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Can a Change in Wall Luminance Prevent Dozing Off at Work?

A replication study on Wall Luminance and its alerting effects, aimed to explore underlying mechanisms

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in Human-Technology Interaction

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Abstract

De Vries, Souman, de Ruyter, Heynderickx, & de Kort (2018) have discovered that varying the level of Wall Luminance is able to induce better sustained subjective alertness. Without increasing light falling on the eye, brightness of the wall was set to three different levels and higher Wall Luminance seemed to counteract the decay in alertness that occurred over the course of the experiment. The current study aims to replicate these findings, and proposes a motivational and associative mechanism that may explain the previously found effect. In an within-subject design, we presented 29 participants with three Wall Luminance levels (Low: 19, Medium: 38, and High: 73 cd/m^2) in an office-like environment. We measured, among others, room appraisal, associations, motivation and alertness in the three different Wall Luminance conditions. We found no effect of Wall Luminance on subjective alertness (χ^2 (2, N = 29) = .06, p = .969), and thus were unable to replicate the results of de Vries et al. (2018). Additionally, we did not find support for the motivational mechanism, but associations and room appraisal seemed to be affected by Wall Luminance. We discuss these findings and propose their implications and aim to explain the lack of effect on alertness in the current study.

1. Introduction

The importance of environmental factors in the office (such as room temperature, noise, and lighting; Kamarulzaman, Saleh, Hashim, Hashim, & Abdul-Ghani, 2011) and their effects on employees' wellbeing, comfort and performance have become clear over the past years. Also, spaces with natural elements (plants, water, daylight, an outdoor view) can be beneficial for wellbeing (Olson, 2015). Although requirements for optimal visual performance (e.g., being able to read a document at your desk) and visual comfort (e.g., no glare from any luminaires or the sun) are extensively documented (EN12464-1:2002), there is more to office lighting than merely these two factors. Ambient conditions, among which lighting, may affect contentment with the physical office space as well as performance (McCoy, 2005). Designs of healthy lighting installations are different than those originating from conventionally held rules, it can for example be beneficial to be able to change intensity and color of the lighting (van Bommel & van den Beld, 2004). It therefore may be a good idea to look *beyond* the obvious and conventional factors when it comes to lighting design.

A recent study by de Vries, Souman, de Ruyter, Heynderickx, & de Kort (2018) explored in what way Wall Luminance, as a single lighting design characteristic, influences office workers. In their experimental set-up, spots in different intensities were used to create three levels of wall brightness. They looked at room appraisal, affective state, subjective alertness and problem solving performance, and how it is affected by these Low, Medium and High Wall Luminance levels. Across the three conditions, light falling on the eye was kept as constant as possible. Their main finding was that participants were better able to stay alert throughout the experiment in the high Wall Luminance condition, compared to the Low and Medium Wall Luminance conditions.

The current study was designed to see whether we are able to replicate this better sustained subjective alertness that was caused by higher Wall Luminance. Furthermore, we aim to uncover why this effect was observed, and through what mechanisms the better sustained subjective alertness occurs. For that, we focus on associative-based and motivational-based mechanisms that may be able to explain (part of) the previously found effect.

We first introduce both the non-image forming and the image forming pathway of light in general. We will elaborate on where automatically processed associations come from, what these associations could provoke and why this is relevant when talking about brightness and alertness in the office. Then, finally, a motivational pathway is proposed.

1.1 (Non-)Image Forming Pathway of Light

When talking about light and alertness, the non-image forming (NIF) pathway of light and its effects are inescapable. Broadly, we can look at the effects of light through two different routes in the brain: the image forming (IF) pathway and the non-image forming pathway (Boyce, 2003). Visual performance and visual comfort requirements are generally based on the image forming pathway; e.g., what levels of light are needed for us to be able to accurately read the paper that is on our desk? It regards signals coming from light falling on the retina, which then finds its way to the visual cortex through our rod and cone photoreceptors, where we are able to form an image (Boyce, 2003). It allows us to perceive our surroundings and see objects, contrasts and colors in our environment.

The NIF pathway functions through a third kind of photosensitive cell, additional to the rods and cones, located in the inner layer of the retina, discovered almost twenty years ago (Brainard et al., 2001; Thapan, Arendt, & Skene, 2001). These cells are called the intrinsically photosensitive retinal ganglion cells, or ipRGCs, and contain the photopigment melanopsin. IpRGCs are inherently responsible for non-visual light responses, but ipRGCs also work as a conduit through which information from the rods and cones are led to the brain in order to form non-visual responses to light (Provencio & Warthen, 2012). The best-known NIF effect of light is entrainment to the circadian clock (Barinaga, 1998). The ipRGCs send signals to the suprachiasmatic nucleus, located in the hypothalamus, which is known as the main controller of our circadian system (Gooley, Lu, Fischer, & Saper, 2003). The light-dark cycle is an important indicator (or ‘Zeitgeber’) that helps us maintain a 24-hour circadian rhythm (Golombek & Rosenstein, 2010), and poorly-timed light can disturb this daily rhythm.

The NIF pathway is not only involved in circadian regulation. It also concerns some more acute effects resulting from light exposure (e.g., Cajochen, 2007). Effects of light through the NIF pathway are quite extensively studied already. Bright light, compared to dim light, can decrease sleepiness (or increase alertness) during the day (Phipps-Nelson, Redman, Dijk, & Rajaratnam, 2003; Smolders & De Kort, 2014). However, results on this are fairly inconsistent in the current literature, as mixed outcomes have been reported (Souman, Tinga, te Pas, van Ee, & Vlaskamp, 2018). It leaves us with inconclusive results regarding the alerting potential of bright and/or blue-enriched light.

Studies merely investigating effects that occur through this NIF pathway may overlook effects that exist alongside the NIF effects, simply because they possibly are falsely attributed to originate in the NIF pathway. Without any studies exploring other mechanisms that are at play, we may not be able to draw a conclusive conclusion about light and its effects on alertness. The present study therefore looks beyond these NIF effects on alertness to see whether brightness of a room may alter people's states, *without* the involvement of the NIF pathway. By keeping the vertical illuminance at eye level constant, and at the same time increasing Wall Luminance, we keep activation of ipRGCs virtually constant but vary the perceived brightness of the environment. Any effects of room brightness on alertness that are found should then be attributed to other mechanisms resulting from information conveyed through the IF pathway, such as associations or an increase in motivation.

1.2 Associative-Based Mechanism

Before we dive into the associations with light and dark that we know may exist, it is needed to understand what associations are and how they work. The mind can be said to consist of two systems (for an overview, see Stanovich & West, 2000). Daniel Kahneman (2011) describes the first system as processing information "*automatically and quickly, with little or no effort and no sense of voluntary control*" (p. 20) and System Two as being involved in "*effortful mental activities, including complex computations*" (p. 21). Shortly said, System One is responsible for associations that are automatically processed, whereas System Two requires purposeful mental effort. These automatic processes of System One can either be learned to the point where they come automatic to you (e.g., learned associations between ideas or understanding social situations) or innate (e.g., avoiding losses). He mentions that System One cannot be switched off (hence, the automatic nature of the system); if you see a word in a language familiar to you, you will automatically read it.

System One is also the system involved in associations, evoking cognitive, physical and emotional responses to stimuli.

Associations with light and dark are embedded in our society, such as the association of black and white with bad and good concepts, respectively. For example, as immoral and moral (Sherman & Clore, 2009). We can find many movies and stories where a light-dark contrast emphasizes who are heroes and who are villains. It is no coincidence that the little mermaid is bright and colorful, while Ursula has a more dark ambiance. The same goes for Snow White with her bright blue and yellow dress and the evil queen dressed in dark purple and black. Or Aladdin in his vivid purple vest and white trousers versus Jafar, who is dressed in burgundy and black. These differences in brightness, of course together with many other factors among which the music, help us interpret what the movie director wants to convey, without taking too much effort as we make these associations practically automatically. It is immediately clear to us who we should see as the good character, and who classifies as bad. Our System One automatically associates the dark with being bad, and light with being good.

1.2.1 Humans and lightness/darkness

We, humans, are diurnal mammals; we are awake during the day and generally sleep during the night. This was precisely the case before there was electrical lighting, when the light-dark cycle was out of our control. During the day, when the sun lit up our environment, it was important to find food and do any activities that needed to take place, such as hunting and building shelter. In the daytime we were awake and alert. In the darkness of the night, we were unable to see clearly enough to do any of such activities and went to sleep, taking our rest for the next day. Darkness impairs our vision, making us fear it because we cannot see possible attacks or threats coming.

This relation of alertness and bright environments (or sleepiness and darker surroundings), can be found in our present-day lives as well. To give an example, bars and clubs or cinemas are a place to relax and forget about our work stress, and are generally very dimly lit. Vice versa, a gym or office where we have to be focused and have responsibilities usually is brighter. And of course, we still mostly sleep during the night even though we are now able to lighten up our world even when it is pitch dark outside. More generally; during the day we have more need to be alert (e.g., at our jobs) than during the night when we are at home without many obligations (or simply go to sleep), possibly making us associate brightness with alertness and darkness with relaxation/sleepiness through our System One.

Cajochen (2007, p. 454) mentioned that a sighted person may "*intuitively feel more alert in a more lit environment compared to darkness*". In his paper, he describes it as a possible placebo effect of light on alertness, stressing the need for more objective measures next to these subjective ones. However, he thereby also implies an associative relationship between brightness and subjective alertness. It might be our System One that makes this inference. We may associate a brighter environment with alertness, forming an actual behavioral effect between the two instead of merely an inconvenient placebo effect.

In a pilot study, we conducted an implicit association task among a group of students in order to see whether we would be able to find an association between brightness and alertness, and between darkness and sleepiness. We used a light fixture that became brighter or dimmer as well as words representing alertness and sleepiness. We asked them to categorize these light scenarios and words, where the categories were either congruent (i.e. brighter and alertness were in one category) or incongruent (i.e. dimmer and alertness in one category). We found an increase in reaction time in the incongruent condition, when compared to the congruent condition. It implies that it is more easy for people to associate brightness with alertness (and darkness with sleepiness) than it is the other way around.

Limited studies have been conducted concerning the overall perception of bright versus darker *rooms*. Brightly lit environments have shown to be evaluated as more lively (Stokkermans, Vogels, de Kort, & Heynderickx, 2017). The concepts of brightness and darkness in general have been subject to more studies. We evaluate bright images of outdoor scenes more positively than their darker counterparts (Beute & De Kort, 2013; Lakens, Fockenberg, Lemmens, Ham, & Midden, 2013). Of course, positive pictures may be already brighter to start with (Lakens et al., 2013), resulting in a less clear-cut causal relationship between brightness and positivity. Though, even when the same exact pictures were used, only differing in their level of brightness, this difference in positive evaluation was found as well, suggesting that brightness makes the pictures seem more positive. Additionally, Lakens et al. (2013) have shown that after a bright image prime, participants categorized positive words (versus negative words) more quickly, implying a profound inner relation between brightness and positivity. A recent study by Schietecat, Lakens, Ijsselsteijn, & de Kort (unpublished manuscript) has revealed that lighting scenarios are evaluated on the activity axis. Meaning that more light is perceived as more active, and could also be associated with arousal, therefore making it very plausible that brightness is indeed associated with alertness.

1.2.2 Behavioral responses

The influence of associations is not limited to mental processes. Associations are able to provoke behavioral responses; darkness can trigger certain behavior. Zhong, Bohns, & Gino (2010) propose that darkness induces a feeling of anonymity, thereby triggering selfish behavior and dishonesty. In the same way, brightness seems to increase people's self-awareness and reflective self-regulation (Steidle & Werth, 2014). A bright room makes duties more pronounced than wishes, possibly leading us to associate a bright room more with having responsibilities compared to a dark room, where we feel more free to act on our wishes. Acting on your responsibilities requires a certain state of alertness, and the pressure of these responsibilities possibly induces a higher alertness level to enable you to take your responsibility and do what you need to do.

Associations seem to be able to induce certain mental states (e.g., alertness) and behavioral responses (e.g., better self-regulation). Both of these examples, alertness and self-regulation, intuitively are important for office workers to carry out their work properly. Maybe we are able to make use of these associations in a way that improves workers' performance and mental state. Then, without requiring any effort from workers (after all, associations are processed automatically) we could create a situation where employers benefit from improved performance and a better overall wellbeing of their employees. But even more importantly, the employees themselves will feel better and may suffer less from fatigue during their working days.

1.3 Motivation-Based Mechanism

Motivation is an important aspect in the work environment. Without a sense of motivation, employees' job commitment suffers (Srivastava & Barmola, 2011) and performance will inevitably also decrease. When talking about motivation in the workplace, most theories focus on general motivation for someone to do their job well (e.g., Herzberg, Mausner, & Snyderman, 1959). General motivation is the overall motivation that one has for their job, which is not subject to much change over the course of time. It is rather constant.

However, there is more to motivation than this general drive that merely captures motivation as a constant factor. Motivational intensity is a momentary state of motivation (Brehm & Self, 1989). Even when a person is highly motivated, one's motivational intensity could be low at any time, as it represents motivation at a certain time point as opposed to general motivation. The best explanation of motivational intensity comes from Brehm and Self (1989): *"It is the difference, for example, between moving 100 pounds of books one book at a time or all at once"* (p. 110). Where in the first case it results in lower motivational intensity at any given point in time, in the second it is a short episode of high motivational intensity. When we want to look at how motivated one is to complete a task, we can determine a self-reported general motivation (e.g. overall job motivation). However, this does not mean that this person is always highly motivated and without any interruption works to reach a goal. The temporary motivation is a *state* rather than a trait factor.

As opposed to general motivation, motivational intensity *is* likely to change from time to time. Motivational intensity is subject to changes in temporary states such as, for example, fatigue. This momentary measure of motivation increases when the perception of effort increases, up to the point where the task seems too difficult to perform (Brehm & Self, 1989). Depletion or fatigue increases perceived effort (Wright, 2014), possibly making a task seem too effortful to even start. It is comparable to initially being fairly well-motivated to finish the paper you are writing, but temporarily feeling like you are unable to because you have already been working on another project the whole day. We know this as ego depletion; one's capacity to exert willpower or active volition is not endless (R. F. Baumeister, Bratslavsky, Muraven, & Tice, 1998). Every act or choice involving self-regulation, initiating behavior (and inhibiting it, for that matter), or exertion of control over yourself 'empties' its resources and thereby negatively influences each subsequent act of volition. This temporal state of fatigue, or depleted state, does not mean that you do not find the paper important, it merely affects your motivational intensity. Momentary motivation is subject to many contextual factors, as opposed to the general, more or less constant, motivation you have to finish the paper. To keep with the book metaphor: some days you may only move one, another day you may feel extremely motivated and pick up twenty at a time.

1.3.1 Motivation and light

There have been several studies linking bright light and motivation together. Daurat et al. (1993) have found that bright light during the night improved alertness as well as performances on a letter cancellation task, a logical reasoning task and a visual discrimination task. During the day, bright light of 2000 lux at eye level improved mood and motivation (as self-reported on a visual analog scale), through the NIF pathway of light. A study by Kohsaka et al. (1999) has investigated what effects one hour of bright light exposure (1000 lux at eye level) for one hour in the morning may have, and found that bright light induced higher self-reported levels of, among others, motivation, alertness and mood. Rectal temperature did not change under bright light exposure. They therefore conclude the changes in motivation, alertness and mood to not be the result of a shift in the circadian clock, but to be of a more acute effect of bright light.

In the literature, motivation and (positive) affect are closely linked (Bye, Pushkar, & Conway, 2007; Isen & Reeve, 2005). Positive affect leads to higher intrinsic motivation, the task is then perceived as more joyful. Veitch, Newsham, Boyce, & Jones (2008) propose a conceptual route from luminous conditions, through appraisal, to affect. But their findings were a surprise; it seemed that lower rates of attractiveness led to higher persistence on their motivation task. An influence of lighting conditions on positive affect may induce higher motivation (Isen & Reeve, 2005), thereby increasing effort (Brehm & Self, 1989) and general task performance and alertness.

1.4 Current Study

Previous findings (de Vries et al., 2018) as well as the literature discussed above, have led us toward the expectation that when Wall Luminance is higher, this leads to better sustained subjective alertness, and possibly also to better sustained *objective* alertness. Secondly, we think that a brighter appearance of the room, could induce alertness through an associative-based mechanism. We additionally expect that higher Wall Luminance induces a higher level of motivation, possibly through higher room appraisal and a positive affective state, and that this increase in motivation causes alertness to be better sustained. The conceptual framework for this study is shown in Figure 1. More specifically, we aim to answer the following question: *“Can a potential change in subjective alertness, caused by a change in Wall Luminance, be explained through associative or motivational-driven mechanisms?”.*

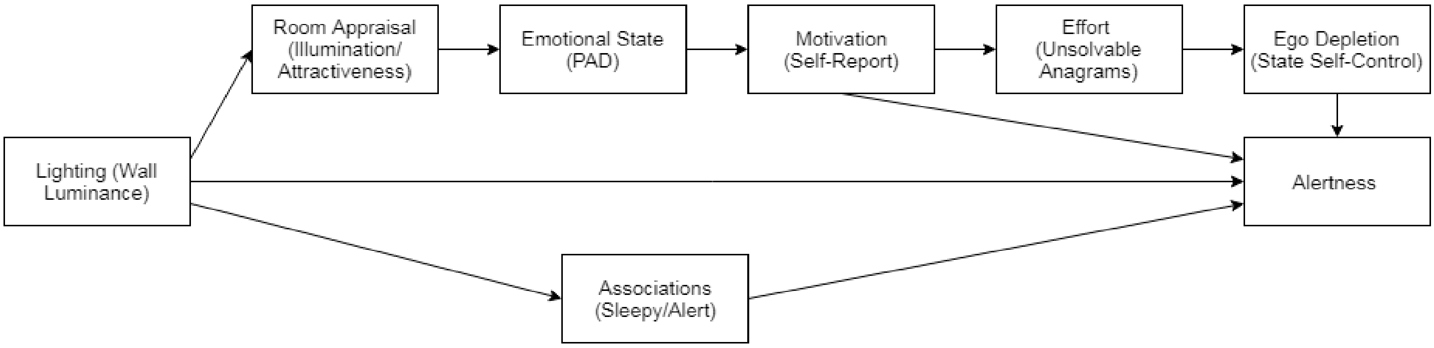

Figure 1. Visual representation of the conceptual model, with the motivational route (on the top) and associative route (bottom).

2. Method

2.1 Design

The study follows a within-subject design with three levels of Wall Luminance (Low: 19, Medium: 38, and High: 73 cd/m^2). Subjective alertness, emotional state and heart rate were measured at the start of the session as well as at the end, leading to the additional within-subject factor 'Time' in session, following a 3x2 design. Each participant took part in three sessions, and experienced one of the Wall Luminance levels during each session. The study took place over three consecutive weeks in April and early May, with two sessions each afternoon, respectively starting at 13.00 h. and 15.00 h.. Up to four participants could take part in the study at the same time. The groups that were hereby formed stayed constant over the course of the experiment; for each session, the participants were in the session with the same fellow participants. Due to unforeseen circumstances (e.g., illness), there were minimal changes in these group formations. Order of the lighting conditions was counterbalanced over the groups. Each group had a fixed time of day and day of the week, to keep matters as constant as possible per group. For example, one group would return on three Mondays and all three sessions started at 13:00 h.

2.2 Participants

In total, 30 students took part in the study (20 female), ages ranged from 19-35 (M = 22.4, SD = 3.0). They received a monetary reward for their participation in the three sessions. Participants were selected (through the JFS participants database) to be native Dutch speakers, had normal or corrected to normal vision, were not color blind and did not suffer from dyslexia. One participant was excluded from the analysis due to missing two of the three session, resulting in 29 participants for the statistical analyses.

2.3 Setting & apparatus

The experiment took place in a room measuring 940 x 870 x 290 cm (length x width x height). Closed roller blinds blocked daylight entrance through the windows. There was a total of eight desks (height 75 cm) in the room, of which four were equipped with computers, these served as desks for participants to take place at. These four desks were placed so that they all faced the same wall (the left wall on the floor plan in Figure 2). This resulted in a different setup than the original study had, where participants sat two by two opposite to each other. We chose the current desk placement and viewing direction because one of the walls (wall on the right in Figure 2) reflected light much less diffusely than the other wall. When directly looking at this wall, it created a more restless visual image and was thought to influence the perception of the room too much. We therefore opted not to let participants face this wall directly. Four desks and chairs were placed in front of the main four desks to add to the feeling of a real office, instead of simply one row of desks.

Computers (23 inch monitors) were used to prompt questions and tasks, everything was programmed to be presented (resolution 1920 x 1080) in the needed order using E-Prime 3.0. The screen, as used during the experiment with a light grey background and black text, added approximately 17 lux to the vertical illuminance on the eye and measured a CCT of 5360 K. The distance between the participants and the monitor was circa 70 cm.

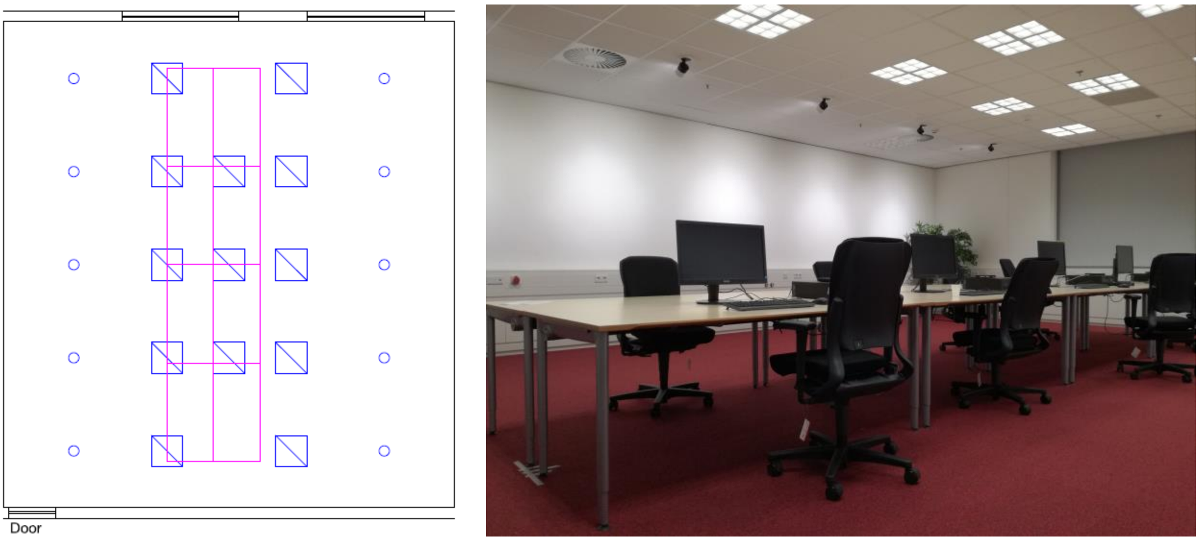

Figure 2. Floorplan (left) and photograph (right) of the experimental setup.

2.3.1 Lighting

In each session one of the three light conditions was presented, with either Low Wall Luminance (19 cd/m^2), Medium Wall Luminance (38 cd/m^2) or High Wall Luminance (73 cd/m^2) as measured including the visible part of the ceiling, excluding luminaires (see Table 1 for more specifics). Luminance measures were done using a calibrated Technoteam LMK 5 Color luminance camera, at 1.2 m height positioned at where the participants' eyes would be. The lighting design was completely based on the one used by de Vries et al. (2018), merely adjusted to better fit the larger office space in this experiment.

Two lighting systems were used, to be able to control Wall Luminance separately from the illuminance levels at eye height and on the desks. Thirteen 60 x 60 cm low glare LED-based office luminaires (Philips PowerBalance, 4000 K, RA > 80, UGR < 16; the small circles on the floorplan in Figure 2) ensured a horizontal illuminance level of 500 lux on the desks (view Table 1 for the exact average illuminance levels). Two rows of five spots (Philips StyliD, 4000 K, RA > 80, to be found on the floorplan as squares) controlled Wall Luminance, distance from the spots to the wall was approximately 150 cm and a center on center spacing of 180 cm. The distance between the wall and the spots was slightly larger than in the original design (distance in original design: 90 cm), and the spots were spaced further apart (original design 120 cm apart). This led to a more diffusely lit wall and less visible contours of light coming from the spots. The lighting design was based on luminance measures obtained at desk 2, therefore these are reported in table 1. Additionally, the range (minimum and maximum value) of measurements at the other desks are provided.

Changing the Wall Luminance caused a slight difference in illuminance measured at eye level. On average, the difference between the Low and High Wall Luminance conditions was approximately 44 lux. Using the toolbox as proposed by (Lucas et al., 2014) and the spectral power distribution, melanopic weighted illuminance at eye level was calculated for all three conditions of Wall Luminance. Melanopic weighted illuminance, as averaged over the four tables, was 114 lux in the Low Wall Luminance condition, 122 lux in the Medium setting, and 139 lux at the High Wall Luminance level.

Table 1

Lighting Measurements of the three Wall Luminance conditions.

Wall Luminance	$L_{avg,wall}$ [cd/m^2]	Range [cd/m^2]	$L_{avg,wall+ceiling}$ [cd/m^2]	Range [cd/m^2]	$E_{avg,desk}$ [lux]	$E_{v,eye}$ [lux]	CCT [K]	LMM_{wall}
Low	23	22.61-23.76	19	18.79-19.10	513	193	3388	1.42
Medium	50	49.25-51.77	38	37.53-38.24	514	208	3399	1.59
High	101	98.25-104.4	73	72.69-74.11	515	237	3428	1.68

Note: $L_{avg,wall}$: Average wall luminance, only measuring the visible part of the wall, at desk 2. $L_{avg,wall+ceiling}$: Average wall luminance, including also the visible part of the ceiling (excluding luminaires), at desk 2. Ranges as documented for $L_{avg,wall}$ and $L_{avg,wall+ceiling}$ represent the range of averages among the four desks. $E_{avg,desk}$: Average illuminance on the desk, as averaged over all four desks. $E_{v,eye}$: Vertical illuminance at the eye, viewing direction at 1.20 m height with screens switched off, as averaged over all four desks. CCT: Correlated color temperature, at desk 2. LMM_{wall}: Logarithmic of ratio maximum to minimum luminance of the wall, as measured at desk 2, reflecting visual interestingness (Loe, Mansfield, & Rowlands, 1994).

2.4 Measurements

Self-reported and objective measures were both used to investigate the effects of wall luminance on, most importantly, alertness. All questionnaires and tasks were presented through a computer screen, and participants provided their answers using the computer mouse or keyboard.

2.4.1 Self-report

We prompted several self-report/subjective measures in four categories. We asked participants about their alertness and mood, how they perceived the room in terms of associations and room appraisal, motivation and self-control, and chronotype.

Affective state: alertness and mood

Subjective alertness was assessed using the 9-point Karolinska Sleepiness Scale (KSS; Akerstedt & Gillberg, 1990). Response options ranged from 1 (‘extremely alert’) to 9 (‘extremely sleepy – fighting sleep’).

Emotional state was measured using the 18-item Pleasure-Arousal-Dominance (PAD) scale (Mehrabian, 1995). Each dimension (Pleasure, Arousal and Dominance) contained six questions measured on a 7-point Likert scale, where a 1 indicated low Pleasure/Arousal/Dominance.

Associations and room appraisals

Associations regarding alertness were administered by displaying 24 words in random order. For each word that was presented, the participants chose whether or not the word fits the room. There were ten words that reflected alertness or sleepiness, the additional 14 words were added as a distraction from the alertness theme. Participants were encouraged to answer quickly, without too much thinking about their answers and give the answer that first comes to mind. Two scores were calculated; a sleepy associations score and an alert association score. Both consisted of how many sleepy (or alert) words the participant indicated to be fitting the room well, and thus ranged from 0 to 5.

Room appraisal was measured using a condensed 8-item version of the room appearance rating system from Veitch and Newsham (1998). Two different dimensions were assessed in the room appraisal items, namely Attractiveness and Illumination. Attractiveness consisted of five items: Unattractive – Attractive, Ugly – Beautiful, Unpleasant – Pleasant, Dislike – Like, Somber – Cheerful, all rated on a visual analog scale ranging from 0 to 1. Attractiveness was then calculated as the average of the five items. Illumination consisted of three items: Vague – Distinct, Dim – Bright, Gloomy – Radiant, and the average of the three items was used as a measure for Illumination.

Motivation and state self-control

Subjective state motivation was assessed using a Dutch translation of the 10-item scale by Sundre (1999). It was originally used to measure students' motivation for a test, which is rather comparable to measuring motivation of participants to complete the tasks presented in this study. One item was removed ('This was an important test for me'), as this question focuses more on an overall motivation to work hard at school, which we expected not to be present in the current study. The remaining nine items were all rated on a 5-point scale ranging from '1 – Strongly disagree' to '5 – Strongly agree'.

State self-control capacity was measured using the 25-item State Self-Control Capacity Scale, all items were rated on a 7-point Likert scale. Scores were computed by adding all answers, resulting in a score ranging from 25 to 175, where the former represents high and the latter indicates lower self-control.

Chronotype

Chronotype was assessed through the Morningness-Eveningness Questionnaire (MEQ; Horne & Östberg, 1976), which allowed us to exclude any extreme chronotypes from the analyses. Even though this questionnaire measures a trait characteristic, it was completed in each of the three sessions to ensure consistency of the experiment's duration in all three sessions.

2.4.2 Tasks

Three tasks were prompted throughout the experiment. Namely, the Remote Associates Task, an Unsolvable Anagram Task, and the Psychomotor Vigilance Task.

Remote Associates Task (RAT)

The Remote Associates Task (Mednick & Mednick, 1967) measured convergent thinking. A Dutch 30-item version was used, developed by (Akbari Chermahini, Hickendorff, & Hommel, 2012), together with a practice version that has not been validated and is therefore excluded from the analysis. Participants were shown ten word problems per session, all presented at the same time, which they should solve in no particular order. Three words were shown, to which participants should find a fourth associative word (e.g., Sleep / Bean / Trash were presented, the wanted word here is 'Bag'). There was a time limit of five minutes to complete the word problems. The practice items were prompted first, and after the time limit participants started the validated items, which again was terminated after five minutes.

Unsolvable Anagram Task (UAT)

An Unsolvable Anagram Task (UAT) was used as an objective measure of motivation and effort. Participants were presented with nine anagrams to solve, of which three were unsolvable. For the unsolvable anagrams, time before participants gave up and went on to the next one was measured. As a measure, we used time spent on unsolvable anagrams divided by the total time (time spent on unsolvable anagrams/(time spent on solvable + time spent on unsolvable anagrams)). The higher this number was, the more motivated participants were to try and solve the anagrams. The nine anagrams were presented one at a time, semi-randomly to avoid showing the three unsolvable ones all after each other to prevent excessive discouragement. Participants could skip an anagram at any time when they were unable to find a solution.

Psychomotor Vigilance Task

As an objective measure for alertness, the visual Psychomotor Vigilance Task (PVT) was conducted. Participants were instructed to respond as quickly as possible when the stimulus appeared on the screen. The delay interval between stimuli was set to be picked randomly between 1000 and 9000 ms. Reaction time (in ms) was time between presentation of stimulus and participant response. The PVT took ten minutes in total.

2.4.3 Physiology

Heart rate was measured continuously throughout the duration of the study as a measure of arousal. For this, Polar H7 chest straps were used that connected to tablets (Samsung Galaxy Tab 2) through Bluetooth, which then registered the R-R intervals. These R-R intervals were then used to calculate both the heart rate (beats/minute) and heart rate variability (rMSSD).

2.5 Procedure

Each session followed the same procedural timeline (Figure 2), the lighting condition was set before participants entered the experiment space. To keep matters as constant as possible, every question was prompted in all sessions, therefore also sex and age, which are unlikely to change between sessions, were asked each session. Participants were welcomed and shortly instructed that they would be completing several questionnaires and tasks on the computer. At the start of the first session, participants also signed informed consent forms. Participants then put on the chest straps and the experiment leader connected them to the tablets. No extensive instructions were given, as the explanation for each different task would be given on the screen. Participants could ask questions to the experiment leader when aspects of the experiment were unclear.

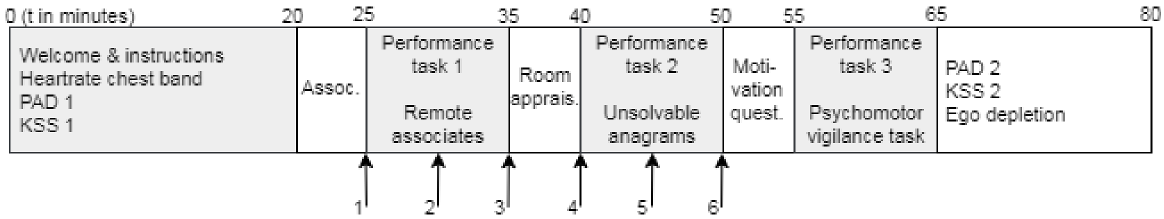

Figure 2. Procedural timeline of the experiment. Arrows represent the times participants had to wait for a sign from the experimenter to move on with the experiment.

Participants were told that they could start and firstly entered their age and sex. Then the KSS was prompted, as well as the first PAD scale. The MEQ followed, and the items were presented in random order. The next block were the associations, during which 24 words were presented in random order, and participants indicated whether they thought the word fitted the room.

The first task was the RAT, which contained two rounds of five minutes. To ensure same starting time, participants were presented with a screen asking them to wait until the experiment leader told them to go on (arrow 1 in Figure 2). The experiment leader then timed five minutes, after which the participants were told to stop and go on to the second round that (arrow 2 in Figure 2), again, after five minutes the participants were instructed to stop (arrow 3 in Figure 2). The first round was a practice round, using RAT items that are not validated. The second round consisted of ten of the thirty RAT items developed by Akbari Chermahini et al. (2012). After this first task, room appraisal was assessed with eight items, presented in random order. When these were completed, participants waited for the experiment leader before they continued.

The second task was the Unsolvable Anagram Task (UAT), which consisted of two rounds, each with nine anagrams, with a maximum time of five minutes. The anagrams were presented one-by-one and participants could move on to the next anagram when they solved it or gave up trying to solve it. Participants started all together (arrow 4 in Figure 2). After five minutes, the experiment leader told them to move on to the second round (arrow 5 in Figure 2). When a participant finished earlier, a screen appeared telling them to wait until the experiment leader tells them to move on to the second round. The second round was the same as the first round, with different anagrams. After the second round of the UAT (arrow 6 in Figure 2), the 9-item motivation questionnaire was presented one item at a time.

The PVT then started as the third task, first with a one minute practice round, ensuring that everyone knew exactly what to do. After this they continued with the full ten minute version. The second measures of the KSS and PAD scales were prompted after the PVT. Lastly, state self-control was assessed using a 25-item scale. Participants waited for everyone to finish, after which they could take off their chest straps and were thanked for their participation.

The second and third sessions were identical to the first one, except for the items presented in the RAT and UAT. Each session presented new items for these two tasks, to make sure they would not still know the answers from the first session and could use them in the second session. Payment took place at the end of the third session.

2.6 Statistical analysis

All analyses were performed using Stata 14. Outliers generally were defined as values over or under three standard deviations from the mean. For the PVT, this was done for each participant according to their *own* mean reaction times and their standard deviations, and all outliers were set to missing. The mean reaction times for the analyses were then calculated, and now mean reaction times *between* the participants were checked for outliers. Three sessions, from three different participants, were excluded from the analyses, because they seemed to influence the model too much. Outliers in reaction times for the anagrams did not seem to greatly affect the model, and were therefore *not* set to missing values. Outliers in the Heart Rate data were also defined as being more than three standard deviations from the mean. For Heart Rate Variability, successive differences between the separate beats were checked for outliers, and additionally inter-beat intervals of over 1.5 seconds were excluded. These outliers were assumed to be measurement errors where the device momentarily did not record heart rate, resulting in large amounts of time between two heartbeats. No further outliers were found.

Linear mixed models (LMMs) were performed for each of the analyses. Because of the within-subject design, participants went through three sessions, resulting in data in which we should bear in mind that there are differences between participants. We therefore included participant as random intercept; the model accounts for repeated measures within participants. Some variables were administered twice (KSS and the PAD scale, as well as the Heart Rate measures) during each session, and therefore included the Time variable, had an additional level in the data. There, it were participants that completed three sessions, in which they completed the PAD and KSS twice and HR was measured twice. In all LMMs where either KSS, a dimension of the PAD scale or a HR measure was the dependent variable, it is mentioned that a *two-level* LMM was used, which indicates that session was introduced as a second random intercept. When it is merely a *one-level* LMM, only participant was a relevant random intercept.

We aimed to provide similar results as those presented in the study by de Vries et al. (2018) so that we are better able to compare results. Therefore, when dealing with categorical independent variables, main effects were derived from the LMM using contrasts of marginal linear predictions. A chi-squared (χ^2) test reflected this main effect, meaning that it showed whether there were any differences between any of the categories (in this case; the Wall Luminance conditions). Post-hoc pairwise comparisons then show the exact differences between all conditions, for which *p*-values are Scheffe corrected for multiple comparisons. For continuous independent variables, the standardized coefficients (β) are reported directly from the LMMs.

3. Results

A complete overview of the main effects of Wall Luminance on *all* measures can be found in Appendix A, Table A1. All Estimated Marginal Means and Standard Errors of each measure in the three different Wall Luminance conditions are presented in Appendix B, Table B1. Appendix C, Table C1, C2 and C3 contain all results of analyses where KSS was the dependent measure.

3.1 Wall Luminance and Alertness

Alertness was measured both subjectively (KSS) and objectively (PVT). We investigated whether Wall Luminance affected these measures.

3.1.1 Karolinska Sleepiness Scale (KSS)

A two-level Linear Mixed Model (LMM) was performed to test the effect of Wall Luminance on the KSS scores. Both Wall Luminance, Time and their interaction (Wall Luminance x Time) are included in the model. Figure 3 shows the estimated marginal means of the KSS score for the three Wall Luminance levels. Results of the LMM revealed that Wall Luminance did not show a significant main effect on KSS (χ^2 (2, N = 29) = .06, p = .969), and neither did the Wall Luminance x Time interaction (χ^2 (2, N = 29) = 1.25, p = .536). Time influenced KSS scores significantly (χ^2 (1, N = 29) = 37.02, p < .001) which indicates a significant difference between KSS1 and KSS2 scores. Participants became less alert (more sleepy) over the course of the experiment, independent from the manipulation of Wall Luminance (KSS1 M = 3.90 vs. KSS2 M = 5.32, p < .001).

Table 2

Estimated marginal means (EMM) and standard errors (SE)

KSS						
	KSS1		KSS2		KSS Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	3.86	.32	5.37	.32	4.62	.25
Medium	4.03	.32	5.10	.32	4.59	.25
High	3.79	.32	5.48	.32	4.64	.25

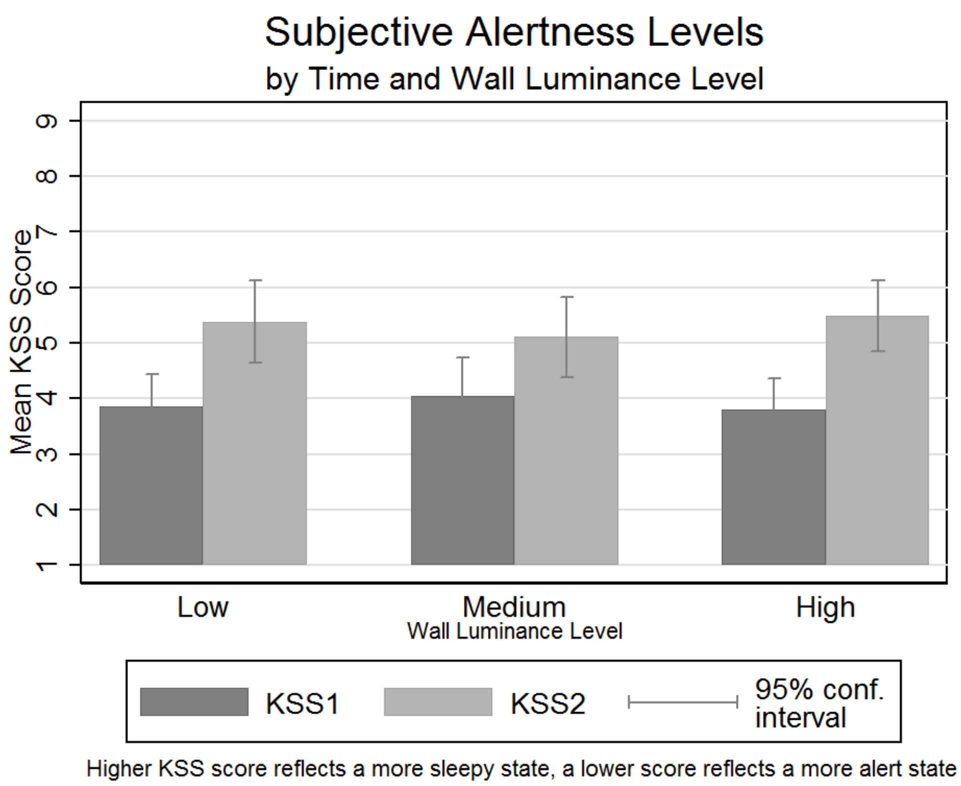

Figure 3. Subjective alertness levels, by Time and Wall Luminance. Whiskers represent 95% confidence intervals. KSS1 is the first KSS measurement in the session, KSS2 is the second measurement of KSS.

Estimated marginal means and their standard errors are presented in Figure 3 and Table 2. Despite the absence of an effect, for comparison to the original paper the differences between the three conditions were further explored by means of pairwise comparisons. No significant differences were found between the average KSS scores (as averaged between KSS1 and KSS2; Table 2 KSS Average) when merely taking into account the different Wall Luminance levels (Low vs. Medium, p = .984; Medium vs. High, p = .998; Low vs. High, p = .972).

Pairwise comparisons did not reveal any significant differences when comparing KSS1 (Low vs. Medium, p = .999; Medium vs. High, p = .997; Low vs. High, p = 1.000; Table 2 KSS1) and KSS2 (Low vs. Medium, p = .993; Medium vs. High, p = .972; Low vs. High, p = 1.000; Table 2 KSS2) separately.

The Medium Wall Luminance condition was the only condition in which no significant difference between the two different time points (KSS1 and KSS2) was found (Medium KSS1 vs. Medium KSS2, p = .225). Both the Low (Low KSS1 vs. Low KSS2, p = .016) and High (High KSS1 vs. High KSS2, p = .004) conditions show a significant increase in sleepiness (decrease in alertness) over the course of the session.

3.1.2 PVT

The Psychomotor Vigilance Task (PVT) reflects objective alertness, and is measured as mean reaction time to a simple visual stimulus over a 10-minute PVT. A one-level LMM was performed to see how Wall Luminance affected PVT reaction times. The mean reaction times were log transformed in order to create a normal distribution and ensure normality of the residuals. The estimated marginal means of original reaction times can be found in Table 3, together with their standard errors.

Wall Luminance did not have a significant effect on log PVT reaction times (χ^2 (1, N = 29) = 2.62, p = .270). Post hoc pairwise comparisons indeed showed no significant differences in reaction times between any of the Wall Luminance conditions (Low vs. Medium, p = .505; Medium vs. High, p = .920; Low vs. High, p = .297).

Table 3

Estimated marginal means (EMM) and standard errors (SE)

Psychomotor Vigilance Task (PVT) in ms

	PVT	
Wall Luminance	EMM	SE
Low	370	8.99
Medium	364	8.92
High	359	8.99

3.2 Associations

We measured to what extend participants associated the room with sleepiness and alertness. Figure 4 shows associations over the different Wall Luminance conditions.

3.2.1 Wall Luminance and Sleepy Associations

A one-level LMM was performed to explore the effect of Wall Luminance on the amount of Sleepy Associations participants reported. A significant effect of Wall Luminance on Sleepy Associations was found (χ^2 (2, N = 29) = 13.24, p = .001). Post hoc pairwise comparisons (estimated marginal means in Table 4 and Figure 4) showed that the High condition resulted in less Sleepy Associations (Low vs. High, p = .005; Medium vs. High, p = .010). There was no significant difference between the Low and Medium condition (Low vs. Medium, p = .973; see Table 4).

Table 4

Estimated marginal means (EMM) and standard errors (SE)

Sleepy and Alert Associations				
	Sleepy Associations		Alert Associations	
Wall Luminance	EMM	SE	EMM	SE
Low	3.03	.33	2.14	.29
Medium	2.97	.33	2.10	.29
High	2.07	.33	3.10	.29

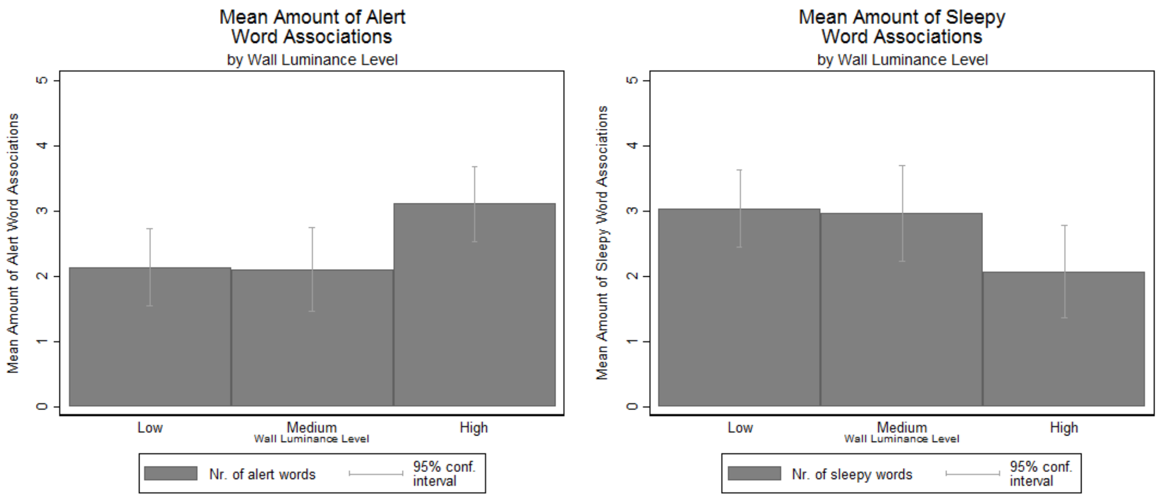

Figure 4. Associations per Wall Luminance level, clearly showing a difference in both alert and sleepy associations between the High vs. the Low and Medium Wall Luminance conditions.

3.2.2 Wall Luminance and Alert Associations

Another one-level LMM was performed to investigate the effects of Wall Luminance on Alert Associations. Wall Luminance showed a significant effect on Alert Associations (χ^2 (2, *N* = 29) = 13.09, *p* = .001; estimated marginal means are presented in Table 4 and Figure 4). Post hoc pairwise comparisons revealed no significant difference between the Low and Medium Wall Luminance conditions (Low vs. Medium, *p* = .994), but the High Wall Luminance level differed from both the Low and Medium levels (Low vs. High, *p* = .009; Medium vs. High, *p* = .006).

3.2.3 Sleepy Associations and KSS

We performed a two-level LMM to see whether Sleepy Associations and KSS scores are correlated. Time and the interaction Sleepy Associations x Time are included to be able to see whether KSS1 and KSS2 might be related to Sleepy Associations differently from each other. As expected, Time yielded a significant correlation with KSS (β = .77, p < .001). Sleepy Associations did not significantly correlate with KSS (β = -.01, p = .914), and the Sleepy Associations x Time interaction also showed no significant effect (β = .11, p = .266).

3.2.4 Alert Associations and KSS

A two-level LMM was performed to look at the correlation between Alert Associations and KSS scores. Again, Time and Alert Associations x Time are included as predictors in the model. Time was significantly correlated with KSS (β = .77, p < .001). Both Alert Associations itself (β = -.08, p = .450) and the Alert Associations x Time interaction (β = -.12, p = .240) were not significantly correlated with KSS.

3.3 Room Appraisal

Room appraisal (RA) was measured through two dimensions: RA Illumination and RA Attractiveness. RA Illumination reflects the brightness of the room as evaluated by the participants, and RA Attractiveness shows how attractive participants evaluated the room to be. In section 3.5, the relation between RA and emotional state (PAD) is explored.

3.3.1 Wall Luminance and RA Illumination

RA in terms of Illumination was scored on a visual analog scale, giving two-decimal scores between 0.00 and 1.00. A one-level LMM predicting RA Illumination using Wall Luminance as independent variable was conducted. Wall Luminance had a significant main effect on RA Illumination (χ^2 (2, N = 29) = 20.89, p < .001).

Pairwise comparisons of estimated marginal means (Table 5, RA Illumination) showed no significant differences in RA Illumination between the Low and Medium conditions (Low vs. Medium, $p = .190$). But there was a difference between the Medium and High levels (Medium vs. High, $p = .025$) and High and Low levels (Low vs. High, $p < .001$). Figure 5 shows how RA Illumination differed over the Wall Luminance conditions, Table 5 shows EMMs and SEs.

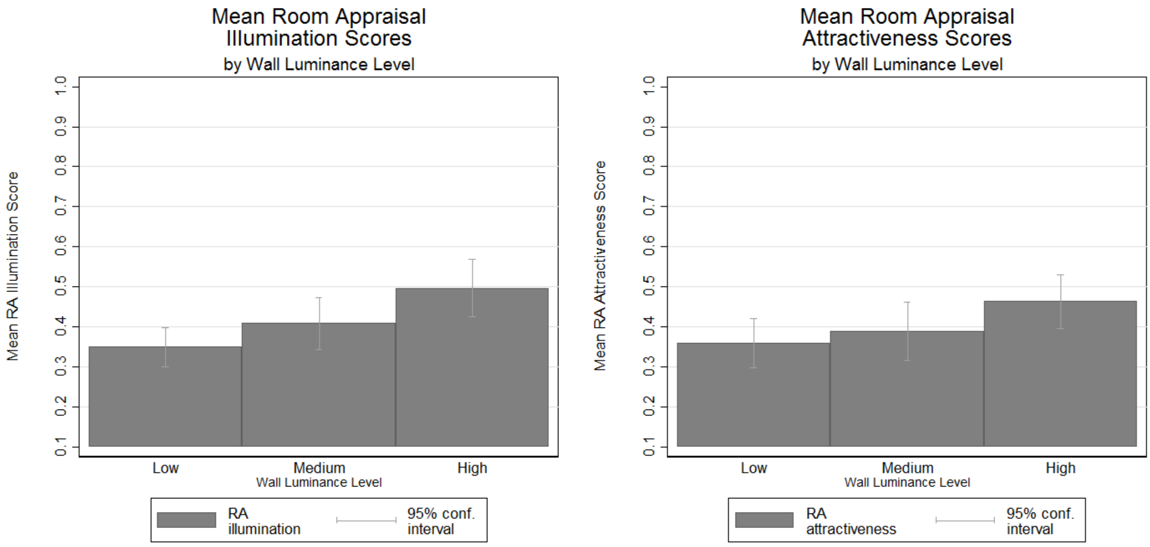

Figure 5. Room appraisal, in terms of Illumination and Attractiveness, by Wall Luminance levels.

Table 5

Estimated marginal means (EMM) and standard errors (SE)

Room appraisal (RA) in terms of Illumination and Attractiveness				
	RA Illumination		RA Attractiveness	
Wall Luminance	EMM	SE	EMM	SE
Low	.35	.03	.36	.03
Medium	.41	.03	.39	.03
High	.50	.03	.46	.03

3.3.2 Wall Luminance and RA Attractiveness

Performing a one-level LMM, we now look at RA Attractiveness with Wall Luminance as independent variable, to see whether our manipulations of Wall Luminance levels influenced the perceived attractiveness of the room. Wall Luminance significantly affected RA Attractiveness (χ^2 (2, N = 29) = 12.06, p = .002). Figure 5 (graph on the right) shows RA Attractiveness in the different Wall Luminance levels.

Post hoc pairwise comparisons of marginal means show no significant difference between the Low and Medium Wall Luminance levels (Low vs. Medium, p = .628) and also no significant difference between the Medium and High Wall Luminance levels (Medium vs. High, p = .055). A significant difference in RA Attractiveness was found between the Low and High Wall Luminance conditions (Low vs. High, p = .003; see Figure 5 and Table 5).

3.3.3 RA Illumination and KSS

A two-level LMM was created to investigate the relation between RA Illumination and subjective alertness (KSS). The interaction RA Illumination x Time and Time itself are also included as predictors. No significant main effect of RA Illumination on KSS was found (β = -.03, p = .771) and, as reported above, Time influenced KSS scores (β = .77, p < .001). The interaction RA Illumination x Time also significantly affected KSS (β = -.27, p = .004).

Because of this significant interaction effect, two LMMs were created with respectively KSS1 and KSS2 as dependent variables. RA Illumination was unrelated to KSS1 (β = -.10, p = .387), but was significantly related to KSS2 (β = -.27, p = .012; Figure 6).

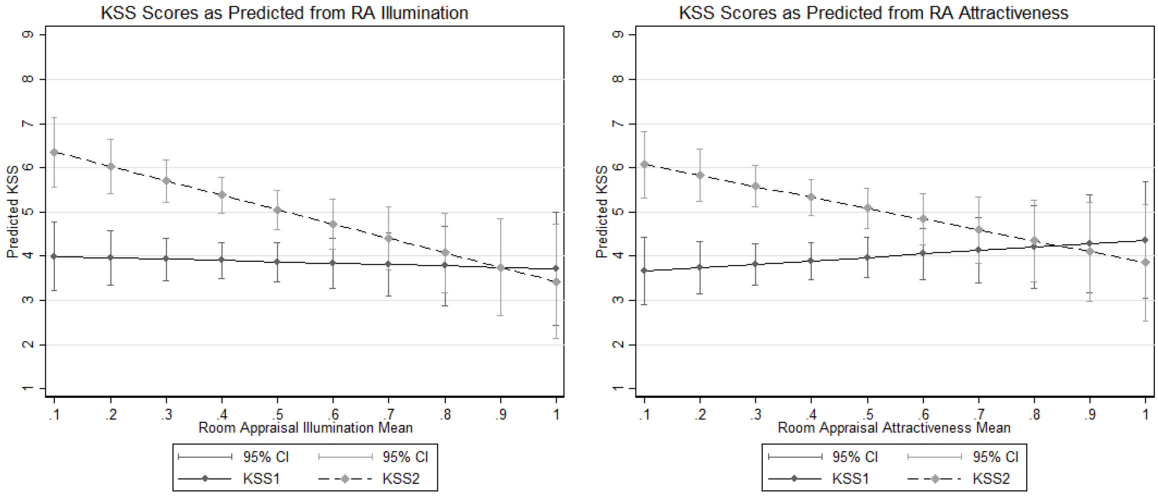

Figure 6. KSS Scores as predicted from RA. Clearly showing the relation between KSS2 and room appraisal on both the Illumination and Attractiveness dimension, and the lack of relation with KSS1.

3.3.4 RA Attractiveness and KSS

An identical two-level LMM was performed as for RA Illumination, now with RA Attractiveness as independent variable. RA Attractiveness did not significantly correlate with KSS (*β* = .08, *p* = .463), but Time was, as expected, positively related to KSS (*β* = .77, *p* < .001). The interaction RA Attractiveness x Time revealed a significant time-dependent correlation between participants' appraisals regarding the attractiveness of the room and their KSS scores (*β* = -.32, *p* = .001).

Because the interaction yielded a significant effect, two LMMs were conducted with respectively KSS1 and KSS2 as dependent variables. RA Attractiveness did not show a significant effect on KSS1 (*β* = .06, *p* = .598), but did significantly correlate with KSS2 (*β* = -.22, *p* = .050; Figure 6).

3.4 Pleasure-Arousal-Dominance (PAD) scale

For each of the dimensions (Pleasure, Arousal, Dominance), we explore whether Wall Luminance showed an effect. All estimated marginal means and standard errors can be found in Table 6. Next, we investigate the PAD and KSS relationship.

3.4.1 Wall Luminance and Pleasure

We performed a two-level LMM with PAD Pleasure as dependent variable. Wall Luminance, Time and their interaction were all included as predictors. We found no significant main effect of Wall Luminance (χ^2 (2, *N* = 29) = .01, *p* = .997), but Time did show a significant main effect (χ^2 (2, *N* = 29) = 60.05, *p* < .001) indicating that PAD Pleasure 1 and PAD Pleasure 2 differ significantly from each other. Pleasure decreased over time (PAD Pleasure 1 vs. PAD Pleasure 2, *p* < .001). The Wall Luminance x Time interaction was not significant (χ^2 (2, *N* = 29) = .13, *p* = .935).

Post hoc pairwise comparisons of EMMs (exact EMMs and SEs in Table 6) indeed showed no significant differences between Wall Luminance levels (Low vs. Medium, *p* = .997; Medium vs. High, *p* = .998; Low vs. High, *p* = 1.000).

3.4.2 Wall Luminance and Arousal

A two-level LMM was performed and again, Time and the interaction Wall Luminance x Time were also included in the model as independent variables, to be able to distinguish between PAD Arousal 1 and PAD Arousal 2. Wall Luminance had no significant main effect on PAD Arousal (χ^2 (2, *N* = 29) = 1.55, *p* = .461), but Time did influence Arousal levels significantly (χ^2 (2, *N* = 29) = 35.15, *p* < .001). No significant interaction effect was found (χ^2 (2, *N* = 29) = 1.55, *p* = .460).

Post hoc pairwise comparisons (EMMs and SEs in Table 6) confirm the absence of a significant main effect of Wall Luminance (Low vs Medium, $p = .736$; Medium vs. High, $p = .905$; Low vs. High, $p = .469$) and show the increase in arousal between the two different time points (PAD Arousal 1 vs. PAD Arousal 2, $p < .001$).

3.4.3 Wall luminance and Dominance

We performed another two-level LMM where Time and the Wall Luminance x Time interaction were included as predictors. Wall Luminance had no significant effect on the Dominance scores ((χ^2 (2, $N = 29$) = .13, $p = .939$), and neither did the Wall Luminance x Time interaction (χ^2 (2, $N = 29$) = .72, $p = .696$). Dominance changed over the course of the session, as Time showed to have a significant effect (χ^2 (2, $N = 29$) = 4.70, $p = .030$).

Post hoc pairwise comparisons (EMMs and SEs in Table 6) indeed showed no significant differences between the Wall Luminance levels (Low vs. Medium, $p = .954$; Medium vs. High, $p = .954$; Low vs. High, $p = 1.000$). PAD Dominance was lower in the second measure than in the first (PAD Dominance 1 vs. PAD Dominance 2, $p = .030$).

3.4.4 PAD and KSS

To see whether the PAD Pleasure dimension correlated with KSS scores, two separate one-level LMMs were performed. Firstly, we performed an LMM with KSS1 as dependent variable and PAD Pleasure 1 as a predictor. We found that PAD Pleasure 1 is significantly negatively correlated with KSS1 ($\beta = -.45$, $p < .001$). The second LMM investigated the relation between PAD Pleasure 2 and KSS2, and showed a significant positive correlation between the two ($\beta = .67$, $p < .001$).

The LMM with KSS1 as dependent variable and PAD Arousal 1 as independent variable showed a significant positive relation between the two (β = .55, p < .001). KSS2 and PAD Arousal 2 were also correlated significantly (β = .66, p < .001).

Lastly, PAD Dominance 1 and KSS1 showed to be negatively correlated significantly (β = -.38, p < .001) and PAD Dominance 2 and KSS2 showed a positive correlation (β = .52, p < .001).

Table 6

Estimated marginal means (EMM) and standard errors (SE)

PAD Pleasure						
	PAD Pleasure 1		PAD Pleasure 2		PAD Pleasure Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	5.25	.19	4.17	.19	4.71	.13
Medium	5.32	.19	4.13	.19	4.72	.13
High	5.30	.19	4.12	.19	4.71	.13
Average	5.29	.11	4.14	.11	-	-
PAD Arousal						
	PAD Arousal 1		PAD Arousal 2		PAD Arousal Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	4.12	.19	4.71	.19	4.42	.16
Medium	3.76	.19	4.76	.19	4.26	.16
High	4.13	.19	4.89	.19	4.51	.16
Average	4.00	.12	4.79	.12	-	-
PAD Dominance						
	PAD Dominance 1		PAD Dominance 2		PAD Dominance Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	4.47	.17	4.09	.17	4.28	.12
Medium	4.40	.17	4.26	.17	4.33	.12
High	4.47	.17	4.09	.17	4.28	.12
Average	4.44	.10	4.15	.10	-	-

3.5 Room Appraisal and PAD Scale

We expected a correlation between room appraisal and the dimensions of the PAD scale. Six two-level LMMs were conducted, for the two room appraisal dimensions and each of the three PAD dimensions. For each LMM, the interaction with Time and room appraisal was also included, to see whether room appraisal is related differently to PAD 1 (measured in the beginning) than it is to PAD 2 (measured at the end). Appendix C, Table C4, contains all correlations between room appraisal and the PAD scale (at both timepoints).

3.5.1 RA Illumination and PAD Scale

RA Illumination did not show a significant correlation with PAD Pleasure (β = -.02, *p* = .802). Bot Time (β = -1.01, *p* = < .001) and the RA Illumination x Time interaction (β = -.32, *p* = .010) were significantly related to PAD Pleasure. We therefore conducted two separate one-level LMMs, with PAD Pleasure 1 and PAD Pleasure 2 as dependent variables, respectively, and RA Illumination as predictor. RA Illumination was not significantly related to PAD Pleasure 1 (β = -.06, *p* = .588) but was significantly correlated to PAD Pleasure 2 (β = -.32, *p* = .002).

RA Illumination was not significantly related to PAD Arousal (β = .04 *p* = .692). Both Time (β = .71, *p* < .001) and the RA Illumination x Time interaction (β = -.37, *p* = .001) showed a significant correlation with PAD Arousal. Again, we ran two separate one-level LMMs to see how RA Illumination was related differently to PAD Arousal 1 and PAD Arousal 2. RA Illumination was not related to PAD Arousal 1 (β = .02, *p* = .841), but was significantly correlated to PAD Arousal 2 (β = -.30, *p* = .004).

RA Illumination did not show a significant correlation with PAD Dominance (β = .04, *p* = .669). Both Time (β = -.33, *p* = .025) and the RA Illumination x Time interaction (β = -.39, *p*

= .008) were significantly related to PAD Dominance. We therefore performed two additional one-level LMMs. RA Illumination was not significantly correlated with PAD Dominance 1 (β = .07, p = .550), but showed a significant relation with PAD Dominance 2 (β = -.26, p = .010).

3.5.2 RA Attractiveness and PAD Scale

We did exactly the same for the RA Attractiveness dimension. RA Attractiveness was not significantly correlated with PAD Pleasure (β = -.02, p = .829). Both Time (β = -1.01, p < .001) and the RA Attractiveness x Time interaction (β =-.30, p = .019) showed a significant relation. Thus, we performed to additional one-level LMMs, with PAD Pleasure 1 and PAD Pleasure 2 as dependent variables and RA Attractiveness as independent variable. RA Attractiveness was not significantly related to PAD Pleasure 1 (β = -.05, p = .655), but showed a significant correlation with PAD Pleasure 2 (β = -.29, p = .007).

RA Attractiveness was not related to PAD Arousal (β = .02, p = .878), Time showed a significant effect (β = .71, p < .001). The RA Attractiveness x Time interaction was not significantly related to PAD Arousal (β = -.22, p = .062). RA Attractiveness also showed no significant correlation with PAD Dominance (β = .05, p = .666) and neither did the RA Attractiveness x Time interaction (β = -1.27, p = .090). Time was significantly correlated with PAD Dominance (β = -.33, p = .028).

3.6 Motivation and Unsolvable Anagrams

Motivation was subjectively measured using a questionnaire, and objectively as the effort exerted when trying to solve Unsolvable Anagrams which measured persistence on an unsolvable task. The two measures were not significantly related (β = .06, p = .649).

3.6.1 Wall Luminance and Self-Reported Motivation

A one-level LMM was performed to see how Wall Luminance influences Motivation. We did not find a significant effect (χ^2 (2, *N* = 29) = 1.56, *p* = .457). Post hoc pairwise comparisons indeed show no significant differences in Motivation scores between the Wall Luminance conditions (Low vs. Medium, *p* = .766; Medium vs. High, *p* = .876; Low vs. High, *p* = .461; Table 7).

3.6.2 Wall Luminance and Unsolvable Anagrams

We performed a one-level LMM, to see how Wall Luminance affected time spent on Unsolvable Anagrams. No significant effect of Wall Luminance was found (χ^2 (2, *N* = 29) = .23 *p* = .890). The post hoc pairwise comparisons therefore also did not show any differences between the three Wall Luminance levels (Low vs. Medium, *p* = .997; Medium vs. High, *p* = .933; Low vs. High, *p* = .903; Table 7).

Table 7

Estimated marginal means (EMM) and standard errors (SE)

Self-Reported Motivation and Unsolvable Anagrams

	Motivation		Unsolvable Anagrams	
Wall Luminance	EMM	SE	EMM	SE
Low	3.72	.11	.60	.02
Medium	3.78	.11	.60	.02
High	3.83	.11	.59	.02

3.6.3 Self-Reported Motivation and KSS

We performed a two-level LMM to investigate the relation between Motivation and alertness (KSS), also including Time and the interaction Motivation x Time as independent variables. Motivation was not significantly correlated with KSS (β = .04, p = .678), and as expected Time was significantly correlated with KSS (β = .77, p < .001). The Motivation x Time interactions showed no significant relation (β = -.14, p = .148).

3.6.4 Unsolvable Anagrams and KSS

A two-level LMM was performed to explore the correlation between the Unsolvable Anagrams and alertness (KSS), including the Time variable as well as the interaction Unsolvable Anagrams x Time. The results showed no significant relations for either the Unsolvable Anagrams (*β* = -.06, *p* = .588) or their interaction (*β* = .01, *p* = .927). Time was significantly related to KSS (*β* = .77, *p* < .001).

3.7 PAD and Self-Report Motivation

In the literature, Emotional state (PAD) and Motivation seem to be related. We will therefore take a look at whether there is a correlation between PAD scores and self-reported Motivation. One-level LMMs are performed for all three of the PAD dimensions, at both Time points in the session. A complete overview of these results can be found in Table C5, Appendix C. Merely the PAD Dominance 2 measure showed a significant negative correlation (*β* = -.29, *p* = .013). None of the other analyses yielded any significant results.

3.8 Heart Rate (Variability)

A two-level LMM was performed to explore what Wall Luminance does with Heart Rate (HR). Wall Luminance, Time and their interaction (Wall Luminance x Time) are included as independent variables. No significant main effect of Wall Luminance was found (χ^2 (2, *N* = 29) = 5.55, *p* = .062) and neither did the Wall Luminance x Time interaction (χ^2 (2, *N* = 29) = .50, *p* = .778). Time did show a significant effect on HR (χ^2 (2, *N* = 29) = 8.79, *p* = .003). Estimated Marginal Means and Standard Errors are presented in Appendix B, Table B1.

We performed another two-level LMM to see what effect Wall Luminance had on Heart Rate Variability (HRV). Because of the very skewed distribution of HRV, its log transformation was used in the model (log(HRV)). Again, Wall Luminance, Time and Wall Luminance x Time are included in the model as predictors. Wall Luminance showed no significant effect on log(HRV) (χ^2 (2, *N* = 29) = .52, *p* = .772) and neither did the Wall Luminance x Time interaction (χ^2 (2, *N* = 29) = 1.45, *p* = .485). Time showed to have a significant main effect on log(HRV) (χ^2 (2, *N* = 29) = 9.76, *p* = .002). Results of analyses of HR(V) on KSS are presented in Appendix C, Table C3.

3.9 State Self-Control

We have investigated the effect of Wall Luminance on State Self-Control, as well as whether State Self-Control is related to subjective alertness.

3.9.1 Wall Luminance and State Self-Control

A one-level LMM was performed to investigate whether Wall Luminance had an effect on State Self-Control. No significant main effect was found (χ^2 (2, *N* = 29) = 1.01, *p* = .603). Estimated Marginal Means and Standard Errors are presented in Appendix B, Table B1.

3.9.2 State Self-Control and KSS

We performed a two-level LMM to see whether there was a relationship between KSS scores and State Self-Control. With KSS as dependent variable, we included State Self-Control scores, Time and the State Self-Control x Time interaction as independent variables. State Self-Control showed to be significantly correlated to KSS (β = .25, *p* = .002), as well as Time (β = .77, *p* < .001) and their interaction (β = .45, *p* < .001). Because of the significant interaction, two additional one-level LMMs were performed to explore the relation between State Self-Control and KSS1 and KSS2 separately. State Self-Control was positively related to KSS1 (β = .32, p = .002), but showed a stronger correlation with KSS2 (β = .69, p < .001).

3.10 Remote Associates Task (RAT)

The Remote Associates Task (RAT) reflects convergent creative thinking. A one-level LMM was performed to look at a possible effect of Wall Luminance on RAT score. Wall Luminance showed no significant effect on RAT score (χ^2 (2, N = 29) = 1.95, p = .378). Results on the relation between RAT and KSS are presented in Appendix C, Table C1. EMMs and SEs are presented in Appendix B, Table B1.

4. Discussion

The main goal of this study was replicating the results of de Vries et al. (2018), who found that an increase in Wall Luminance caused better sustained subjective alertness throughout the experiment. In order to do so, we carefully replicated their design by using the same luminaires, lighting design and most of the same measures. We created three levels of Wall Luminance (19, 38, and 73 cd/m^2) and kept vertical illuminance at eye level and horizontal illuminance on the desk as constant as possible over these conditions. Whereas their original study was rather explorative in its nature, we concentrated on the effect of Wall Luminance on alertness. Additionally, we aimed to explain their unexpected results. We theorized that there may be a motivational and/or associative pathway causing better sustained alertness. Therefore, we extracted some tasks and questionnaires that in their study did not show to be relevant (e.g., two separate measures of room appraisal and the Stroop task), and replaced them with new ones that were more of interest in explaining the effects of Wall Luminance on alertness. This resulted in a few inevitable differences in the setups of the two experiments, which were necessary to serve the goal of diving deeper into the why and how of Wall Luminance's influence on alertness.

We were unable to replicate the results on subjective alertness as reported in the study by de Vries et al. (2018). No clear difference was found in sustained subjective (KSS) or objective (PVT) alertness over the three Wall Luminance conditions. KSS scores showed that participants simply tended to get sleepier throughout the experiment, independent of Wall Luminance levels. Reaction times for the PVT were not significantly different over the three conditions, indicating that participants were in practically the same state of alertness in the different Wall Luminance levels.

Room appraisal (RA), for the Illumination dimension, was higher in the High Wall Luminance condition than it was in the Low and Medium conditions. For RA Attractiveness, there was merely a difference between the Low and High conditions. A very similar pattern appeared for the associations. Participants associated the High Wall Luminance condition more with alertness than the Low and Medium conditions, without showing a difference between Low and Medium Wall Luminance levels. We saw exactly the same when looking at associations with sleepiness, now the other way around. The High Wall Luminance level showed a significantly *lower* association with sleepiness than the other two conditions.

We saw no effects of Wall Luminance on any of the other measures (overview: Appendix A, Table A1). Wall Luminance did not alter subjective motivation (questionnaire) or objective motivation/effort (unsolvable anagrams), neither did it influence emotional state (PAD). Heart rate and heart rate variability were not significantly moderated by Wall Luminance, just as the creative thinking task (RAT). State self-control also remained unaffected by Wall Luminance.

Going back to the conceptual model in Figure 1, we expected some additional correlations between variables. Firstly, we explored a possible relation between room appraisal and PAD. We found, for RA Illumination, that a *higher* score meant a *lower* score on all three PAD Scale dimensions at the second timepoint. Participants that evaluated the room as being brighter, reported lower scores on pleasure, arousal and dominance at the end of the experiment. RA Attractiveness showed the same for the pleasure dimension. Overall, room appraisal was not correlated with any of the emotional state dimensions as measured in the beginning of the experiment. The first emotional state measure (PAD 1) was not technically a baseline, but was administered very early on in the experiment when participants had only been in the room shortly, and could indeed very well be unaffected by room appraisal. This suggests that some time needs to be spent in the room before room appraisal affects emotional state. Finding a relation between room appraisal and emotional state is not surprising, although it was unexpected to find a negative relationship. It is somewhat in line with findings of Veitch et al. (2008), who found that the more attractive a room was evaluated, the less motivated participants seemed. They found a similar, unexpected, negative relation which we would have expected to be positive. Despite the fact that in their study it merely concerned the RA Attractiveness dimension, it is remarkable that we found such an adverse relation as well.

Our results did not show a relation between emotional state and motivation, or between motivation and KSS. Motivation and how much effort participants put into the unsolvable anagrams was also unrelated. This may mainly be due to the overall high scores on motivation; on a scale of 1-5, merely ten times participants reported a 3 or lower (from a total of 87 observations). Both state self-control and alertness showed to be unrelated to Wall Luminance, but they were correlated with each other. This is not an unexpected relationship, as fatigue has been linked to a lack of self-regulation before (Baumeister & Heatherton, 1996); people are more likely to be in a state of low self-control when they are fatigued. While unrelated to the lighting conditions, it supports the hypothesized relation between state self-control and alertness as presented in Figure 1.

We did find that room appraisal as well as associations differed over the Wall Luminance conditions. Whereas we expected to find a step-wise or more linear increase over the three Wall Luminance conditions, we only found a difference when looking at the High condition compared to the other two. The Low and Medium conditions seemed indistinguishable in terms of room appraisal, for both dimensions. We therefore can conclude that the Low and Medium Wall Luminance conditions may have been too much alike to be evaluated differently, or cause a difference in associations.

That the Low and Medium condition were not different enough to be distinguished in terms of room appraisal and associations may be due to our Low condition, which was not as low as the Low Wall Luminance condition in the study by de Vries et al. (2018; 12 vs. 19 cd/m^2). If the Low Wall Luminance condition had been lower than it was now, it may have created enough difference between the Low and Medium conditions to make participants better able to differentiate between them. We followed a 1:2 ratio for each increase of luminance level, unintentionally deviating from that slightly in the highest setting. The original study differed in ratio between the Low and Medium settings, where in the Medium condition Wall Luminance was three times what it was in the Low setting. With a lower Low Wall Luminance condition, which would have ensured the same 1:3 ratio between the lowest two conditions, we could have increased the difference in evaluation between the Low and Medium conditions. We were, however, unable to create a lower Wall Luminance level by dimming the spots any further, or we would have had to switch them off completely. Turning the spots off created a very different atmosphere compared to the other two conditions which rather clearly showed the direct light of the spots, creating large bright circles on the wall. In the study by de Vries et al. (2018), the spots were switched off in the lowest setting, allowing them to reach lower average Wall Luminance altogether. We chose to use the lowest possible setting of the spots, which in hindsight may not have been low enough.

Thus, the Low conditions might have had to be lower in order to create three conditions that were all evaluated differently in terms of room appraisal and associations. However, in our results we see that there is no slight, almost significant trend that might be made more pronounced by choosing more extreme Wall Luminance conditions. In the study by de Vries et al. (2018), the Medium condition was chosen based on preferred lighting settings (Veitch & Newsham, 2000). The Low and High levels were then appointed as respectively one third and double the Medium condition. We have used the same method for determining the conditions, but deviated from it to keep the spots turned on, and were therefore unable to lower the Low condition any further.

When comparing the current results for room appraisal with the earlier results by de Vries et al. (2018), we see somewhat lower scores in general as well as a more narrow range (Table 8). Especially in the High Wall Luminance condition, in the study by de Vries et al. (2018) participants found the room more attractive (.56 vs. .46) and brighter (.61 vs. .49) than in the current study. The distance between the participants and the lit wall did not differ much (approximately 4.7 m in the original study, versus 5.0 m in this study), because we moved the desks somewhat closer to the wall to be sure to prevent glare from the luminaires.

Table 8

Comparing room appraisal scores between the study by de Vries et al. (2018) and the current study

	RA Attractiveness (Mean)		RA Illumination (Mean)	
Wall Luminance	de Vries et al., 2018	Current study	de Vries et al., 2018	Current study
Low	.42	.36	.38	.35
Medium	.53	.39	.54	.41
High	.56	.46	.61	.49

We were unable to conduct the experiment in the exact same room as the one used in the study by de Vries et al. (2018), causing differences in the lighting design. The present room was larger than theirs was, and the spots were placed further from the wall because fire sprinklers were located where we originally wanted to mount the spots. The distance between the spots and the wall was 150 cm, whereas in the original study It was approximately 90 cm. They were also placed further away from each other (center on center spacing: 120 vs. 180 cm), as in both designs merely five spots were used, where in the current study they were distributed over a longer wall. This caused the wall to be more uniformly lit. This was indeed reflected by the logarithm of ratio maximum to minimum luminance. This ratio indicates interestingness (Loe et al., 1994), and may have caused the differences in room appraisal scores between the two studies. In the current study, these ratios for the Low, Medium and High conditions were 1.42, 1.59 and 1.68. Which are fairly close together. It did not differ as much over the different conditions as it did in the study by de Vries et al. (2018; where the ratios were 1.16, 1.62 and 1.83, respectively). Lower interestingness could mean that participants were less stimulated by the room and therefore did not feel a better sustained alertness differences between the three conditions.

Besides the deviations in the physical experiment room, the current study contained several different measures than the original experiment did. We included unsolvable anagrams as a measure of motivation and effort, as it reflects persistence. Unsolvable anagram tasks can also be used to induce stress (e.g.; Weidner, Friend, Ficarrotto, & Mendell, 1989; Zellner et al., 2006) or fatigue (e.g.; Geeraert & Yzerbyt, 2007). By replacing the originally used alternate uses task, a task measuring divergent creative thinking, with unsolvable anagrams, and the Stroop task with the PVT, we may have created an overall more mentally exhausting procedure. KSS1 scores were rather similar but somewhat higher in the current study: 3.54 in the original study, versus 3.90 in our study. We did find much higher KSS2 scores compared to the study of de Vries et al. (2018), which makes sense because Wall Luminance here did not show any effect, and over the conditions we merely found that participants got more sleepy throughout the experiment. However, we would not expect such a great difference in the Low condition. Where participants in the current study on average scored 5.37 on KSS 2, in the original study this was 4.59, where a score of 5 carries the label “neither sleepy or alert”. In the present study, participants seemed to move into the ‘sleepy’ side of the KSS toward the end of the session. This may be due to the more mentally exhausting design in this study, which could have overruled the previously found effect of Wall Luminance. There is only so much sleepiness that such a lighting condition may be able to prevent, and the current design possibly has induced too much sleepiness. On the other hand, increased mental fatigue has shown to have the potential to cause greater effects of bright light on subjective sleepiness (Smolders & De Kort, 2014). These results regarded NIF effects, but possibly also translate to the IF pathway.

Another difference was the timing of the two experiments, both a seasonal discrepancy as well as a difference in time of day that the experiment was conducted. We chose to run two sessions each day, allowing us a maximum of 40 participants in three weeks. One of the sessions took place at 13.00 h. (and lasted until roughly 14.30 h.), and the other at exactly the same time as the original experiment (15.00 – 16.30 h.). Participants performing in the first of these sessions could have been affected by a post-lunch dip (Monk, 2005). When simply looking at KSS1 scores, we did see that participants in the earlier session scored higher ($M_{13.00h}$ = 4.20, $SD_{13.00h}$ = 1.66; $M_{15.00h}$ = 3.63, $SD_{15.00h}$ = 1.51). The KSS2 scores show to be higher in the second session of the day ($M_{13.00h}$ = 5.10, $SD_{13.00h}$ = 1.59; $M_{15.00h}$ = 5.52, $SD_{15.00h}$ = 2.03). There seems to be a difference in the change in sleepiness between the two sessions. Where the 15.00 h. groups start off (KSS1) with a *higher* mean alertness level, they end (KSS2) with a *lower* mean alertness level, as compared to the 13.00 h. groups; they seem to show a greater difference between the two measurements of subjective sleepiness. In hindsight, conducting one session per afternoon, such as in the original study, may have gotten rid of this discrepancy. Because of the already rather low sample size (N = 29) and the within-subject design, conducting the analyses for the two groups separately ($N_{13.00h}$ = 13, $N_{15.00h}$ = 16) would result in a very low power for both analyses (respectively, .47 and .59).

Secondly, our study took place in April and extended into early May. The experiments ran by de Vries et al. (2018) were conducted in December and January, during winter. People are exposed to significantly more bright light during summer days than they do on winter days (Guillemette, Hébert, Paquet, & Dumont, 1998), due to higher daylight levels as well as a shorter period of darkness at night. Bright light exposure during the day has shown to improve early evening performance (Münch, Linhart, Borisuit, Jaeggi, & Scartezzini, 2012), as well as prevent afternoon sleepiness (Kaida et al., 2006). Additionally, it is suggested that higher prior light exposure may diminish effects of subsequent lighting conditions (Smith, Schoen, & Czeisler, 2004). These factors may influence alertness levels of participants differently over the seasons, causing our findings to differ from those of de Vries et al. (2018). However, the beforementioned effects are related to the NIF pathway of light, and we are unsure whether and how prior light exposure may influence this study, which investigates the role of the IF pathway.

Another explanation could be that de Vries et al. (2018), as it was a more explorative study, including a large number of measures and their effects of Wall Luminance, found a coincidental effect on alertness. When conducting many different analyses, there is bound to be one that shows to be significant. Their effect was pretty evident, with an effect size d_z = 0.65; right between begin a ‘medium’ or a ‘large’ effect (Cohen, 1992). We would therefore expect it to show up in a replication study. Despite that, it may still have been an accidental finding, explaining the lack of an effect in this study.

4.1 Future research

With the current study and the one by de Vries et al. (2018), there now have been two studies that explore how Wall Luminance may affect alertness, of which one showed that higher Wall Luminance could prevent participants from getting sleepy throughout the 1.5 hours the experiment lasted. While we were unable to replicate these results, our research did show that participants do appreciate higher Wall Luminance, as reflected in room appraisal scores. They also associate a room with higher Wall Luminance more with alertness, and vice versa. These are effects that deserve to be explored further, to see why these associations do not seem to lead to a difference in alertness, and what this increase in room appraisal may lead to. Future research may investigate to what extent, and for which ranges of Wall Luminance, these effects occur. More replications, mainly focused on diving deeper into the associations and room appraisal paths, could show whether or not Wall Luminance indeed has a positive contribution to the wellbeing of workers, and whether it may be a part of room design that deserves more attention that it currently gets.

5. Conclusion

The current study revealed that subjective and objective alertness was not significantly influenced by Wall Luminance. We could thus not replicate the results as found by de Vries et al. (2018), which revealed better alertness under higher wall luminance compared to Low and Medium Wall Luminance. This may be caused by the differences in between the two studies, or because of an initially incidental effect which does not show to be replicable. Either way, we cannot be conclusive about the effect of Wall Luminance on sustained alertness.

We proposed two conceptual routes from Wall Luminance to alertness, the first one concerning associations with different Wall Luminance conditions. The levels of Wall Luminance, caused variations in associations with alertness and sleepiness. Participants associated the High condition more with alertness, and the Low and Medium conditions were associated with sleepiness. Yet, while the different light settings were able to induce associations as expected, these associations did not lead to a difference in actual state of alertness.

Secondly, we proposed a conceptual route from Wall Luminance to alertness, through Room appraisal, emotional state and motivation. Wall Luminance did affect Room appraisal, and we found a partial relationship between room appraisal and emotional state. Next to the absence of a significant effect on alertness, Wall Luminance did not show significant effects on state self-control and motivation. Thereby, our results were unable to support the hypothesized motivational route to alertness. We merely saw a change in room appraisal, caused by Wall Luminance.

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Appendix A – Main effects of Wall Luminance

Table A1

Main effects of Wall Luminance, Time and the Wall Luminance x Time interaction on each dependent variable.

	Wall Luminance		Time		Wall Luminance x Time	
	χ^2	*p*	χ^2	*p*	χ^2	*p*
KSS	.06	.969	37.02	< .001	1.25	.536
PVT	2.62	.270				
Associations – Sleepy	13.24	.001				
Associations – Alert	13.09	.001				
RA Illumination	20.89	< .001				
RA Attractiveness	12.06	.002				
PAD Pleasure	.01	.997	60.05	< .001	.13	.935
PAD Arousal	1.55	.461	35.15	< .001	1.55	.460
PAD Dominance	.13	.939	4.70	.030	.72	.696
Self-Reported Motivation	1.56	.457				
Unsolvable Anagram Task	.23	.890				
Heart Rate	5.55	.062	8.79	.003	.50	.778
Heart Rate Variability	.52	.772	9.76	.002	1.45	.485
State Self-Control	1.01	.603				
Remote Associates Task	1.95	.378				

Time and Wall Luminance x Time could only be incorporated in the analyses for variables that were measured twice during each session. For all other variables, these spaces are left blank.

Appendix B – Estimated Marginal Means and Standard Errors

Table B1

Estimated marginal means (EMM) and standard errors (SE) of each measure.

PAD Pleasure						
	PAD Pleasure 1		PAD Pleasure 2		PAD Pleasure Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	5.25	.19	4.17	.19	4.71	.13
Medium	5.32	.19	4.13	.19	4.72	.13
High	5.30	.19	4.12	.19	4.71	.13
Average	5.29	.11	4.14	.11		
PAD Arousal						
	PAD Arousal 1		PAD Arousal 2		PAD Arousal Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	4.12	.19	4.71	.19	4.42	.16
Medium	3.76	.19	4.76	.19	4.26	.16
High	4.13	.19	4.89	.19	4.51	.16
Average	4.00	.12	4.79	.12		
PAD Dominance						
	PAD Dominance 1		PAD Dominance 2		PAD Dominance Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	4.47	.17	4.09	.17	4.28	.12
Medium	4.40	.17	4.26	.17	4.33	.12
High	4.47	.17	4.09	.17	4.28	.12
Average	4.44	.10	4.15	.10		
KSS						
	KSS1		KSS2		KSS Average	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	3.86	.32	5.37	.32	4.62	.25
Medium	4.03	.32	5.10	.32	4.59	.25
High	3.79	.32	5.48	.32	4.64	.25
Average	3.90	.22	5.32	.22		

Estimated marginal means (EMM) and standard errors (SE) of each measure, continued.

	PVT		Sleepy Associations		Alert Associations	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	370	8.99	3.03	.33	2.14	.29
Medium	364	8.92	2.97	.33	2.10	.29
High	359	8.99	2.07	.33	3.10	.29

	RA Illumination		RA Attractiveness		RAT	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	.35	.03	.36	.03	4.29	.34
Medium	.41	.03	.39	.03	4.24	.34
High	.50	.03	.46	.03	4.83	.34

	Motivation		Unsolvable Anagrams		State Self-Control	
Wall Luminance	EMM	SE	EMM	SE	EMM	SE
Low	3.72	.11	.60	.02	101.21	5.08
Medium	3.78	.11	.60	.02	94.76	5.08
High	3.83	.11	.59	.02	98.55	5.08

	Heart Rate		Heart Rate Variability	
Wall Luminance	EMM	SE	EMM	SE
Low	77.96	1.92	.07	.01
Medium	80.94	1.93	.08	.01
High	77.34	1.91	.06	.01

Appendix C – Standardized Coefficients of LMMs Summarized

Table C1

Standardized coefficients (β), reflecting the correlation of each measure with KSS scores.

Independent variable	*β*	*p*
Time	.77	< .001
Alert Associations	-.01	.914
Alert Associations x Time	.11	.266
Sleepy Associations	-.08	.450
Sleepy Associations x Time	-.12	.240
RA Illumination	-.03	.771
RA Illumination x Time*	-.27	.004
RA Attractiveness	.08	.463
RA Attractiveness x Time*	-.32	.001
Motivation	.04	.678
Motivation x Time	-.14	.148
Unsolvable Anagrams	-.06	.588
Unsolvable Anagrams x Time	.01	.927
State Self-Control	.25	.002
State Self-Control x Time*	.45	< .001
Remote Associates Task	.01	.956
Remote Associates Task x Time	.00	.984

Interactions marked with an asterisk (*) yielded significant results, therefore also separate analyses on KSS1 and KSS2 were conducted. See Table C2 for these results.

Table C2

Additional analyses to those in Table C1. Separate analyses on KSS1 and KSS2 were conducted for three variables. Standardized coefficients (β) reflect the correlation.

	KSS1		KSS2	
	β	*p*	*β*	*p*
RA Illumination	-.10	.387	-.27	.012
RA Attractiveness	.06	.598	-.22	.050
State Self-Control	.32	.002	.69	< .001

Table C3

Standardized coefficients (β) reflecting correlations with KSS1 and KSS2, for both the PAD scale and Heart Rate measures.

	KSS1			KSS2	
	β	*p*		*β*	*p*
PAD Pleasure 1	-.45	<.001	PAD Pleasure 2	.67	<.001
PAD Arousal 1	.55	<.001	PAD Arousal 2	.66	<.001
PAD Dominance 1	-.38	<.001	PAD Dominance 2	.52	<.001
HR 1	.22	.058	HR 2	.14	.236
HRV 1	.02	.882	HRV 2	-.02	.838

Table C4

Standardized coefficients (β) reflecting correlations between room appraisal (RA Illumination and RA Attractiveness) with the PAD scale, at both timepoints.

	PAD Pleasure 1		PAD Pleasure 2	
	β	*p*	*β*	*p*
RA Illumination	-.06	.588	.32	.002
RA Attractiveness	-.05	.655	-.29	.007
	PAD Arousal 1		PAD Arousal 2	
RA Illumination	.02	.841	-.30	.004
RA Attractiveness	.04	.758	-.18	.101
	PAD Dominance 1		PAD Dominance 2	
RA Illumination	.07	.550	-.26	.010
RA Attractiveness	.14	.226	-.22	.050

Table C5

Standardized coefficients (β) reflecting correlations with subjective Motivation, for the PAD scale measures

	Motivation	
	β	*p*
PAD Pleasure 1	-.03	.805
PAD Pleasure 2	-.17	.163
PAD Arousal 1	-.09	.453
PAD Arousal 2	-.20	.087
PAD Dominance 1	-.02	.849
PAD Dominance 2	-.29	.013