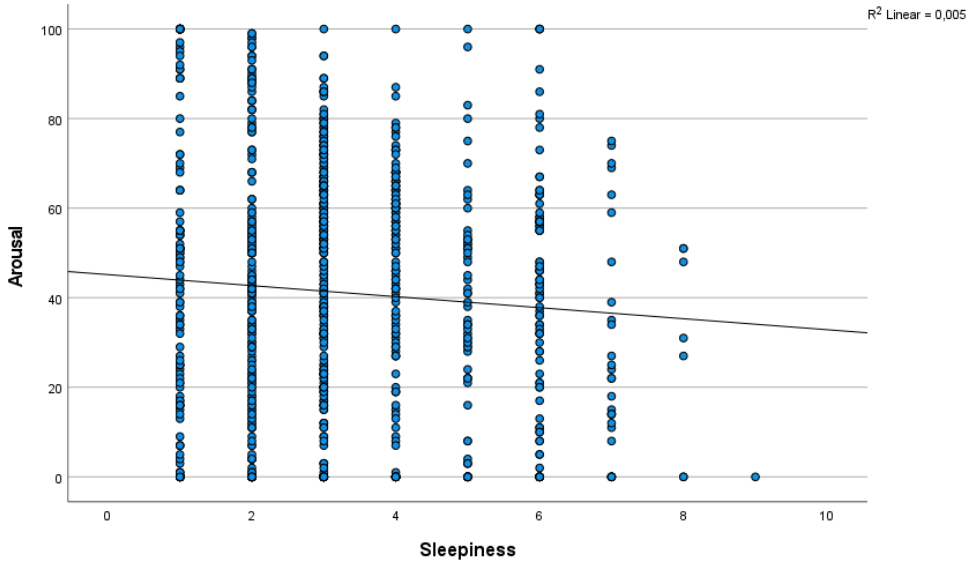

Figure 43. *A scatterplot with Sleepiness on the x-axis and Arousal on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction effect between Healthy and Liking of raisins on Arousal is also significant: Arousal is generally lower in the Healthy condition than in the Unhealthy condition, but the effect of Liking of raisins is stronger in the Healthy condition than in the Unhealthy condition (see figure 44).

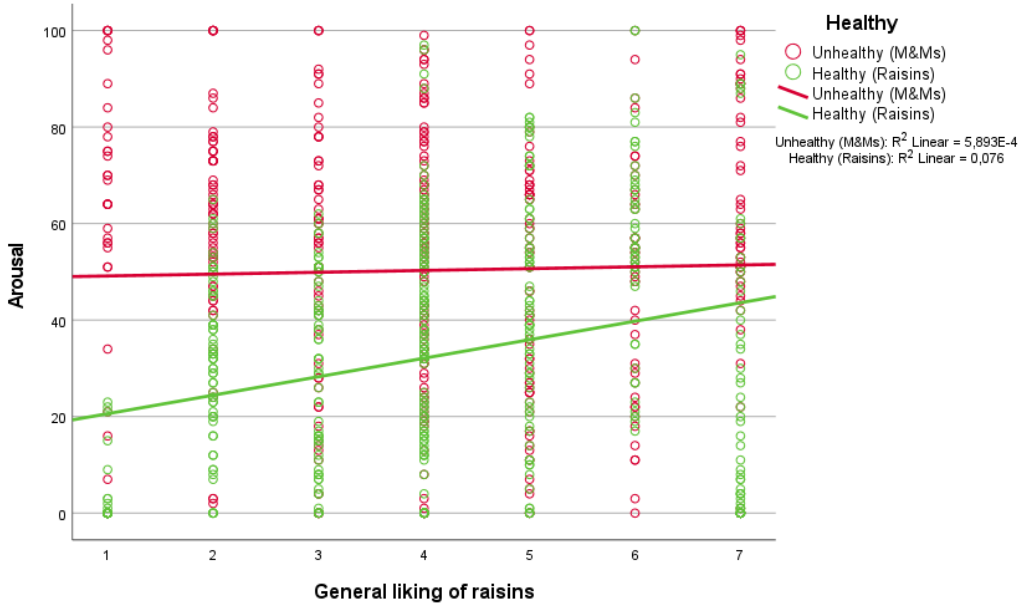

Figure 44. *A scatterplot with General liking of raisins on the x-axis and Arousal on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

The interaction effect between Healthy and Liking of M&Ms on Arousal is significant as well: Arousal is generally higher in the Unhealthy condition than in the Healthy condition. The effect of Liking of M&Ms is stronger in the Unhealthy condition than in the Healthy condition (see figure 45).

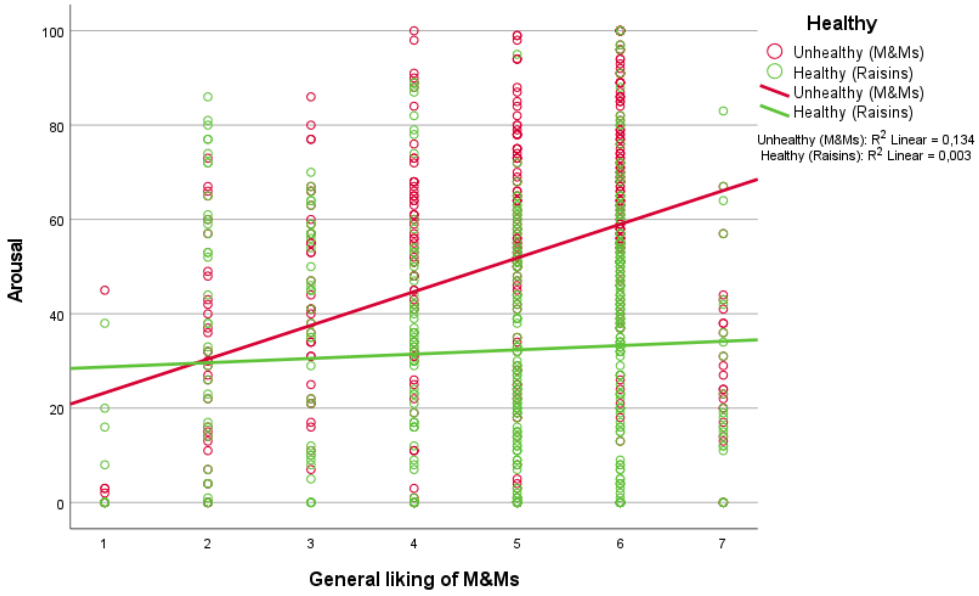

Figure 45. *A scatterplot with General liking of M&Ms on the x-axis and Arousal on the y-axis. The data-points are marked by the Healthy condition, with the red colour marking the Unhealthy condition and the green colour marking the Healthy condition. The effect is visualised with the fitted lines through the data-points.*

3.3.7.3. Effects on Sleepiness

Table 17 shows the significance table for the LMM with Sleepiness as dependent variable.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	141.474	522.984	0.000
Healthy	1	840.330	3.178	0.075
Bright	1	835.702	30.801	0.000
Warm	1	835.064	0.057	0.811
pleasure	1	858.424	2.518	0.113
arousal	1	869.971	10.855	0.001

Table 17. *The significance table of the final LMM with Arousal as dependent variable. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange.*

The effect of Bright on Sleepiness was significant, showing a higher level of Sleepiness in the Dim condition compared to the Bright condition (see figure 47).

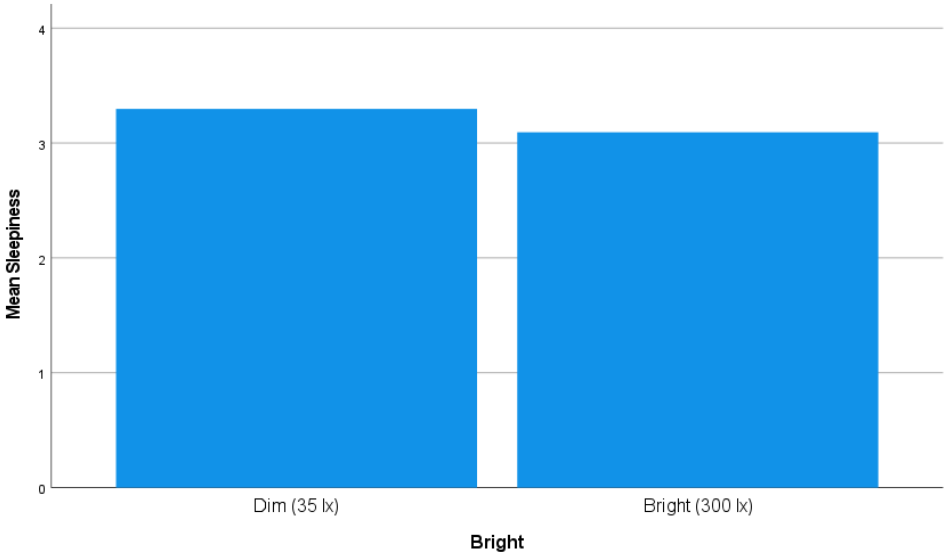

Figure 47. *A bar chart with Bright on the x-axis and mean Sleepiness on the y-axis.*

3.4. Discussion

The main exploratory research question that Study 1 was trying to answer was:

Main RQ Study 1:
"To what extent, if any, does emotional state and other factors influence the effect of ambient light on eating behaviour?"

- To answer this question, different exploratory sub-questions were formulated: RQ1.1. Does ambient light directly influence eating behaviour of healthy and unhealthy snacks, and if yes, to what extent?
- RQ.1.2. Is eating behaviour of healthy and unhealthy snacks directly influenced by emotional state, and if yes, to what extent?
- RQ.1.3. Is emotional state directly influenced by ambient light, and if yes, to what extent?
- RQ.1.4. Is eating behaviour of healthy and unhealthy snacks directly influenced by mental alertness, and if yes, to what extent?
- RQ.1.5. Is eating behaviour of healthy and unhealthy snacks directly influenced by other variables, such as hungriness, healthiness, liking of raisins, liking of M&Ms, age, and gender, and if yes, to what extent?
- RQ1.6. Does emotional state have a mediating or moderating effect on the influence of ambient light on eating behaviour, and if yes, to what extent?

In this section, these research questions will be answered one by one.

An overview diagram of all statistically significant effects is given in figure 48 and 49. The diagram was split into two, with figure 48 showcasing the effects of Pleasure and figure 49 showcasing the effects of Arousal.

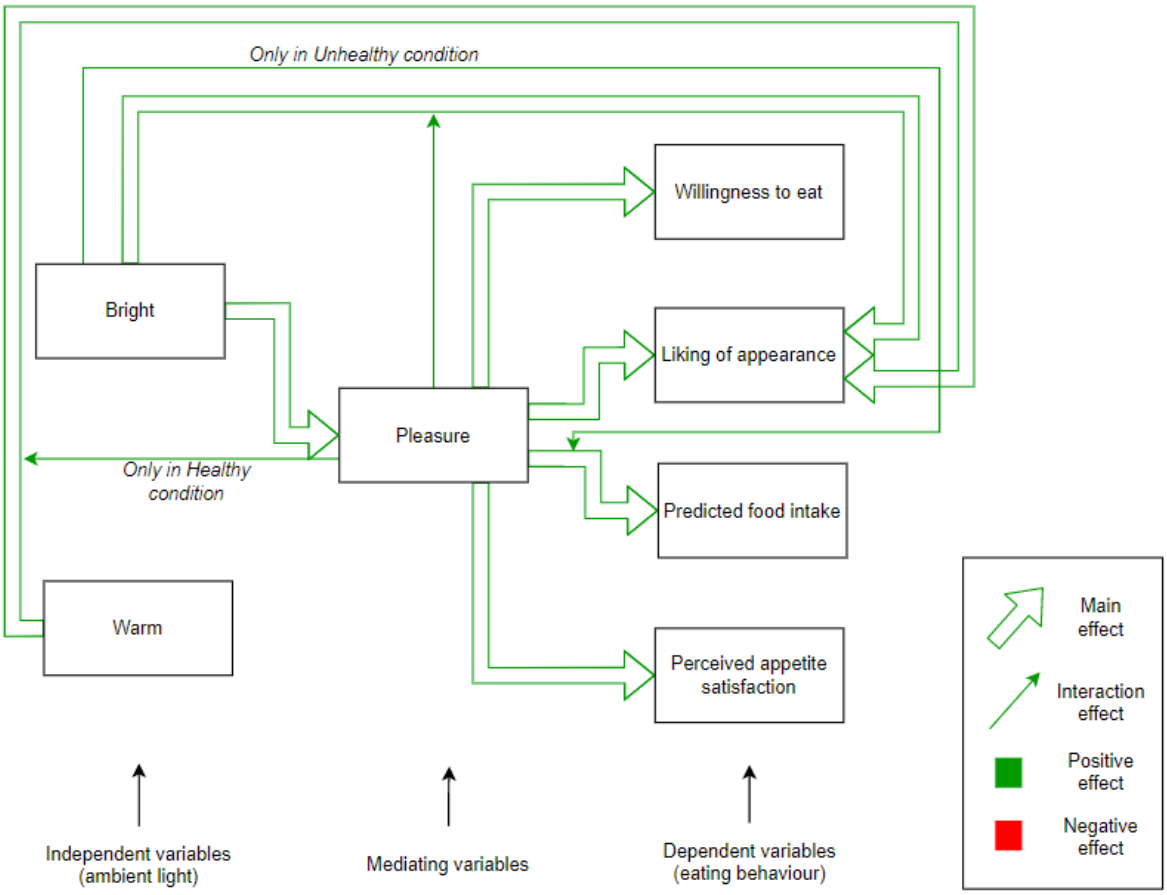

Figure 48. *An overview diagram of the statistically significant results of the exploratory survey. From left to right, the displayed variables are the independent variables (ambient light), the mediating variables (emotional state) and the dependent variables (eating behaviour). The main effects of Pleasure are highlighted. Broad arrows indicate main effects; thin arrows indicate an interaction effect.*

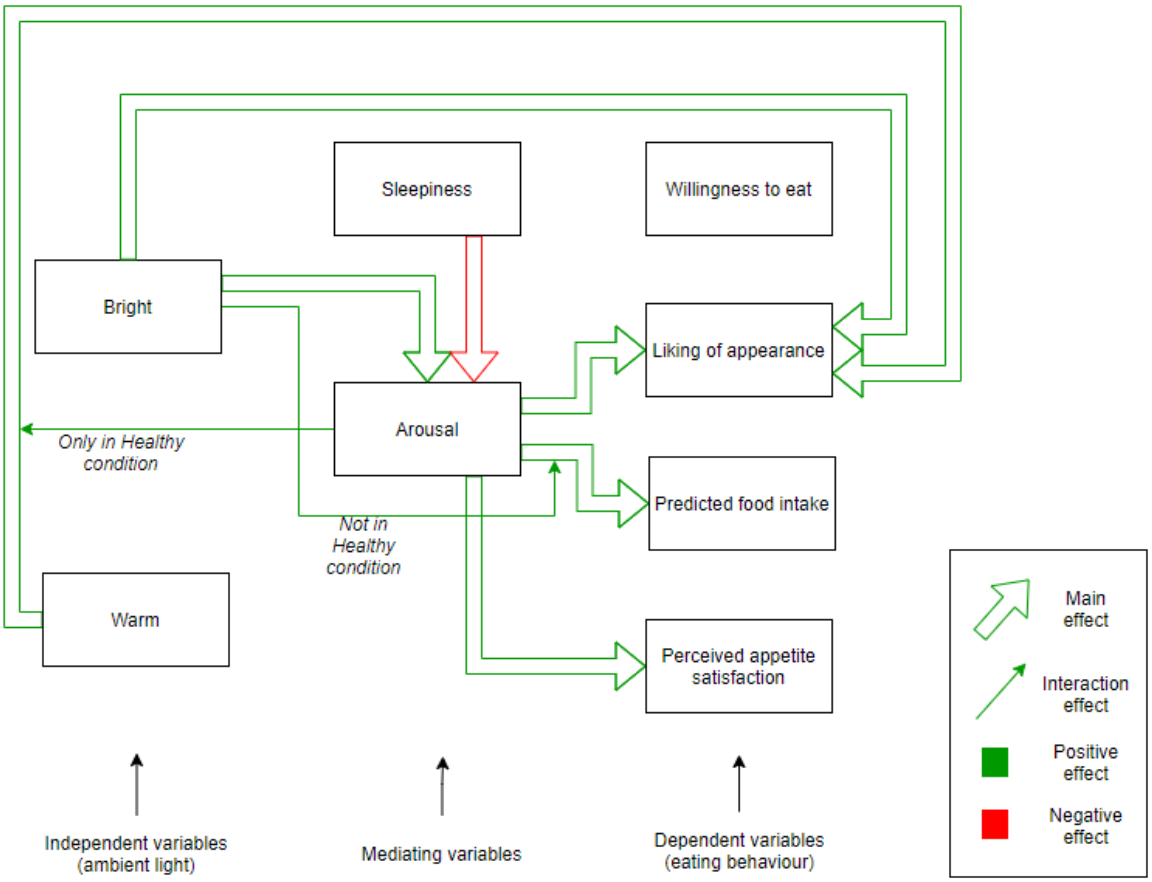

***Figure 49**. An overview diagram of the statistically significant results of the exploratory survey. From left to right, the displayed variables are the independent variables (ambient light), the mediating variables (emotional state) and the dependent variables (eating behaviour). The main effects of Arousal are highlighted. Broad arrows indicate main effects; thin arrows indicate an interaction effect.*

RQ.1.1. Does ambient light directly influence eating behaviour of healthy and unhealthy snacks, and if yes, to what extent?

It was hypothesized that ambient light will directly influence eating behaviour of healthy and unhealthy snacks. Illuminance level and a warm colour temperature will positively increase hedonic response, appetite satisfaction and food intake.

Ambient light directly influenced Liking of appearance, but no other measures of eating behaviour. Willingness to eat, predicted food intake and perceived appetite satisfaction were all not directly significantly affected by the light condition.

Liking of appearance was, on average, almost 1 point on the Likert scale higher in the Bright condition for both the healthy and the unhealthy snack. This effect was found in both the Healthy and the Unhealthy condition.

Liking of appearance was also influenced by colour temperature: in the Cold condition, the snacks were rated on average almost 1 point on the Likert scale higher on liking of appearance

than in the Warm condition. This effect was however not significant for the unhealthy snacks only, but rather for the healthy snacks.

In this study, the hypothesized effect of ambient light on eating behaviour is mostly based on physical and emotional processes. It is hypothesized by many researchers (e.g. Oberfeld et al., 2009; Small et al., 2004; Katsuura et al, 2005; Srivastava et al., 2013) that ambient light influences our physiology. For example, bright light exposure might cause alteration of the levels of circulating serotonin, a neurotransmitter associated with mood regulation. Mood, in turn, is known to influence (amongst others) liking of food, taste perception and food choice (Noel & Dando, 2006; Gibson, 2006). Bright light is also known to influence valence and arousal, both components of emotional state. This is confirmed by the data of the current study; both pleasure (valence) and arousal are significantly higher in the Bright condition compared to the Dim condition. In other literature, emotional state is linked to eating behaviour (Macht, 2008; Robbins & Fray, 1980). This effect is the main focus of this study and will be discussed when answering RQ1.2.

The direct influence of illuminance level and colour temperature on Liking of appearance might be explained not by emotional processes, but by simple visual processes. Light conditions visually varied very strongly, altering the appearance of the snacks as well. Similar effects have been found in previous research. Hasenbeck et al. (2014), presented green, red, and blue bell peppers under lighting that varied in RGB colour and illuminance, while participants indicated their willingness to eat the bell pepper as well as their liking of the appearance of the food. They found that yellow and blue lighting increased liking of appearance for red, green, and yellow bell peppers. Yellow lighting improved willingness to eat, while blue lighting decreased willingness to eat. Additionally, low illuminance levels led to a decreased liking of appearance and willingness to eat as compared to high illuminance levels. Congruent colouring of food and light led to increased liking of appearance and willingness to eat. Hasenbeck et al. hypothesized that under congruent lighting as well as bright lighting, food appears clearer and more natural, while under harsh incongruent lighting as well as dim lighting, food appears unnatural, increasing hesitation and decreasing and willingness to eat. While these study designs are not comparable, the argumentation behind this explanation remains similar. A high illuminance level and a cold colour temperature are the most similar to natural daylight, making it easy to recognize and judge the illuminated snack. This might explain the increase in liking of appearance.

While liking of appearance is moderately correlated with the other eating behaviour-variables, it remains the only measure of eating behaviour that is directly influenced by the ambient light conditions.

Willingness to eat, Perceived appetite satisfaction and Predicted food intake are all not directly influenced by light condition, but might be indirectly influenced, which will be discussed further when answering RQ1.3.

Food choice was directly influenced by ambient light conditions. Participants tended to choose M&Ms in all conditions but show a stronger tendency towards M&Ms in the Dim conditions compared to the Bright conditions. Amongst participants, general liking of M&Ms was higher than liking of raisins. Previous research found similar results and hypothesized a positive correlation between brightness of light and self-control (Biswas et al, 2017; Cajochen, 2007). A

lower level of self-control leads to a greater chance of choosing unhealthy food. This process is reflected by the findings of the current study: dim light might have led to a lower level of self-control and thus the choice for M&Ms.

RQ.1.2. Is eating behaviour of healthy and unhealthy snacks directly influenced by emotional state, and if yes, to what extent?

It was hypothesized that emotional state will directly influence eating behaviour of healthy and unhealthy snacks. Level of valence and level of arousal will positively increase hedonic response, appetite satisfaction and food intake.

Pleasure, the valence of emotional state, was statistically significant in almost all models. A higher level of pleasure directly led to a higher Willingness to eat, Liking of appearance, Perceived appetite satisfaction and Predicted food intake. Arousal directly positively affected Liking of appearance, Perceived appetite satisfaction and Predicted food intake.

An extensive research review on emotional eating-literature by Macht (2008) states that emotions, both specific emotions such as anger and joy and more diffuse and long-term emotions, have been found to affect many aspects of eating behaviour, such as eating motivation, hedonic response, food choice, food intake and even metabolism and digestion.

More specifically, research has found people in an emotional state with positive valence (in other words, with a higher level of pleasure), tend to rate food as more pleasant (e.g. Bongers et al., 2013) and tend to increase their intake (Evers et al., 2013). At the other hand, negative emotion leads to an increase in appetite and food intake for some, but a decrease in appetite and food intake for others (Macht, 2008). The current findings suggest a that a higher level of pleasure positively improves hedonic response and increases appetite and intake, albeit in a hypothesized setting based on photographs and imagination, and not in a real setting.

RQ.1.3. Is emotional state directly influenced by ambient light, and if yes, to what extent?

It was hypothesized that ambient light will directly influence emotional state. Bright light as well as a warm colour temperature will increase valence and arousal.

The current findings show that Pleasure and Arousal are positively influenced by the brightness of the ambient light. Other studies have found similar results, especially for long-term (30+ minutes) exposure to bright light (Smolders & De Kort, 2014; Leichtfried et al., 2015). These studies mostly focus on the non-image forming (NIF) effects of illuminance on alertness and mood. In the effects of light on humans, a distinction can be made between image forming and non-image forming effects (Boyce, 2003). Here, image-forming (IF) effects refers to the activation of the visual system, which enables us to see the world around us. For this, the light enters the eye, and through the retina signals are sent towards the different brain regions that are involved in vision such as the Lateral Geniculate Nucleus (LGN). Light however also affects our physiology and psychology, and it does so through non-image forming effects (NIF). For

this, light also travels from the eye (via the retina) to the brain, but signals are sent to brain areas involved in physiology, mood, and behaviour.

NIF effect are often not acute and involve a long-term exposure to light. In the current study, NIF effects of brightness are improbable, as the study is very short and participants are not physically exposed to the light, but rather only see photos of the conditions. It is possible that all effects found in the current study are IF effects. Acute NIF effects of ambient light on emotional state are not widely researched, but the current finding that Pleasure and Arousal are improved under acute bright light is confirmed by a study by Li et al. (2021).

Pleasure also has an interaction effect with brightness, which will be discussed when answering RQ1.4.

RQ.1.4. Is eating behaviour of healthy and unhealthy snacks directly influenced by mental alertness, and if yes, to what extent?

It was hypothesized that mental alertness will directly influence eating behaviour of healthy and unhealthy snacks. A high alertness will improve hedonic response to healthy snacks and decrease food intake of unhealthy snacks.

Mental awareness was measured in terms of sleepiness on the widely used Karolinska Sleepiness Scale. Sleepiness was had a non-significant effect on all measures of eating behaviour. Sleepiness was a significant predictor for Arousal, which in turn has a significant effect on most measures of eating behaviour (see RQ.1.2.).

The mean level of sleepiness was higher in the Dim condition than in the Bright condition, but no interaction effects were significant.

As discussed in section 3.1, the study design was not ideal for the exploration of the topic of mindful eating and mental alertness. Research on mindless eating often includes the induction of a mindless state. The current study design did not allow for the induction of a mindless state. The focus of the participants was by design guided towards the food, as they had to answer many questions about it. Sleepiness (and conversely mental alertness) was implemented as a replacing measure. Based on previous research (Pardi et al., 2017; Shiv and Fedorikhin, 1999), it was hypothesized that a decrease in mental alertness would lead to an increase in hedonic response towards and predicted intake of the unhealthy food compared to the healthy food, but this hypothesis is not supported by the data.

Pardi et al. (2017) did find data to support this hypothesis: they found that a lower level of subjective alertness led to an increase in food intake. Their explanation for their findings was interesting: they hypothesized that people with a lower level of alertness might be less willing to recognize food as unhealthy, and thus would eat more than when they would recognize a food to be unhealthy. In the current study, two types of food are presented: raisins and M&Ms. While not explicitly stated, it is implicitly made known that there is a “healthy” food type and an “unhealthy” food type. As participants don’t have to make that distinction and judgement for themselves, it might not matter what their current mental awareness is when rating the unhealthy food, as they are already made aware that the food is unhealthy, especially compared to the healthy food.

RQ.1.5. Is eating behaviour of healthy and unhealthy snacks directly influenced by other personal factors, and if yes, to what extent?

Other covariates (hungriness, healthiness, liking of raisins, liking of M&Ms, age, and gender) were added to the models to explore whether eating behaviour was influenced by these variables and to ensure a better model fit.

In many models, either liking of a snack or the interaction between the Healthy condition and liking of a snack had a significant effect on eating behaviour. Participants were more willing to eat the M&Ms when they had a higher liking of M&Ms. Liking of appearance was not influenced by liking of a snack. Perceived appetite satisfaction of raisins was higher when coinciding with a liking of raisins. Predicted food intake was generally considerably higher for M&Ms than for raisins, however, a higher liking of raisins led to a relative increase in predicted food intake in the Healthy condition. The same effect was true for liking of M&Ms in the Unhealthy condition. This effect makes sense logically: people would be more likely to have a more positive response to food that they like. These terms were included in the models to improve the fit of the model and explain more of the variance, and this goal was achieved.

Hungriness and healthiness were (almost) never significant and were thus often dropped from the models. These factors being insignificant might be because the study was online and based on photographs and imagining eating the food, instead of actually having to eat the snacks.

Age and gender had non-significant effects on all measures of eating behaviour. In eating behaviour research, males and females often tend to have differently significant results amongst different studies: in a study by Rebollar et al. (2017) females participants rated yoghurt as sweeter under the high illuminance condition and a study by Cho et al. (2015), who found that blue lighting decreased the food intake of men, but not of women. It is hypothesized that the difference in gender might be based on differences in neural responses to visual cues, for example women having increased brain activity in regions involving inhibition control when presented with food-related visual cues (Cornier et al., 2010). However, no significant differences amongst different genders were found in the current study.

RQ1.6. Does emotional state have a mediating or moderating effect on the influence of ambient light on eating behaviour, and if yes, to what extent?

It was hypothesized that valence and arousal of emotional state will have a moderating effect on the influence of ambient on hedonic response and food intake.

Significant interaction effects occur between Pleasure and Bright on both Liking of appearance and Predicted food intake (albeit only in the Unhealthy condition). Both interactions show that the Pleasure effect is stronger in the Bright condition than in the Dim condition. So in a bright environment, the valence of the emotion has a stronger effect on Liking of appearance and Predicted food intake of unhealthy food than it would in a dim environment. The interaction effect between Pleasure and Warm is also significant for Liking of appearance, meaning that in a warmly lit environment, the valence of the emotion has a stronger effect on Liking of appearance.

Warmth and Arousal have a significant interaction effect on Liking of Appearance; however, this effect is negligible.

Brightness and Arousal also interact significantly in the Unhealthy condition on Predicted food intake, but the effect is negligible.

Combining the direct effects (also see RQ1.1 and RQ1.2) and the indirect, moderation effects, the following significant mediation effects are found in the data:

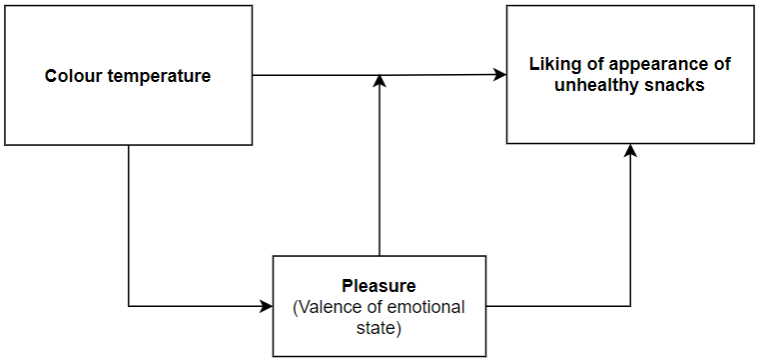

***Figure 50**. A diagram showing the structure of effects of Colour temperature, Pleasure and Liking of appearance of unhealthy snacks.*

When a person is in a positive emotional state, they will have a more positive hedonic response towards unhealthy food when the food is illuminated with warm light compared to when the food is illuminated with cold light. The opposite is true as well: when a person is in a negative emotional state, they will have a more negative hedonic response towards food when it is illuminated with warm light. In other words, their hedonic response towards food becomes stronger under bright light than under dim light.

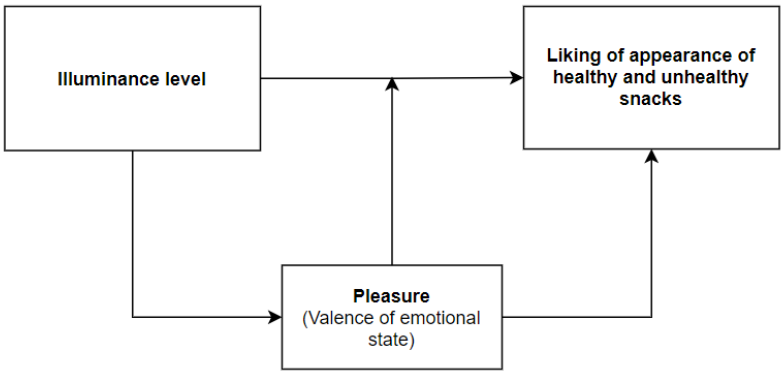

***Figure 51**. A diagram showing the structure of effects of Illuminance level, Pleasure and Liking of appearance of healthy and unhealthy snacks.*

When a person is in a positive emotional state, they will have a more positive hedonic response towards food when the food is illuminated with bright light compared to when the food is illuminated with dim light. The opposite is true as well: when a person is in a negative emotional state, they will have a more negative hedonic response towards food when it is

illuminated with bright light. In other words, their hedonic response towards food becomes much stronger under bright light than under dim light. This effect is roughly visualised in figure 52.

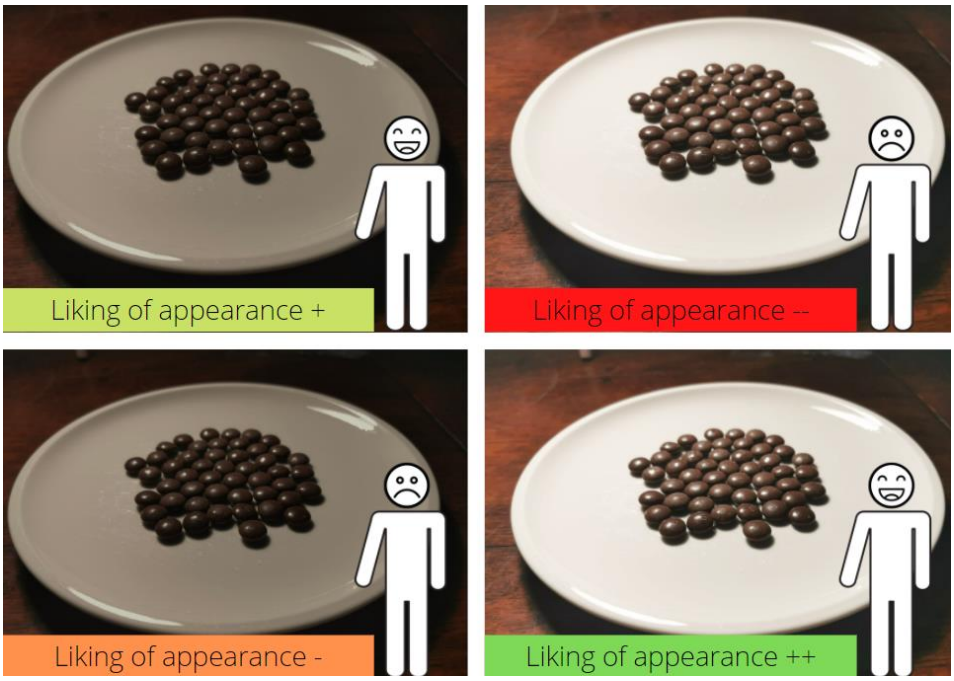

***Figure 52**. A visual showing the moderation effect of pleasure on the influence of illuminance level on liking of appearance. One plus- or minus-sign indicates a moderate effect, while two signs indicate a stronger effect. The figure was created and coded intuitively, for the sole purpose of roughly demonstrating and visualising the effect.*

The influence of illuminance level on liking of appearance is thus both mediated and moderate by level of pleasure.

Bright light increases the intensity to which people like the appearance of snacks: an unhappy person will like a snack even less and a happy person will like the snack even more. As bright light also increases level of pleasure, this would mean that illuminating a snack with dim light lowers level of pleasure and dampens the intensity of liking of appearance.

Moreover, a person in a positive emotional state predicts to eat slightly more of an unhealthy snack when food is brightly illuminated compared to when it is dimly illuminated. Conversely, a person in a negative emotional state predicts to eat slightly less of an unhealthy snack when it is brightly illuminated.

These notions are in line with findings from other literature. Both Bongers et al. (2013) and Evers et al. (2013) found that people with a positive valence tended to rate food as more pleasant and tended to increase their food intake of unhealthy snacks compared to people with neutral emotions. Moreover, food that is illuminated in natural, bright light leads to people more easily recognizing and judging a food and thus increasing their liking of appearance and food intake (Hasenbeck, 2014).

These mediating and moderation effects do explain some of the interpersonal differences found in the data. The data is fairly spread out between participants, leading to a fairly high variance as well as bad fits of trend lines. It was found that the interaction effect does account for some of the variance between participants, but a large part of the variance remains

unaccounted for. First, it should be confirmed in a follow-up study whether this effect still holds in a physical setting. Then, it is possible to discuss possible reasons behind the effect.

3.4.1. Limitations

The results of the exploratory study are impacted by some limitations, which will be described in this section. Limitations that exist for both Study 1 and Study 2 are discussed in the general limitations section (section 5.2).

First, as concluded early in the study design process, it should be noted that the ecological validity of this exploratory study is low. A large sample was necessary to ensure a high power of the study. An online survey based on photographs of food was the best option for this exploratory study. However, research comparing physical and virtual lighting environments has found that photo reproductions evoke the least realistic psychological response (Chen, Cui & Hao, 2019). Participants were not actually exposed to light conditions, but rather only saw images of them. Stronger effects, or ever weaker effects, of the light conditions could be found in real-life settings, especially when considering the difference between visual (image forming) effects and non-image forming effects.

Moreover, as this study was an online survey, external conditions were not constant over all participants. Differences could be how the light conditions in their personal environment were, how disturbed they were while completing the study, whether they were in a silent room or in a room with music, how the architecture of their room was, and many more aspects. This might have added to larger interpersonal differences that could not be accounted for.

The scope of this study was mindless snacking. In practice, no effect of mental alertness on eating behaviour was found. As also discussed when answering RQ1.4 in section 3.4.1, the study design was not ideal for the exploration of the topic of mindful eating and mental alertness. Research on mindless eating often includes the induction of a mindless state. The current study design did not allow for the induction of a mindless state. The focus of the participants was by design guided towards the food, as they had to answer many questions about it. Sleepiness (and conversely mental alertness) was implemented as a replacing measure. Based on previous research (Pardi et al., 2017; Shiv and Fedorikhin, 1999), it was hypothesized that a decrease in mental alertness would lead to an increase in hedonic response towards and predicted intake of the unhealthy food compared to the healthy food, but this hypothesis is not supported by the data.

Pardi et al. (2017) did find data to support this hypothesis: they found that a lower level of subjective alertness led to an increase in food intake. Their explanation for their findings was interesting: they hypothesized that people with a lower level of alertness might be less willing to recognize food as unhealthy, and thus would eat more than when they would recognize a food to be unhealthy. In the current study, two types of food are presented: raisins and M&Ms. While not explicitly stated, it is implicitly made known that there is a “healthy” food type and an “unhealthy” food type. As participants don’t have to make that distinction and judgement for themselves, it might not matter what their current mental awareness is when rating the unhealthy food, as they are already made aware that the food is unhealthy, especially compared to the healthy food.

3.4.2. Recommendations for future work

The mediation and moderation of pleasure on illuminance level and hedonic response (in particular liking of appearance) is interesting. The direct effects of the interaction (the effect of

illuminance on hedonic response and the effect of emotional state on hedonic response) are both well documented in previous research. However, the mediation and moderation of the two effects is not well-documented. In combination with the very small effect of the interaction between illuminance level and predicted intake, this serves as a nice basis for a follow-up study, in which participants will be actually exposed to different light settings and will actually see and eat food. The nature of the mediation or moderation of emotional state on the effect of illuminance of eating behaviour will be examined in more detail as well. Additional research is required before speculating more about the nature of these possible effects.

3.5. Conclusion

This exploratory study has as a goal to explore the topics around main research question: "To what extent, if any, is the influence of ambient light on eating behaviour mediated by emotional state?". To do so, an online survey was designed in which participants rated photographs of healthy and unhealthy snacks in different lighting conditions, varying in illuminance and colour temperature.

A mediating and moderating effect of pleasure was found on the effect of illuminance level on the liking of appearance of healthy and unhealthy snacks.

Pleasure directly influences all measures of eating behaviour, from liking of appearance to willingness to eat and perceived appetite satisfaction to predicted food intake. This confirms the notion that emotional state influences eating behaviour.

Bright light only directly increases liking of appearance of a snack. This is most likely due to image-forming (IF) effects of the illuminance level and colour temperature of light. Ambient light, however, does influence both pleasure and arousal, which in turn influence most measures of eating behaviour. Moreover, moderation effects exist between illuminance level of light and pleasure. Based on these findings, a happy person will have a more positive hedonic response towards brightly lit food compared to dimly lit food, and a sad person will have a more negative hedonic response towards brightly lit food compared to dimly lit food. Moreover, a happy person predicts to eat slightly more of an unhealthy snack that is brightly illuminated than of an unhealthy snack that is dimly illuminated.

The interaction between illuminance level and hedonic response (in particular liking of appearance) is interesting. The main effects of the interaction (the effect of illuminance on hedonic response and the effect of emotional state on hedonic response) are both well documented in previous research. However, the interaction between the two effects is not well-documented. In combination with the very small effect of the interaction between illuminance level and predicted intake, this serves as a nice basis for a follow-up study, in which participants will be actually exposed to different light settings and will actually see and eat food. The nature of the mediation or moderation of emotional state on the effect of illuminance of eating behaviour will be examined in more detail as well. Additional research is required before speculating more about the nature of these possible effects.

4. Study 2: Zooming in on the influence of illuminance and emotional state on eating an unhealthy snack

With the exploratory study done and some preliminary results discussed, a more focussed research question can be formulated that will help answering the main research question. In the exploratory study, it was found that bright light as well as positive emotional state positively affect certain factors of eating behaviour. Moreover, a moderation effect exists between valence and illuminance on eating behaviour as well. This effect will be examined in more detail in a physical study.

4.1. Background

Previous research, as well as the exploratory study conducted previously, established the effect of illuminance on hedonic response. To summarize, bright light increases the liking of appearance and willingness to eat of food, as food appears more natural which decreases hesitance to eat and improves hedonic response (Hasenbeck et al., 2014). In the exploratory study, liking of appearance but not willingness to eat was increased under bright light. Bright light is also known to improve mood and emotional valence. This effect is more robust with long term-exposure to bright light (Smolders & De Kort, 2014; Leichtfried et al., 2015), but acute bright light has also been known to improve emotional valence (Li et al., 2021). The exploratory study showed that pleasure and arousal, both measures of emotional state, were higher under bright light. Finally, emotional state has a well-documented effect on eating behaviour. Positive emotion leads to a more positive hedonic response and an increase in food intake. Again, this effect is reflected in the outcome of the exploratory study.

It is highly probable that all effects that were found in the exploratory setting were image-forming effects (IF). These effects are described by Boyce (2003). Image-forming (IF) effects refers to the activation of the visual system, which enables us to see the world around us. For this, the light enters the eye, and through the retina signals are sent towards the different brain regions that are involved in vision such as the Lateral Geniculate Nucleus (LGN). IF effects of bright light are not widely researched, but it is known to influence emotional state (Li et al., 2021) and subjective mental alertness (Yang et al, 2018).

Light however also affects our physiology and psychology, and it does so through non-image forming effects (NIF). For this, light also travels from the eye (via the retina) to the brain, but signals are sent to brain areas involved in physiology, mood, and behaviour. NIF effect are often not acute and involve a long-term exposure to light.

The findings of the exploratory study are interesting, but need to be validated ecologically, as these findings are all based on photographs and thus the image-forming (IF) pathway of light. To assess whether these IF effects still exist when participants are exposed to light conditions and whether non-image forming effects may arise, an experimental setting should be used.

The goal of the study is to support healthy eating. To do so, it is important to know how environmental and emotional factors influence intake of food. If it is known what influences the response to unhealthy food, this knowledge could be used to make unhealthy food less attractive and/or to limit intake of unhealthy food. The exploratory study found some small differences between the influence of ambient light on eating behaviour of healthy versus unhealthy food. For example, colour temperature did improve liking of appearance of healthy food, but no effect on liking of appearance of unhealthy food was found. More interestingly, an interaction effect between brightness and pleasure was found on predicted intake of unhealthy

food, but not on predicted intake of healthy food. A lot of recent studies focus of the influence of lighting on healthy food (Hasenbeck et al. (2014) focus on bell peppers, Rebollar et al. (2017) focus on yogurt). However, there is a big focus on unhealthy food in the domain of research on the effect of emotion and mood on food (Bongers et all, 2013; Evers et al, 2013). The current study will combine these domains by examining the combined effect of lighting and emotional state on unhealthy food.

4.1.1. Research questions

The main research question of this study is:

"To what extent, if any, does the illuminance level of ambient light influence the hedonic response and/or food intake of an unhealthy snack, and to what extent (if any) does emotional valence affect this relationship?"

To make answering easier, the research question is divided into several sub-questions and hypotheses.

- RQ2.1. Does illuminance level directly influence hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?
    - H2.1: A high illuminance level will positively influence hedonic response and/or food intake of an unhealthy snack.
- RQ2.2. Does illuminance level directly influence valence of emotional state, and if yes, to what extent?
    - H2.2: Bright light will lead to an increase in valence of emotional state.
- RQ2.3. Does valence of emotional state directly influence hedonic response to and or/food intake of an unhealthy snack, and if yes, to what extent?
    - H2.3: A higher valence will lead to a more positive hedonic response and an increase in food intake.
- RQ2.4. Does valence of emotional state have a mediating or moderating effect on the influence of illuminance level on hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?
    - H2.4: Valence of emotional state will have a moderating effect on the influence of illuminance level on hedonic response and food intake.
- RQ2.5. Is hedonic response to and/or food intake of an unhealthy snack (M&Ms) influenced by other personal factors, and if yes, to what extent?
    - H2.5 Liking of M&Ms and round will affect hedonic response and food intake.

4.2. Methodology

To answer the research question and its sub-questions, an experimental lab study was designed.

4.2.1. Study design

An experimental study was designed in which participants were presented with an unhealthy snack (a bowl of chocolate M&Ms) in two different light conditions. The snack type was chosen based on previous research (Salerno, Laran & Janiszewski, 2014; Biswas et al., 2017) and the exploratory study. The light conditions were created with a dimmable Philips Hue White Ambiance bulb connected to Bluetooth and a UNI-T® Mini Light Meter (UT383) and had a

varying illuminance: either dim (35 lx) or bright (300 lx). Both conditions had a constant colour temperature of 4000K, which is neutral warm. The independent variable is thus:

- Illuminance (lx)

The study used a within-participants design, meaning all participants were exposed to all conditions. The condition was randomized over participants to balance the study design and prevent fatigue- or response biases.

Participants were asked to rate some qualities of the food on a digital questionnaire. It was also measured how much participants ate in each round. Measuring how much a person eats might influence their intake, as they might feel uncomfortable eating and might be overly aware of their intake. This problem was identified and solved by Lowe and Maycock (1988) as well as Evers, Stok and de Ridder (2010) and Evers et al. (2013). What they did was providing participants with nonsense-questions about the food, which ensured that they would eat the food without raising suspicion, while secretly weighing the bowls after each manipulation. A similar deception was implemented in the current research. Participants were specifically asked to rate the M&Ms on "crispiness", a concept that is not of interest but does ensure that participants eat the snack before answering other questions about hedonic response. Between conditions, participants were asked to shortly leave to room, so that the experiment leader could alter the light conditions, weigh the bowl of M&Ms and fill it up to the original level again.

The following dependent variables were measured:

- their current level of pleasure;
- their hedonic response:
    - willingness to eat (How willing are you to eat this snack?);
    - liking of appearance (How much do you like how this snack looks?);
- Appetite satisfaction (How much does this food satisfy your appetite?);
- Intake (measured in grams).

Emotional valence, or level of pleasure, was measured in the same way as in the exploratory study, with the Affective slider by Betella and Verschure (2016) (see figure 53). On this slider, participants can visually match their emotional state to the emoticons. This results in a number ranging from 0 to 100.

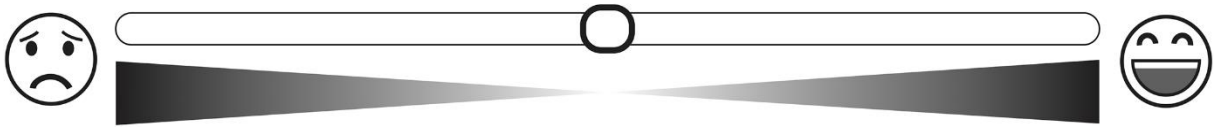

Figure 53. *The pleasure measure of the Affective slider designed by Betella and Verschure (2016).*

Hedonic response and was measured on appropriately labelled (e.g. 1 = won't like at all – 7 = will like extremely) 7-point Likert scales, based on combined similar research (Liem, Aydin & Zandstra, 2012; Hasenbeck et al., 2014) and the exploratory study.

Intake was measured in grams, using a standard kitchen scale with no decimal points.

The experiment was designed to be as concise as possible, to improve chances of participant recruitment. This was necessary, as there was a time constraint on the data collection.

The study design was approved by the UTwente Ethics Commission under the reference number RP 2021-38.

4.2.2. Participants

Participants were recruited based on convenience sampling on the campus of the University of Twente in Enschede, The Netherlands. In total, 40 participants completed the study, which 18 male, 21 female and 1 who identified as an "Other" gender. The mean age of the participants was 27,8. No Upon completion of the experiment, participants were rewarded with a small bag of M&Ms. They were told they would get a small surprise at the end of the study, but not told what, as this might have influenced their intake of the M&Ms during the experiment.

4.2.3. Data analysis

The variables were coded as follows in table 18:

Variable name	**Variable description**
Independent variable	
Condition (LMM)	The independent variable used in the LMM, illuminance level. Condition = 1 refers to the Bright condition (300lx), Condition = 2 refers to the Dim condition (35lx).
Bright (MEMORE)	The independent variable used in the MEMORE analysis, illuminance level. A dummy variable, Bright = 1 refers to the Bright condition (300lx), Bright = 0 refers to the Dim condition (35lx).
Covariate, hypothesized as mediating variable	
Pleasure	The level of Pleasure measured from 0 to 100. Indicates the positivity of the current emotional state.
Dependent variables	
Willingness	Willingness to eat the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).
Crispiness	Crispiness of the snack, measured on a 7-point Likert scale (1 = not crispy at all, 7 = extremely crispy). Deception measure to stray attention from food intake.
Appearance	Liking of appearance of the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).
Satisfaction	Appetite satisfaction of the snack, measured on a 7-point Likert scale (also see Section 3.2.1.).
Intake	The amount of M&Ms that were eaten after each round, measured in grams.
Covariates	
Hungriness	Current level of hungriness, measured on a 7-point Likert scale (also see Section 3.2.1.).
Liking_of_M&Ms	General liking of M&Ms, measured on a 7-point Likert scale (also see Section 3.2.1.).
Age	Current age in years.
Gender	Gender (1=male, 2=female, 3=other).
Round	The round in which the measurements took place, in a temporal manner. There were 2 rounds in total. Conditions were randomized over rounds.

Table 18. *The variables that were measured and coded for the analysis, including a description of the variables.*

Similar to the survey data analysis, for analysis of the data, a linear mixed model (LMM) was chosen, due to the repeated measurements of the different eating behaviours over for 2 different conditions over time. To do so, the data was restructured to a long format. Data was cleaned up and checked for outliers. To assess whether there were large interpersonal differences in the data, the mean, standard deviation and coefficient of variation (standard deviation/mean) were calculated.

Participant ID was used to define the subjects in the LMM, as the correlation between the repeated measurements per subject is to be modelled. The repeated variable is the dummy variables representing the different conditions, namely Condition representing brightness (0=dim i.e. 35 lx, 1=bright i.e. 300 lx) This variable was also set as the factor of the model.

The dependent variable that was defined as the covariate was Pleasure. It was also checked whether Hungriness, Liking of M&Ms and Age and Gender influenced the dependent variable by adding them as a covariate in the model. Categorical variables were treated as fixed effects in the model, while continuous variables were treated as random effects. Insignificant covariates are dropped from the final model.

The residuals were structured by using compound symmetry structure as variances and covariances of the subjects' residuals are homogeneous, meaning that there is a correlation between two separate measurements (due to the measurements being very close in time), but it is assumed that the correlation is constant regardless of how far apart the measurements are. Subject (participant ID) was added as a random intercept to indicate the clustering of the data.

For all final LMM's, the significance table of all included variables will be shown. The direction and strength of the effect will be visualised in graphs.

It was hypothesized that effects might exist between dependent variables. A correlation table was made to analyse the correlations between the dependent variables.

To assess a possibility for a moderating effect of a covariate, interaction terms were included in the model as well. The interaction term that was tested was Condition*Pleasure, as it is hypothesized that Pleasure mediates the effect of Condition on eating behaviour measures. It is important to note that an interaction effect thus reflects a moderation effect, not a mediating effect. A significant interaction effect does not always mean that there is a significant mediation effect, as an interaction does not imply a causal sequence. Repeated measures are generally difficult for standard mediation analysis. For mediation analysis on data with two repeated measures however, a relatively new model was developed.

To do a mediation analysis on the repeated measures, the MEMORE (Mediation and Moderation for Repeated Measures) macro for SPSS, developed by Montoya and Hayes (2017) was used. The model estimates the direct effect of a variable X (the independent variable) on a variable Y (the dependent variable), the direct effect of a potential mediator (M) on Y, and the indirect effect of X on Y through M using non-parametric bootstrapping. The current data analysis produces four models, with X always being Condition, M being Pleasure and X being respectively Willingness to eat, Liking of appearance, Appetite satisfaction and Intake.

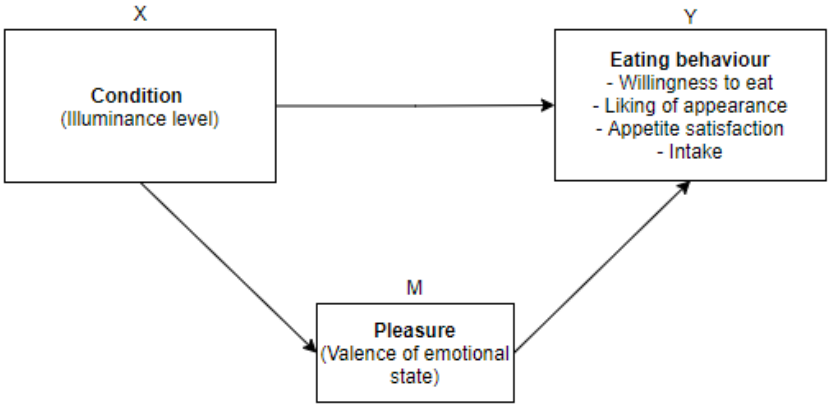

***Figure 54**. Hypothesized mediation effect of Pleasure on the main effect of Condition on Eating behaviour*

The power of the study was calculated using the G*Power software. As a within-subject design is used with a linear mixed model, with 40 participants, a significance level 0.05 and a moderate hypothesised effect size, the calculated power is 80%. This means that there is an 80% chance of findings significant results if an effect exists in a population.

4.3. Results

Data was cleaned up and reviewed for any outliers by exploring and evaluation boxplots of the data.

Two possible outliers were found for the variable Pleasure, as seen in figure 55.

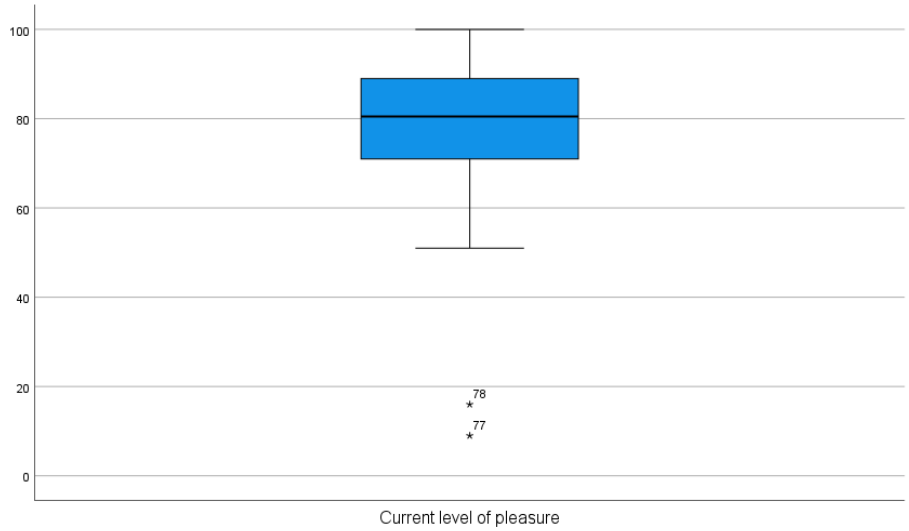

***Figure 55**. Boxplot of current level of pleasure.*

Pleasure has a median of 81 and is almost always rated 50 or higher, indicating a positive valence of the current emotional state. However, there are two data-points that fall strongly under this range. It was considered whether these two low data-points of Pleasure could be outliers. No experimental error was found, so to understand the nature of these outliers,

different models, either containing or not containing these outliers, were considered and compared to each other. Such a method might highlight interesting effects of these outliers. In all cases, the different modes showed very similar significant effects and a similar trend in effect direction. The data-points were thus not considered outliers and were included in all final models.

Table 19 shows an overview of all means, standard deviations and coefficients of variations. Most variables have a coefficient of variation ranging from 0.2 to 0.4. Appetite satisfaction has a somewhat higher variation (0.47). Intake has the highest variation (0.86).

Descriptives of all dependent variables

	Mean	Std. Deviation	Coefficient of variation
Level of Pleasure	78.75	16.412	0.208
Liking of appearance	5.45	1.457	0.267
Willingness to eat	5.91	2.026	0.343
Appetite satisfaction	4.33	2.036	0.471
Intake in grams	7.71	6.613	0.857
Current hungriness	4.08	1.156	0.284
Liking of M&Ms	5.10	1.696	0.333
Gender	1.58	0.546	0.347
Age	27.80	10.766	0.387

Table 19. *The mean and standard deviation of all measured variables.*

4.3.1. Intake

The significance table of the final LMM with Intake as dependent variable is shown in table 20.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	67.101	1.617	0.208
Condition	1	37.650	0.130	0.720
Pleasure	1	62.560	0.082	0.776
Condition * Pleasure	1	37.792	0.229	0.635
Round	1	36.131	6.153	0.018

Table 20. *The significance table of the final LMM with Intake as dependent variable. Significant effects are highlighted in green.*

Condition, Pleasure and the interaction between Condition and Pleasure are all non-significant.

Round also has a positive significant effect on Intake: mean intake was significantly higher in the second round compared to the first round, as seen in figure 56.

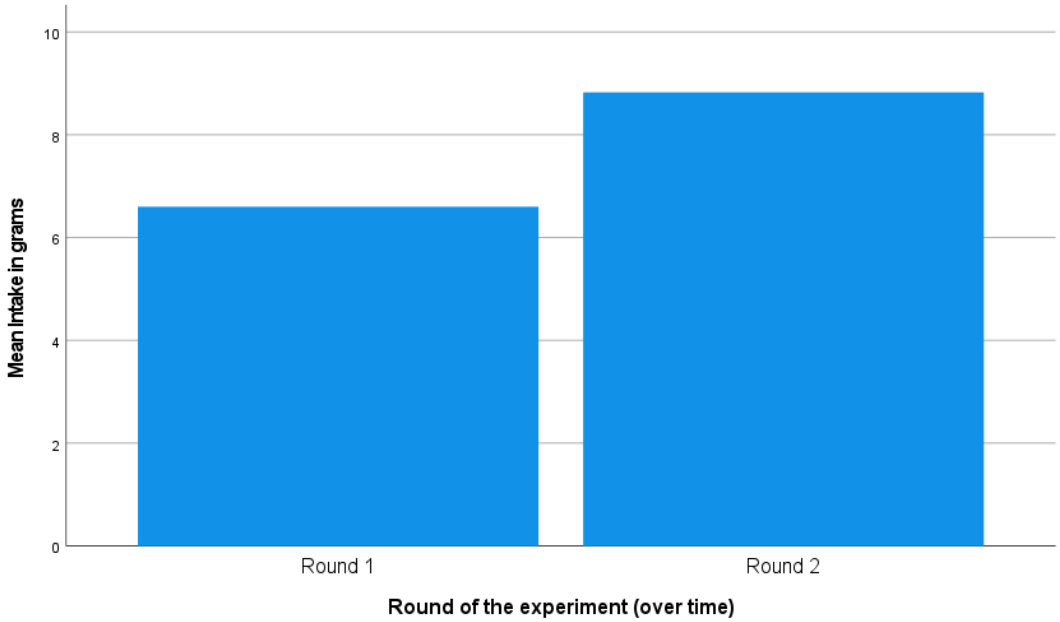

Figure 56. *A bar chart with Round on the x-axis and mean Intake on the y-axis.*

From the MEMORE model, strength and significance of direct effects were similar to those found in the LMM. The MEMORE model revealed that the indirect effect of Condition on Intake via Pleasure was positive (IE = 0.04) but non-significant: 95%CI=(-0.260,0.310).

4.3.2. Liking of appearance

The significance table of the final LMM with Intake as dependent variable is shown in table 21.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	48.646	20.701	0.000
Condition	1	38.674	6.151	0.018
Pleasure	1	49.303	21.956	0.000
Condition * Pleasure	1	38.833	4.975	0.032

Table 21. *The significance table of the final LMM with Liking of appearance as dependent variable. Significant effects are highlighted in green.*

Condition showed had a significant effect where Liking of appearance was higher in the Bright condition than in the Dim condition (see figure 57).

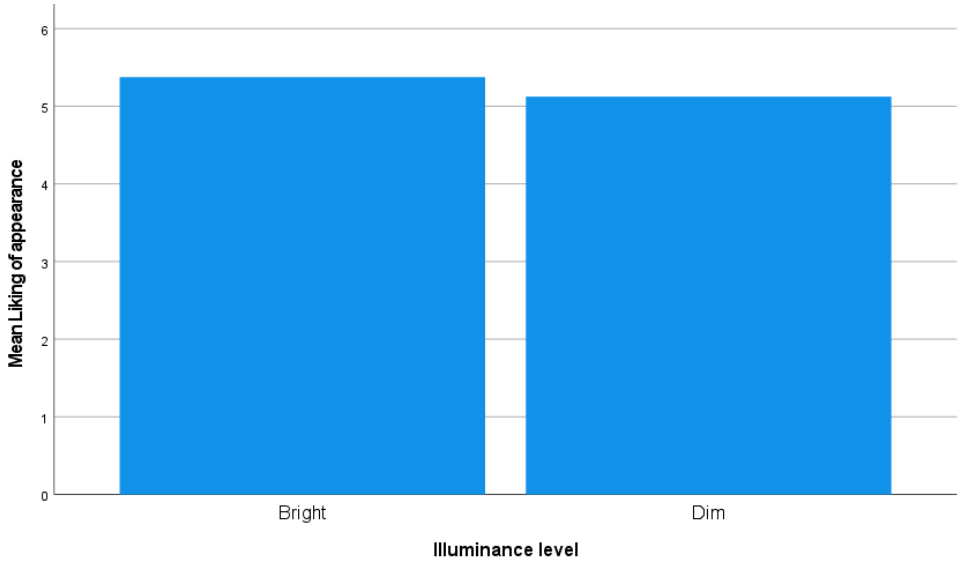

Figure 57. *A bar chart with Illuminance level on the x-axis and mean Liking of appearance on the y-axis.*

Pleasure has a small significant effect on Liking of appearance in the positive direction, as seen in figure 58. The two outliers are included in the model as they do not significantly influence the effect.

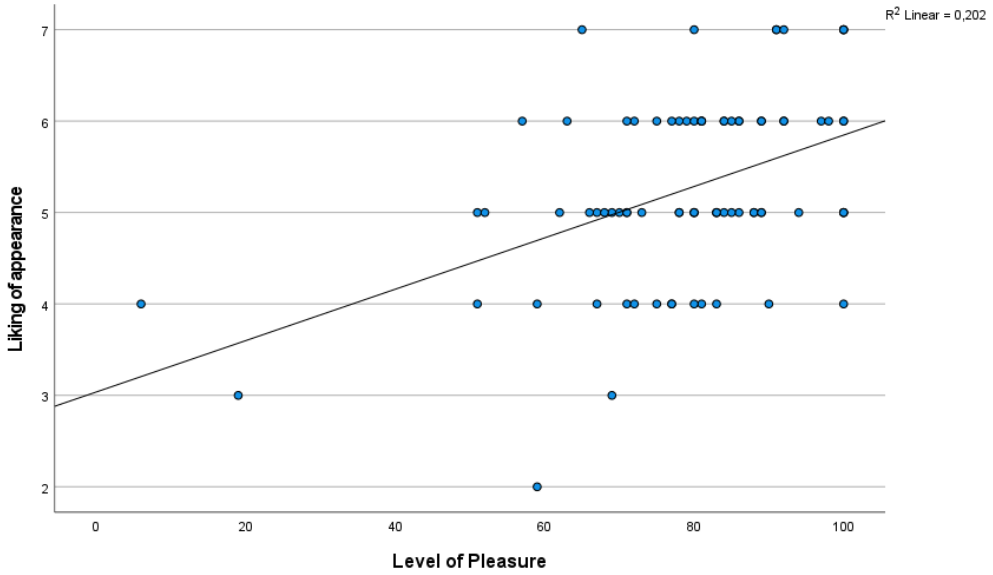

Figure 58. *A scatterplot with Pleasure on the x-axis and Liking of appearance on the y-axis. The effect is visualised with the fitted line through the data-points.*

The interaction effect between Condition and Pleasure was also significant, where the pleasure effect is stronger in the Dim condition than in the Bright condition (see figure 59).

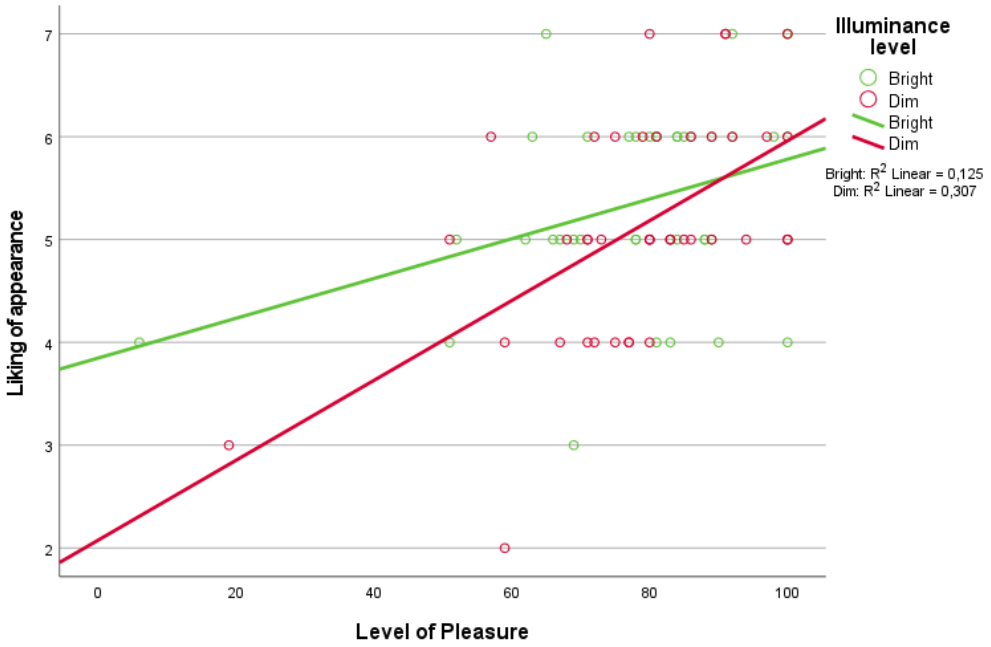

Figure 59. *A scatterplot with Pleasure on the x-axis and Liking of appearance on the y-axis. The data-points are marked by the Illuminance level, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

From the MEMORE model, strength and significance of direct effects were similar to those found in the LMM. The MEMORE model revealed that the indirect effect of Condition on Intake via Pleasure was positive (IE = 0.08) but non-significant: 95%CI=(-0.185,0.397).

4.3.3. Willingness to eat

The significance table of the final LMM with Intake as dependent variable is shown in table 22.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	75.902	9.748	0.003
Condition	1	36.400	12.629	0.001
Pleasure	1	74.706	17.446	0.000
Condition * Pleasure	1	36.526	12.345	0.001

Table 22. *The significance table of the final LMM with Willingness to eat as dependent variable. Significant effects are highlighted in green, effects that show a trend towards significance are highlighted in orange.*

The effect of Condition on Willingness to eat is significant and in the positive direct, albeit very small, as seen in figure 60.

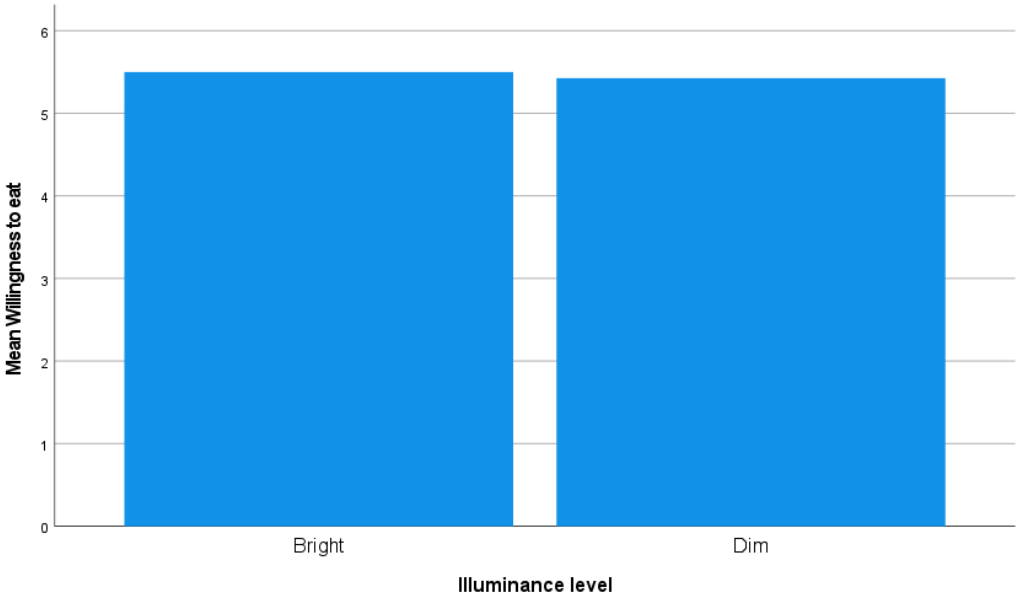

Figure 60. *A bar chart with Illuminance level on the x-axis and mean Willingness to eat on the y-axis.*

Pleasure also has a significant effect on Willingness to eat in the positive direction (see figure 61). The two outliers are included in the model as they do not significantly influence the effect.

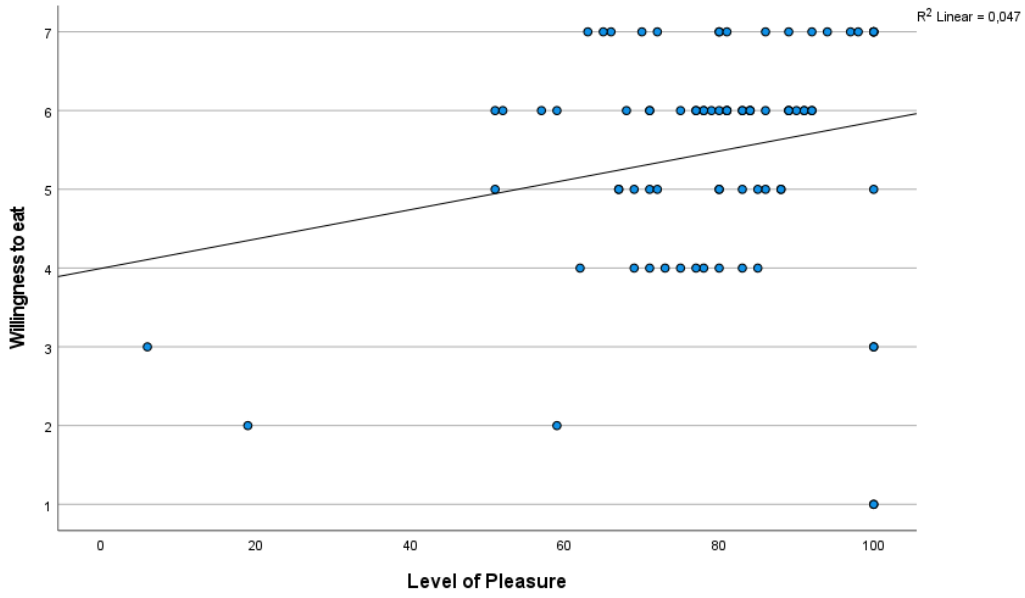

Figure 61. *A scatterplot with Pleasure on the x-axis and Willingness to eat on the y-axis. The effect is visualised with the fitted line through the data-points.*

The model revealed a significant interaction effect between Pleasure and Condition on Willingness to eat; the Pleasure effect is stronger in the Dim condition than in the Bright condition (see figure 62).

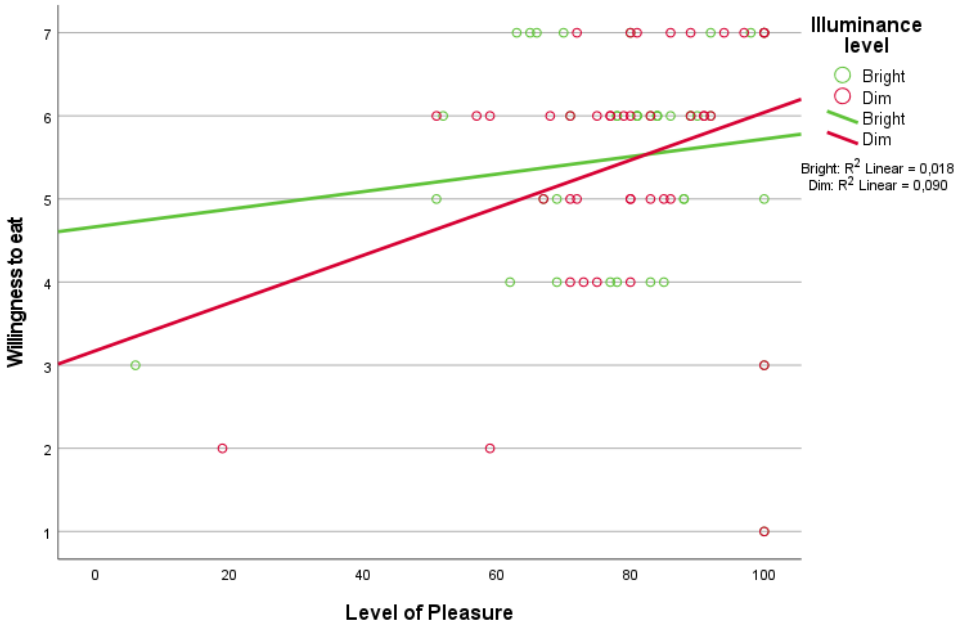

Figure 62. *A scatterplot with Pleasure on the x-axis and Willingness to eat on the y-axis. The data-points are marked by the Illuminance level, with the red colour marking the Dim condition and the green colour marking the Bright condition. The effect is visualised with the fitted lines through the data-points.*

From the MEMORE model, strength and significance of direct effects were similar to those found in the LMM. The MEMORE model revealed that the indirect effect of Condition on Intake via Pleasure was positive (IE = 0.08) but non-significant: 95%CI=(-0.185,0.397).

4.3.4. Appetite satisfaction

The significance table of the final LMM with Intake as dependent variable is shown in table 23.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	70.346	15.589	0.000
Condition	1	37.844	1.439	0.238
Pleasure	1	62.548	3.600	0.062
Condition * Pleasure	1	37.941	1.443	0.237

Table 23. *The significance table of the final LMM with Appetite satisfaction as dependent variable. Significant effects are highlighted in green.*

Condition and Pleasure have a non-significant effect on Appetite satisfaction. The interaction between Pleasure and Condition is not significant either.

From the MEMORE model, strength and significance of direct effects were similar to those found in the LMM. The MEMORE model revealed that the indirect effect of Condition on Intake via Pleasure was small but positive (IE = 0.025) but non-significant: 95%CI=(-0.078,0.123).

4.3.5. Correlation between dependent variables

A correlation matrix (table 24) shows that some independent variables are significantly correlated (correlation is significant at the 0.05 level, 2-tailed), varying from very weak ($r < 0.3$) to weak ($0.3 < r < 0.5$). The correlations that are the least weak exist between Willingness to eat

and Liking of appearance (r = 0.37) and between Willingness to eat and Appetite satisfaction (r = 0.38).

		Liking of appearance	Willingness to eat	Appetite satisfaction	Intake in grams
Liking of appearance	Pearson Correlation	1	.369**	.261*	0.048
	Sig. (2-tailed)		0.001	0.019	0.647
	N	80	80	80	80
Willingness to eat	Pearson Correlation	.369**	1	.381**	.281**
	Sig. (2-tailed)	0.001		0.000	0.012
	N	80	80	80	80
Appetite satisfaction	Pearson Correlation	.261*	.381**	1	0.155
	Sig. (2-tailed)	0.019	0.000		0.171
	N	80	80	80	80
Intake in grams	Pearson Correlation	0.048	.281**	0.155	1
	Sig. (2-tailed)	0.647	0.012	0.171	
	N	80	80	80	80

Table 24. *The correlation matrix of all dependent variables of eating behaviour. Significant effects (two-tailed) are highlighted in green.*

4.3.6. Effects on Pleasure

The significance table of the final LMM with Pleasure as dependent variable is shown in table 25.

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	39.000	248.539	0.000
Condition	1	39.000	0.000	1.000

Table 25. *The significance table of the final LMM with Pleasure as dependent variable. Significant effects are highlighted in green.*

Condition does not have a significant effect on Pleasure.

4.4. Discussion

A lab study was performed as a follow-up to the exploratory, in order to get a better answer to the main research question of the thesis: "To what extent, if any, is the influence of ambient light on eating behaviour mediated by emotional state?". To do so, a main research question for this study along with several sub-questions were formulated. These will be answered in the following sections. The limitations of the lab study in particular will be discussed as well. A general discussion as well as recommendations for future research will be presented later on in section 5.

The main research question that this study was trying to answer was:

Main RQ Study 2:
"To what extent, if any, does the illuminance level of ambient light influence the hedonic response and/or food intake of an unhealthy snack, and to what extent (if any) does emotional valence affect this relationship?"

In order to answer this question, it was divided into sub-questions:

- RQ2.1. Does illuminance level directly influence hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?
- RQ2.2. Does illuminance level directly influence valence of emotional state, and if yes, to what extent?
- RQ2.3. Does valence of emotional state directly influence hedonic response to and or/food intake of an unhealthy snack, and if yes, to what extent?
- RQ2.4. Does valence of emotional state have a mediating or moderating effect on the influence of illuminance level on hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?
- RQ2.5. Is hedonic response to and/or food intake of an unhealthy snack (M&Ms) influenced by other personal factors, and if yes, to what extent?

In this section, these research questions will be answered one by one.

An overview diagram of all statistically significant effects is given in figure 64.

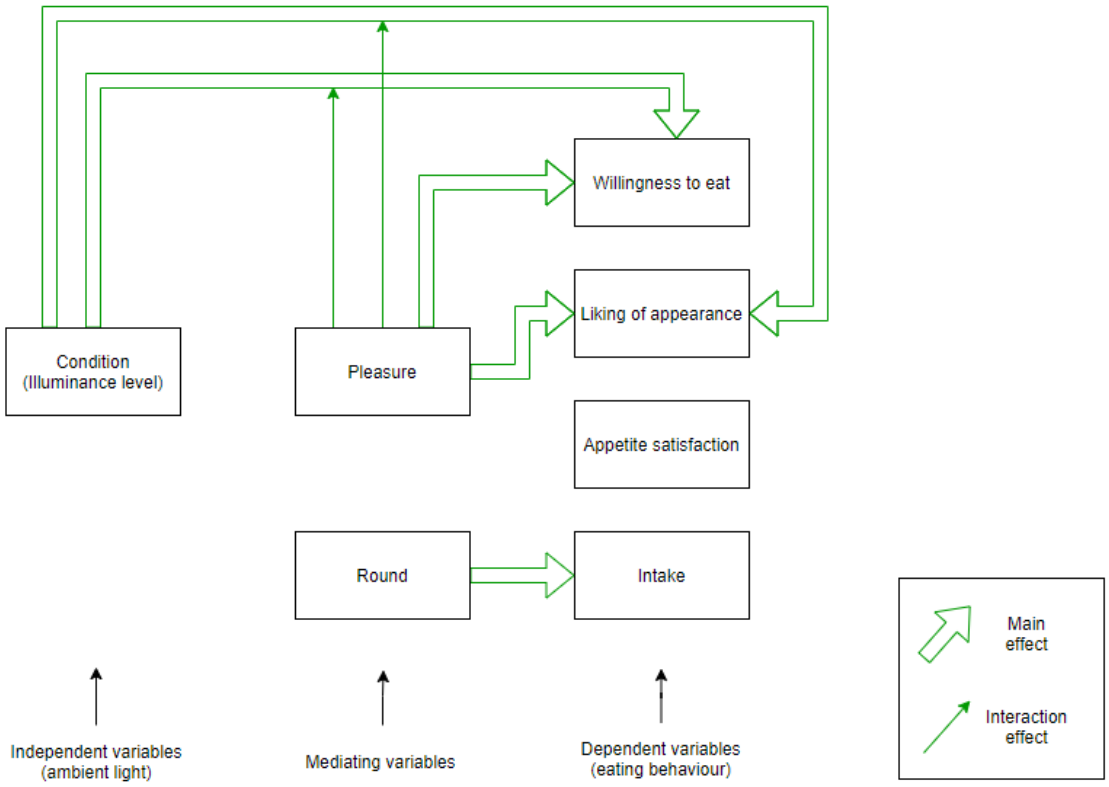

Figure 64. *An overview diagram of the statistically significant results of the exploratory survey. From left to right, the displayed variables are the independent variables (ambient light), the mediating variables*

(emotional state and round) and the dependent variables (eating behaviour). Broad arrows indicate main effects; thin arrows indicate an interaction effect.

RQ.2.1. Does illuminance level directly influence hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?

It was hypothesized that a high illuminance level will positively influence hedonic response and/or food intake of an unhealthy snack.

Illuminance level directly influenced willingness to eat and liking of appearance of the unhealthy snack, but not appetite satisfaction and intake.

While the effect of illuminance level on willingness to eat and liking of appearance of food has been documented in the past (e.g. Hasenbeck et al., 2014; Rebollar et al., 2017), so is the effect of illuminance level on food intake (Ross, 1974; Biswas et al., 2017).

Hasenbeck et al. (2014) found that bright light led to a higher liking of appearance and appetite satisfaction of bell peppers. Rebollar et al. (2017) found similar findings based on their participants eating yoghurt. A notable difference between their studies and the current study is that they used healthy food and not unhealthy food, such as the M&Ms used in this study. This difference in scope and design might explain the difference in findings. Possibly, the effect of illuminance on liking of appearance and appetite satisfaction is only present in healthy food, but willingness to eat in both unhealthy and healthy food. Further research is necessary to confirm such a hypothesis.

Ross (1974) found that obese people ate more nuts when the bowl of nuts was brightly illuminated than when the bowl was dimly illuminated. Conversely, Biswas et al. (2017) found that restaurant patrons order and consume fewer calories in a bright environment compared to a dim environment. A study by Bschaden et al. (2020) found no difference on intake of soup between a dim and a bright environment, however, participants did eat more in dim light with a tablecloth, highlighting the influence and importance of overall setting and ambiance of an environment on eating behaviour. The large differences in environments between the different studies might indeed be more important than previously thought. The current study was carried out in a lab setting, the study by Ross (1974) in a bar, the study by Biswas (2017) in a restaurant and the study by Bschaden (2020) in an experimental setting, but with attention to ambient details such as table linen. Both experimental settings found no effect of illuminance on food intake, indicating that the ecological validity of setting might influence the strength and direction of the effect of illuminance level on food intake more than previously thought. In order to learn more about the effect of ambient light on eating behaviour in specific scenarios (e.g. in a bar, in restaurant or at home) future research with high ecological validity is necessary. Findings cannot be easily generalized over settings.

The effect of illuminance on appetite satisfaction is not as robust. Studies have researched the influence of light colour on appetite satisfaction, suggesting that dim light might increase satisfaction (Wansink & Van Ittersum, 2012). Findings are not very robust, and satisfaction might be based more on learned associations and knowledge about food than on short-term light exposure.

RQ.2.2. Does illuminance level directly influence valence of emotional state, and if yes, to what extent?

It was hypothesized that illuminance level would increase a participants' valence of emotional state. However, no data was found to support this hypothesis, as the effect of illuminance level on pleasure was non-significant.

Previous research has often found an effect of bright light on mood and emotion. As discussed in section 3.4.1., illuminance level has both an image forming (IF) and a non-image forming (NIF) effect on humans. The more acute IF effect of bright light on Pleasure is not broadly researched but has been confirmed by Li et al. (2021). The NIF effects have been more well-documented: bright light often leads to an increase in valence and arousal (Smolders & De Kort, 2014; Leichtfried et al., 2015; Cajochen, 2007). However, this study only exposed participants to light conditions for a very short time (on average around 3 minutes to bright light and 3 minutes to dim light). NIF effects often occur after more long-term (30+ min) exposure to light conditions. The lack of long-term exposure might be a reason for the illuminance level not influencing valence of emotional state in the current study.

Pleasure was also not influenced by any other variables that were measured, meaning that the level of pleasure of participants was based on an external source. This source can range from a plethora of economical, physiological and psychological reasons.

RQ.2.3. Does valence of emotional state directly influence hedonic response to and or/food intake of an unhealthy snack, and if yes, to what extent?

It was hypothesized that a higher valence will lead to a more positive hedonic response and an increase in food intake.

Pleasure, the valence of emotional state, directly increased willingness to eat the unhealthy snack and liking of appearance of the snack. Pleasure did not significantly influence the intake and appetite satisfaction of the snack.

Hedonic response is thus significantly influenced by emotional state. This is in line with findings from previous research on the influence of emotions and mood in eating behaviour.

Some research has found that people in an emotional state with positive valence (in other words, with a higher level of pleasure) tend to rate food as more pleasant (e.g. Bongers et al., 2013). The same research, however, finds that intake is also improved. Nonetheless, food intake is not always influenced by emotion, especially positive emotion. In this research domain, the focus often lies on the effect of emotion on eating for emotional eaters versus non-emotional eaters. An emotional eater will overeat in response to strong, mostly negative emotions (Kaplan & Kaplan, 1957). Bongers et al. (2013) found a significant increase in food intake in emotional eaters who experience a positive mood, and a trend towards an increase in intake for non-emotional eaters in a positive mood. A negative mood leads emotional eaters to have a higher food intake than non-emotional eaters (Oliver, Wardle & Gibson, 2000). The influence of emotional state on food intake is thus affected by whether a person is an emotional eater or not. Moreover, it seems that not the valence of the emotion, but rather the strength of the emotion dictates food intake, as both positive and negative emotions increase food intake.

In this study, valence of the emotion was not manipulated, but rather was considered a dependent variable. It was hypothesized that emotional state would be influenced by illuminance level, however, not evidence was found to support this theory. The collected dataset almost only contained levels of pleasure higher than 50, meaning that all participants (except 2 out of 40) had a positive emotional state. All inferences have been based upon participants having a positive emotional state. Because a positive effect was found of (positive) pleasure on hedonic response, this seemed a linear effect, meaning that negative emotion would lead to lower hedonic response. However, as not enough actual negative emotions were captured, it cannot be said with certainty that the effect is indeed linear. It might be so that the relation between emotional state and hedonic response is very different from the effects that were found in the current study because negative emotions were not recorded. Moreover, the level of arousal was not measured in this study, mostly to simplify the study design and because more interesting effects of pleasure arose from the exploratory study. Would arousal have been measured, then the hypothesized effect of strength of emotion on hedonic response and food intake might have been examined. Finally, the current study design did not consider whether a participant was an emotional eater or a non-emotional eater. This information can have a large effect on food intake and should be considered in future research.

RQ.2.4. Does valence of emotional state have a mediating or moderating effect on the influence of illuminance level on hedonic response to and/or food intake of an unhealthy snack, and if yes, to what extent?

It was hypothesized that valence of emotional state would have a mediating effect of the influence of illuminance on hedonic response and/or food intake.

This hypothesis was disproven by the data. Mediation analysis on all hedonic response measures (willingness to eat, liking of appearance and appetite satisfaction) and food intake yielded no significant results. This is mainly due to the fact that no illuminance level had no significant direct effect on Pleasure.

No mediation effect was found; however, a moderation effect was found.

It was also hypothesized that the effect of valence of emotional state on hedonic response to and food intake of an unhealthy snack was stronger under bright light than under dim light.

This hypothesis was also disproven by the data. An interaction effect was found between illuminance level and pleasure on willingness to eat, however, the effect of valence of emotional state on hedonic response to and food intake of an unhealthy snack was somewhat stronger under dim light than under bright light. Moreover, an interaction effect was found between illuminance level and pleasure on liking of appearance, where the effect of valence of emotional state on hedonic response to and food intake of an unhealthy snack was significantly stronger under dim light than under bright light.

The structure of the direct- and moderation effects are found in figure 65 and figure 66.

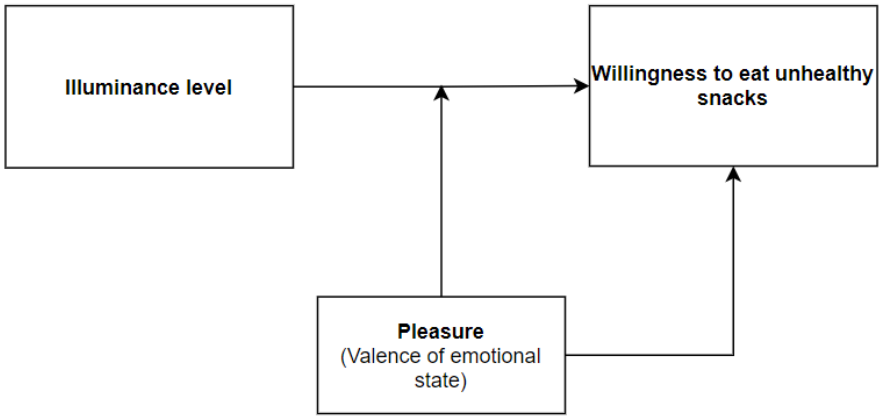

Figure 65. *A diagram showing the structure of effects of Illuminance level, Pleasure and Willingness to eat unhealthy snacks.*

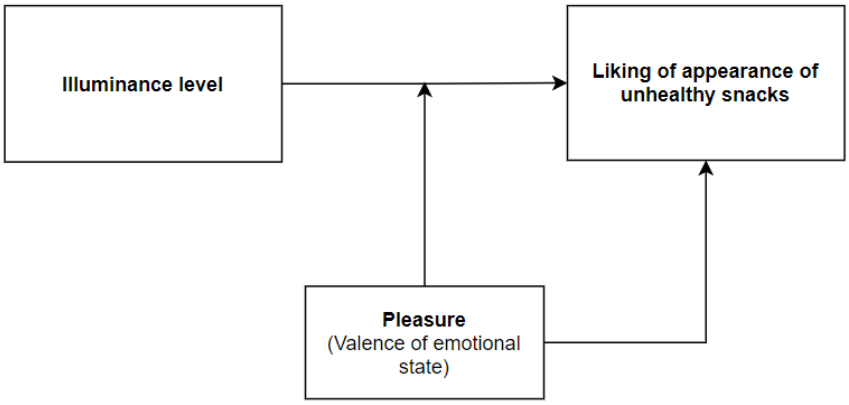

Figure 65. *A diagram showing the structure of effects of Illuminance level, Pleasure and Liking of appearance of unhealthy snacks.*

No significant interaction was found between illuminance and pleasure on willingness to eat in the exploratory survey. Rather, significant interaction effects between illuminance and pleasure on liking of appearance and food intake were found. These interaction factors had a reverse direction: the hedonic response was stronger under bright light than under dim light.

These findings suggest that a person with a very positive emotion would be somewhat more willing to eat, as well as like the appearance, of an unhealthy snack that is dimly illuminated than an unhealthy snack that is brightly illuminated. The difference in liking of appearance and willingness to eat appears to be even stronger for negative emotion: a person with a negative emotion would be much less willing to eat, as well as like the appearance, of an unhealthy snack that is dimly illuminated.

To illustrate this effect, it was visualised in figure 66.

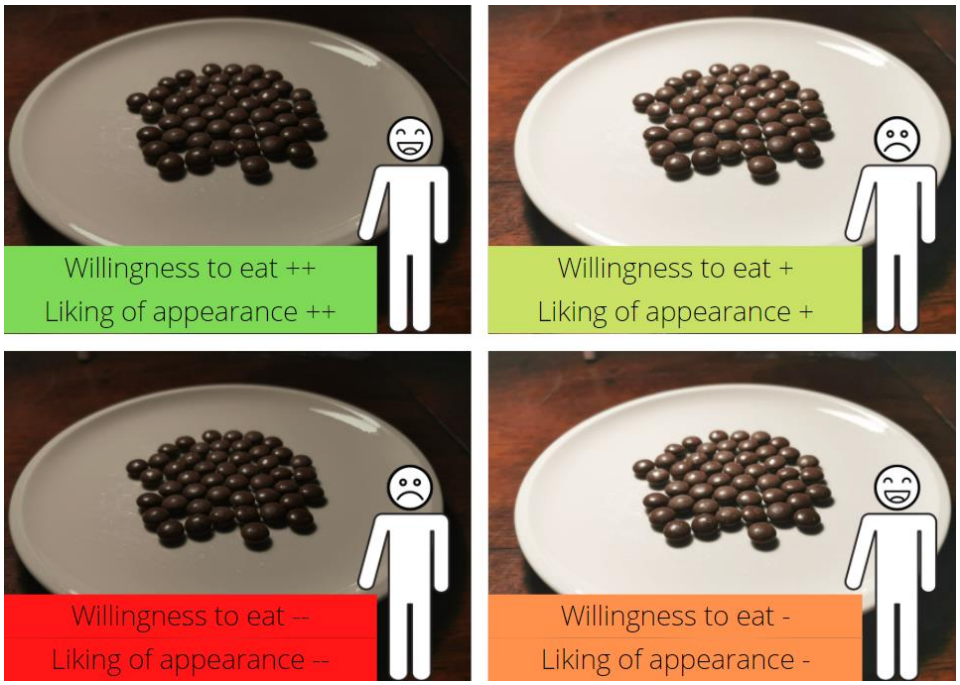

Figure 66. *A visual showing the moderation effect of pleasure on the influence of illuminance level on liking of appearance and willingness to eat. One plus- or minus-sign indicates a moderate effect, while two signs indicate a stronger effect. The figure was coded intuitively for the sole purpose of roughly demonstrating and visualising the effect.*

Dim light increases the intensity to which people like the appearance of snacks: an unhappy person will like a snack even less in dim light and a happy person will like the snack even more.

As explored when answering RQ2.1 and RQ2.2, both illuminance and pleasure directly influence willingness to eat and liking of appearance. These effects are also supported by existing literature: in many researched, bright light influences (amongst others) willingness to eat and (strong) positive emotions can increase hedonic response to unhealthy food. Overall, hedonic response is higher under bright light than under dim light. However, in the dim condition, valence has a much stronger effect on hedonic response than in the bright condition.

Previous research has already found that negative emotion leads to a more negative hedonic response, which is confirmed by the current findings. These findings suggest that this effect is even stronger in dim light (and thus weaker in bright light). However, these effects do not translate to a difference in intake, at least on short term.

In this study, illuminance does not directly influence valence, however, valence of the emotional state does moderate the effect of illuminance on willingness to eat and liking of appearance. This moderation effect thus explains a part of the variance of the data and thus accounts for slight interpersonal differences in the data.

RQ.2.5. Is hedonic response to and/or food intake of an unhealthy snack (M&Ms) influenced by other personal factors, and if yes, to what extent?

It was hypothesized that round, hungriness, liking of M&Ms, age and gender might act as covariates on hedonic response and/or food intake. For this reason they were added to iterations of the model. However, hungriness, liking of M&Ms, age and gender had non-significant effects in all iterations of the models and were thus not included in the final model. Round, the variable representing the temporal design of the study (participants were presented different conditions in two rounds), had a significant effect on intake. In fact, intake was not significantly affected by any other variable than round. Interestingly, people ate more M&Ms in the second round compared to the first round. While on average in Round 2 only about 2 additional M&Ms were eaten compared to Round 1, this is a large effect considering that participants only ate (on average) 7 M&Ms in total.

People might have eaten more in the second round because they wanted to enjoy the M&Ms as much as possible, without eating too much and feeling embarrassed about it. This is pure speculation, but this effect should nonetheless be considered in study design of future research.

4.4.1. Limitations

The results of this study are impacted by some limitations, which will be described in this section. Limitations that exist for both Study 1 and Study 2 are discussed in the general limitations section (section 5.2).

First of all, it was found that participants did not eat a lot of M&Ms. The average intake was around 7 M&Ms in total, so over two rounds. The caloric difference between 2 or 7 M&Ms is very low, so in real life, these differences would not matter at all. Reducing intake of M&Ms, an unhealthy snack, from 7 to 2 pieces is not a great real-life application. It might have been more interesting if people ate more of the M&Ms. This would require a different, longer study design, perhaps with a more elaborate deception, such as in studies by Lowe and Maycock (1988), Evers, Stok and de Ridder (2010) and Evers et al. (2013). They did provide participants with long questionnaires with nonsense-questions about the food, which ensured that they would eat the food without raising suspicion. The current study was pitched as a 5-minute study about eating and rating M&Ms. This framing was used to attract as many participants as possible. This was necessary, as data collection during a global pandemic is even more challenging than it would normally be. However, due to this framing, participants might have felt rushed to indeed stay in the 5-minute timeframe, and uncomfortable as they knew it was an experimental setting.

The ecological validity of this study should also be considered. While the validity is much higher than for the online exploratory study, the lab setting did not approximate a real-life setting. Unhealthy snacking behaviour might occur when watching TV while sitting on a couch, or in a social setting. The lab setting means that findings are less easily translated to a real-life situation, while this might be more the important as effects of ambient light on eating behaviour might be more dependent on other environmental factors (such as table linen [Bschaden, 2020] and ambient sound and music [Zellner et al., 2017; Kantono et al., 2016]) than previously thought. Future research might benefit from a study design in a real-life setting.

5. Discussion

To answer the research question “To what extent, if any, is the influence of ambient light on eating behaviour mediated by emotional state?”, an exploratory online study and an experimental lab study were performed. Sub-questions from these studies were already

answered in section 2.4.1 and section 3.4.1. In the following section, the main research question will be answered based on the combined results from the two studies.

5.1. Research question

The main research question of this study was:

"To what extent, if any, is the influence of ambient light on eating behaviour mediated by emotional state?"

By answering RQ1.6, it was found that in a setting based on photographs of food and imagination of eating, the influence of illuminance level and colour temperature on hedonic response to healthy and unhealthy food is both mediated and moderated by emotional state, in specific level of pleasure (see figure 67 and 68). Valence moderates the effect of illuminance level and colour temperature on liking of appearance. Apart from a moderation effect, a mediation effect is apparent, as illuminance level positively influences valence and arousal, which in turn positively influence liking of appearance of food.

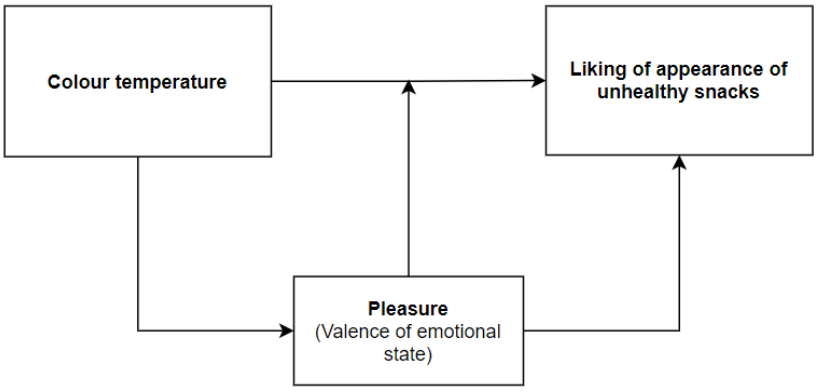

***Figure 67**. A diagram showing the structure of effects of Colour temperature, Pleasure and Liking of appearance of unhealthy snacks.*

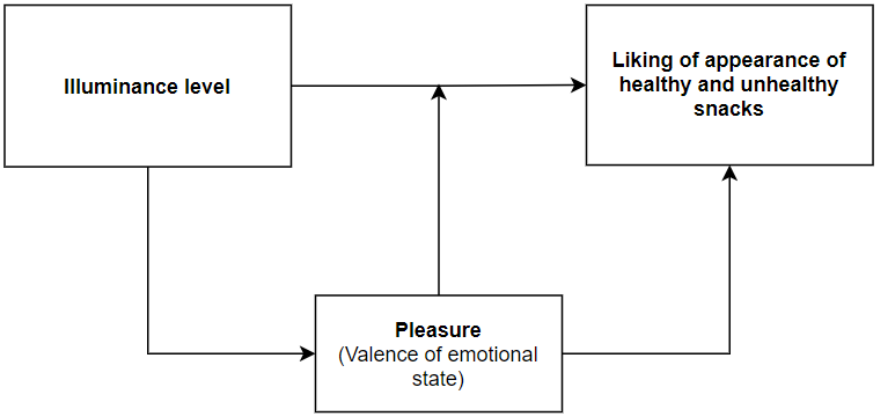

***Figure 68**. A diagram showing the structure of effects of Illuminance level, Pleasure and Liking of appearance of healthy and unhealthy snacks.*

This latter effect was furtherly explored in an experimental lab setting, where participants were physically exposed to the light conditions and the food, which they actually ate. From this study design, mediation analysis was possible. While answering RQ2.4, no mediation effects were found; however, some moderation effects were found. Similar direct effects of illuminance level and pleasure on liking of appearance and willingness to eat were found. A moderation effect of pleasure was found on the effect of illuminance level on liking of appearance, as well as on willingness to eat, which was not present in the online study (see figure 69 and 70). No effect of either illuminance level, pleasure nor an interaction between those on intake, which was found in the online study, was found. Moreover, the mediation effect found in the online study was not recreated from the findings from the physical study, as illuminance level did not directly influence level of pleasure.

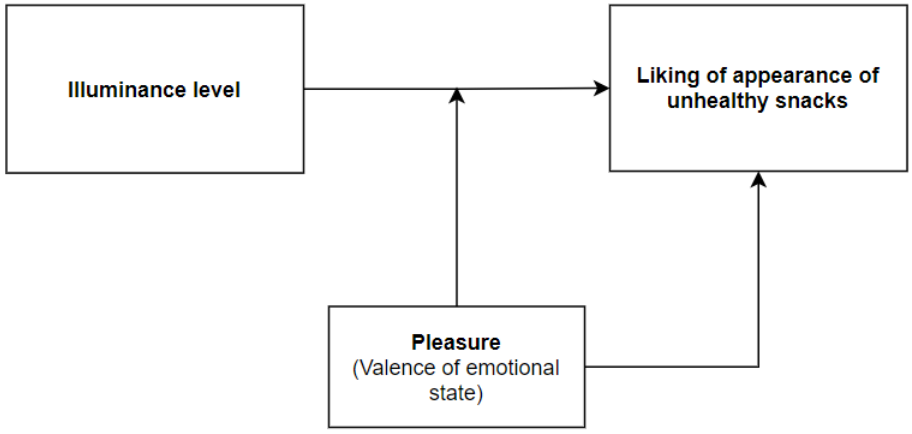

Figure 69. *A diagram showing the structure of effects of Illuminance level, Pleasure and Willingness to eat unhealthy snacks.*

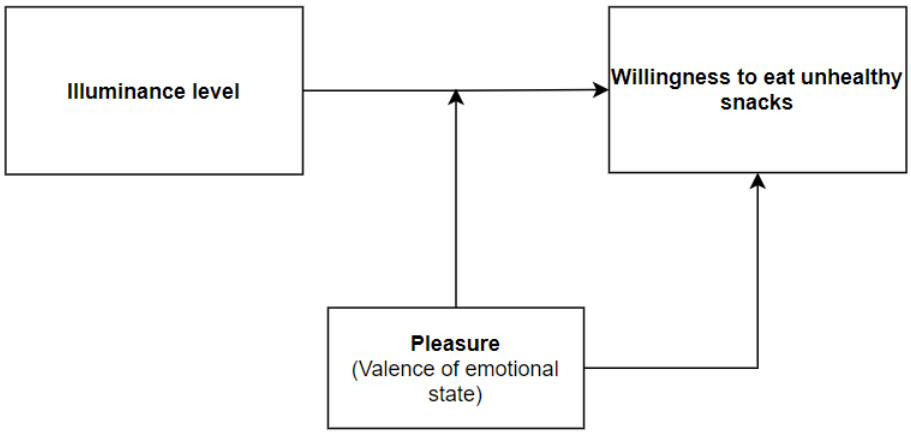

Figure 70. *A diagram showing the structure of effects of Illuminance level, Pleasure and Liking of appearance of unhealthy snacks.*

Interestingly, the moderation effect found in the physical study was very different from the moderation effect found in the online study, as visualised in figure 71 and 72.

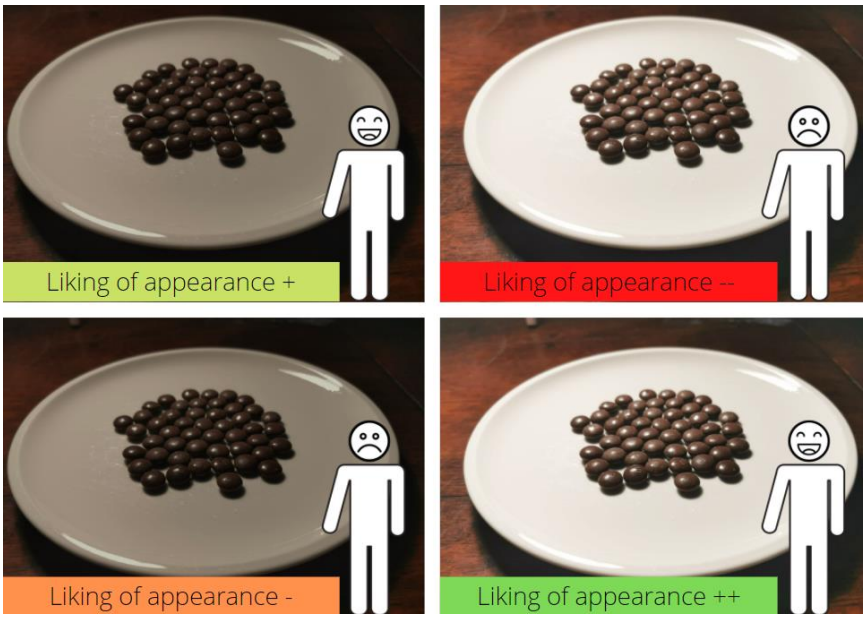

Figure 71. *A visual showing the moderation effect of pleasure on the influence of illuminance level on liking of appearance, as found in Study 1. One plus- or minus-sign indicates a moderate effect, while two signs indicate a stronger effect. The figure was coded intuitively for the sole purpose of roughly demonstrating and visualising the effect.*

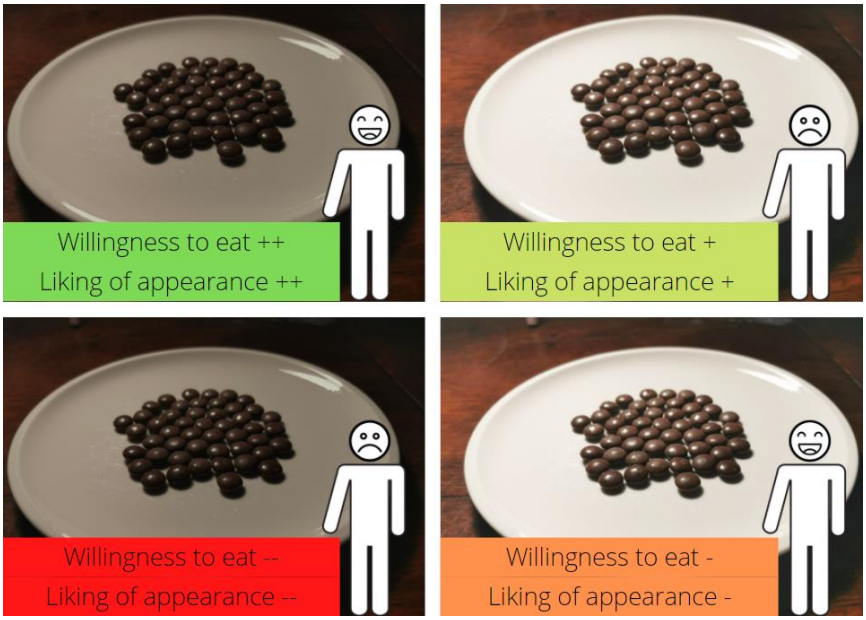

Figure 72. *A visual showing the moderation effect of pleasure on the influence of illuminance level on liking of appearance and willingness to eat, as found in Study 2. One plus- or minus-sign indicates a moderate effect, while two signs indicate a stronger effect. The figure was coded intuitively for the sole purpose of roughly demonstrating and visualising the effect.*

Whereas in the online study (figure 71), the effect of pleasure on liking of appearance was much stronger under bright light, in the physical study (figure 72), the effect of pleasure on liking of appearance was actually stronger under dim light. Disregarding pleasure, liking of appearance was higher under bright light for both the online and physical study.

First of all, the fact that there is a difference means that emotional state should not be disregarded when researching any effect of illuminance on eating behaviour, especially hedonic response.

This difference might have multiple explanations.

First of all, the difference in study design. The online study was distributed around noon. Participants all completed the survey around the same time and did so from their own location. It would not be strange to assume that they performed the study in a relatively bright location, with either daylight from windows or artificial light from lamps. On the other hand, the physical study took place in an office space which was completely dark, except for the lamp that illuminated the M&Ms. Natural light was barred from the room. This was done to ensure an even and constant distribution of the light. This difference might have led to a difference in experiencing the light conditions. In the online study, the photograph of the bright condition matched their own environment, while in the physical study, the dim condition was closer to the rest of the environment. Possibly, this affected the outcomes of the two experiments.

Apart from the environmental lighting conditions, the difference between the photographs of a snack and the actual physical snack might influence the outcome as well. Imagination of eating might not yield the same responses and preferences as actually eating a snack. This difference has not yet been researched in the domain of eating behaviour, but is prevalent in research in virtual reality, where differences between virtual and physical manipulation have been researched (Terrenghi et al., 2007; Agarawala & Balakrishnan, 2006) Indeed, people can respond differently to manipulations when presented virtually or digitally compared to physically. Jang et al. (2016) conclude in their VR study that direct manipulation for knowledge retention is better than passive viewing. Whether this would indicate that responding and rating snacks is done better actively than passively, is an interesting topic for future research.

As to why the direction of the effect was different, that might have to do with the types of food that were used in the experiments. Hasenbeck et al. (2014) found that bright light led to a higher liking of appearance and appetite satisfaction of bell peppers. It is important to note that this is healthy food, not unhealthy food such as the M&Ms used in this study. This difference in scope and design might explain the difference in findings. Indeed, in the survey, illuminance level more strongly affected the liking of appearance of healthy food than the liking of appearance of unhealthy food. Healthy food might have a different impact on liking of appearance of the food and should be researched in the future.

It should also be noted that this study did not consider whether a participant was an emotional eater of not. An emotional eater will overeat in response to strong, mostly negative emotions (Kaplan & Kaplan, 1957). Bongers et al. (2013) found a significant increase in food intake in emotional eaters who experience a positive mood, and a trend towards an increase in intake for non-emotional eaters in a positive mood. A negative mood leads emotional eaters to have a higher food intake than non-emotional eaters (Oliver, Wardle & Gibson, 2000). The influence of emotional state on food intake is thus affected by whether a person is an emotional eater or not. Moreover, it seems that not the valence of the emotion, but rather the strength of the emotion dictates food intake, as both positive and negative emotions increase food intake. This

effect is reflected in the current findings, as light conditions increased the intensity to which people like the appearance of snacks: an unhappy person will like a snack even less and a happy person will like the snack even more. The difference in findings might be caused by a different distribution of emotional- and non-emotional eaters. This factor should be considered in future research.

As to whether large interpersonal differences in the data were found and whether the found mediating and moderation effects explained for those differences: yes, and partly. Variance and standard error between participants were relatively high. This was reflected by the fits of the trend lines, which had very low goodness of fit. As a within-participant design was used, strength and direction of the found significant effects should be reflected correctly, but there were large differences between participants, which the mediating and moderating effects of emotional state did not completely account for. No conclusive answer can be given to the question where the large interpersonal differences come from. Possibly, learned associations and personal food preferences play a larger role in these differences than previously thought.

5.2. Limitations

The results of the study design of the exploratory study are impacted by some limitations, which will be described in this section. Limitations that exist only for Study 1 or Study 2 were discussed in their respective limitations sections (section 3.4.2 and section 4.4.2).

As discussed previously, in the lab study, participants were only exposed to the light conditions for a very short time (approximately 5 minutes). In the exploratory study, participants were not physically exposed to ambient light conditions at all. Most effects of lighting, especially NIF effects, only occur after long-term exposure (30+ minutes) to lighting conditions. It is probable that the results of the current study are all acute IF effects. This means that longer exposure to the light conditions might lead to very different results, as NIF effects often influence our physiology and psychology, For this, light also travels from the eye (via the retina) to the brain, but signals are sent to brain areas involved in physiology, mood and behaviour.

The results of Study 1 and Study 2 varied on many different levels. This might be based on different limitations, most of which have been discussed in section 5.1.

In both Study 1 and Study 2, valence of the emotion was not manipulated, but rather was considered a dependent variable. The collected datasets almost only contained levels of pleasure higher than 50, meaning that almost all participants had a positive emotional state. All inferences have been based upon participants having a positive emotional state. Because a positive effect was found of (positive) pleasure on hedonic response, this seemed a linear effect, meaning that negative emotion would lead to lower hedonic response. However, as not enough actual negative emotions were captured, it cannot be said with certainty that the effect is indeed linear. It might be so that the relation between emotional state and hedonic response is very different from the effects that were found in the current study because negative emotions were not recorded. Moreover, the level of arousal was not measured in Study 2, mostly to simplify the study design and because more interesting effects of pleasure arose from the exploratory study. Would arousal have been measured, then the hypothesized effect of strength of emotion on hedonic response and food intake might have been examined further.

In the exploratory study, a significant effect of a mediation of valence and arousal on the effect of colour temperature on liking of appearance of healthy and unhealthy snacks was found. This effect was not furtherly investigated due to time constraints: Study 2 had to be as concise as possible, so it was decided to only further research the effect of illuminance on pleasure and eating behaviour.

Both studies still contained large interpersonal differences in responses and effects that were not accounted for. The found mediating and moderating effects of emotional state did account for some of the variation, but not all of it. These differences might be due to participants being either emotional eating or not (as discussed in section 5.1) or due to learned associations that vary from person to person.

Finally, most dependent variables of both studies yielded exclusively self-reported data. Only food intake was quantitatively measured in Study 2. Emotional state, mental alertness, all eating behaviour measures and all other covariates were measured on self-report scales. This has as a consequence that responses might be biased or inaccurate (Rosenman, Tennekoon & Hill, 2011).

6. Conclusion

Although direct effects of ambient light on eating behaviour and emotional state as well as direct effects of emotional state on eating behaviour are well-documented, not much is known about the extent to which emotional state mediates and moderates the effect of ambient light on eating behaviour. It was hypothesized in existing literature that it is exactly this effect that causes large interpersonal differences in research on ambient light and eating behaviour. To explore the influence of emotional state on the effect of illuminance and colour temperature on snacking behaviour, two studies were carried out: one to explore the many facets of ambient light, emotional state and eating behaviour, and one to follow up on the most interesting findings of the exploratory study.

Mostly, the known direct effects of ambient light on eating behaviour and emotional state as well as direct effects of emotional state on eating behaviour were confirmed, although not always on every aspect of eating behaviour but especially for liking of appearance of food. Study 1 found both a mediation and a moderation effect of valence of emotional state on liking of appearance, where bright light increases the intensity to which people like the appearance of snacks: an unhappy person will like a snack even less and a happy person will like the snack even more. As bright light also increases level of pleasure, this would mean that illuminating a snack with dim light lowers level of pleasure and dampens the intensity of liking of appearance. Study 2 found no mediation effect of valence but did find a moderation effect of valence on the effect of illuminance level on liking of appearance. This moderation effect was in the opposite direction of the moderation effect found in Study 1: here, not bright but dim light increased the intensity to which people like the appearance of snacks. This difference might have been caused by four different factors. Firstly, the difference between environmental light in both studies. Secondly, the difference between the photographs of Study 1 and the physical, live experimental setup of Study 2. Thirdly, the type of food that was used: the effect in Study 1 on unhealthy food might have been a Type II error. And lastly, the unconsidered influence of a person inherently being an emotional eater or not.

Results are not conclusive and unaccounted interpersonal differences in the findings still exist. Future research with long-term exposure and manipulation of emotional state is necessary to formulate a conclusive answer and to be able to support healthy eating through the modulation of emotional state with ambient light.

6.1. Recommendations for future work

Based on the current findings and limitations, some recommendations for future work are given.

To be able to confirm the presence and direction of a moderating and mediating effect of emotional state on the influence of ambient light on eating behaviour, additional research is necessary. It is recommended that such a follow-up study would be in a real-life setting, ensuring higher ecological validity. Light conditions should be exposed for a longer duration, to examine both IF and NIF effects of light. Emotional state should also be manipulated, to ensure that both emotions with positive and negative valence are recorded. Moreover, emotional state should be measured quantitatively as well, with measures as heart rate and galvanic skin response. To further examine interpersonal differences between participants, more personal information should be gathered. It would be very interesting to infer whether participants are emotional eaters or non-emotional eaters. Moreover, learned associations could be researched more in-depth.

Based on future research, a more conclusive answer to the research question might be given. This would be a good addition to the current research field and might have implications that can support healthy eating, by monitoring emotional state and alter light conditions accordingly.

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