General information

- Relationship between alertness, chronotype and light exposure
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Abstract

This study with explorative design investigates the influence of light exposure, and that of individual chronotype, on alertness during the day. The chronotype is often closely related to light exposure, and therefore, the aim of the current study is to independently analyse the influence of light exposure and chronotype on alertness during the day. Data was gathered from 29 individuals over the course of 7 days. During these days, participants wore a light logger for the entire day, and got two types of questionnaires: a sleep diary, followed by 6 random prompts throughout the day about their subjective alertness. Data was analysed using multilevel regression. The proposed three-level model had too few data, which is why a two-level model was implemented. No significant effects were found for light exposure or time of day. As for chronotypes, there was a statistically significant difference between early chronotype ($p < 0.001$) and other chronotypes in terms of influence on alertness. No other significant effects were found. The results might be partly explained by the noisiness of the data, as only 11 participants had data for all days in the study period.

Introduction

Alertness is defined as achieving and maintaining a state of high sensitivity to incoming stimuli (Posner, 2008) associated with high levels of environmental awareness (Figueiro et al., 2009). Past research showed that alertness influences many cognitive functions, such as perceptual skills (Figueiro, 2016), motor skills (Lajunen et al., 1998), reasoning abilities (Curcio et al., 2001), and judgment and decision-making capabilities (van Dongen et al., 2004). Alertness is, therefore, an important neurobehavioural performance measure, and to improve our understanding which cognitive function it influences, it is essential to determine what internal and external variables could affect our alertness.

Light exposure has been found to constitute a potent modulator of non-visual functions, including improvement of alertness (Badia et al., 1991). For instance, high correlations with alertness and the degree of melatonin suppression were shown when exposed to light in the evening (Cajochen et al., 2000). Moreover, neuroimaging studies show that light exposure modulates brain responses to non-visual cognitive tasks in different ways, depending on the amount of light, the intensity, and duration of the light exposure (e.g. Vandewalle et al., 2009). These studies show that light has a significant influence on our everyday mood and alertness.

The concept of alertness is partly subjective and might therefore be correlated to an individual's preferred bedtimes and wake-up time, known as one's *chronotype* (Horne & Östberg, 1976). Early and late chronotypes differ in their subjective and objective build-up of sleep need during wakefulness (Mongrain et al., 2004; Taillard et al., 2003). For instance, it has been shown that evening types performed better and had higher brain activation than morning types in their subjective evening hours, with greater alertness when compared to early/normal types (Schmidt et al., 2009; Matchock and Mordkoff, 2009)

The aim of the current study is to independently analyse the influence of light exposure and chronotype on alertness during the day. Even though these effects have been investigated in previous studies, as mentioned above, it is interesting to revisit these themes from the perspective of COVID-19 situation. The reason for this is that nowadays, people work more from home and therefore they might spend more time inside, under lower illuminance levels. This can affect their alertness. Furthermore, it is interesting to see whether the difference between chronotypes in terms of alertness in evening hours is still present.

Based on research in the domain, the research questions used in the current report are:

1. What is the influence of light exposure on alertness during the day?
2. What is the influence of individual chronotype on alertness during the day?

For the first research question, it is expected that participants who are being exposed to a lot of daylight will experience a higher level of alertness throughout the day. Based on the differences between chronotypes indicated above, the hypothesis for the second research question is that late chronotypes will experience higher alertness in the evening compared to morning and intermediate types.

Method

Study Design:

The study was performed in a non-experimental setup in the field. The study was conducted using a light measuring device and an application in order to administer surveys. Data collected over the course of 7 days was analysed using multilevel regression.

Participants:

The participants were students from the Eindhoven University of Technology that participated in the course 0HM200 “Psychology of light and time”. There were 29 students that participated in the study, out of these 8 were male and 21 were female. The age of the participants was between 21 and 25 years old (M = 22.9, SD = 0.99). The male participants were between 22 and 24 years old and the female participants between 21 and 25 years old.

Measurements:

The measurements of this study were conducted in two ways. First, light exposure levels were collected using a light measuring device that the participants wore on top of their clothing. These recorded the ambient light levels that the participant was exposed to throughout the day. Secondly, by administering surveys, using the MetricWire app. Two types of questionnaires were sent out: randomized prompts with questions concerning alertness and time spent outside randomly throughout the day between 9:00 AM and 10:00 PM, as well as a daily sleep diary questionnaire at 9:00AM.

Procedure:

The participants were informed of the study design in a general briefing. They then signed an informed consent form. After signing, they received a light level measuring device, each with a unique code written on the back of the device. The participants were instructed to wear the device at all times for the next 7 days, except when they were doing sports or bathing, where they had to put it face down to stop any measurements from being taken, and when they were asleep, then they placed the device face up on their night stand. Throughout the 7 days of measurements, the participants received surveys at random times, consisting of questions about alertness and time spent outside. At the end of the study period, the participants returned the devices in order for the data to be collected.

Analysis:

The analysis was conducted in the statistical programme Stata 16. First, the data was cleaned and modified in order to be appropriate for analysis. Then it was imported into Stata and checked for strange cases and outliers, after which it was analysed using multilevel regression.

Results

The data was structured in the following way (Figure 1): each measurement of light intensity and alertness was nested per day, which was in turn nested per participant. In the exploratory part of the data analysis, it was found that the data collected was very noisy in nature. This was expressed in the amount of groups in the third level: where 210 groups were expected (7 days times 29 participants), only 164 groups exist. Only 11 participants responded every date in the data collection period. Therefore, the 2nd-level (date) was mostly left out of the analysis.

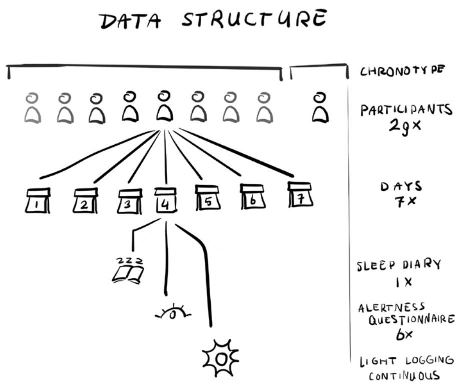

Figure 1 Graphical representation of data structure

Alertness was modelled as a continuous variable from a 9-point likert scale, ranging from “extremely alert” to “very sleepy, great effort to keep awake”. This was interpreted as a continuous variable rather than a categorical one to allow for more in-depth analysis. Light exposure was modelled as a continuous variable, with illuminance (lux) values.

Effect of light on alertness during the day

The multi-level model was created as described above with alertness (M= 3.78, SD= 2.49) as target variable and light intensity (M=182.74, SD= 292.52) as main predictor.

The interclass variance at the participant level was .0455442 (SD= .028467), and the empty model (only including the levels and target variable) was significant (p = 0.013), meaning that subjective alertness was very dependent on which participant was considered.

Adding the random intercept of light intensity and time of day does not improve the empty model with p = 0.013 and an R-squared of -0.0021 (Snijders/Bosker Level 2), with both added predictors testing insignificant: with light intensity (p = 0.234) and time of day (p = 0.594).

Adding random slopes for light exposure and time does not improve the model fit and even makes it insignificant as a whole (p = 0.0874), with the same R-squared of -0.0021 (Snijders/Bosker Level 2) as in the random intercepts model. All models were run with the restricted maximum likelihood (REML) option in Stata. Using a non-REML method, the model fit was worse, with p = 0.1166.

When considering the 11 participants that had data on all dates in the data collection period and using the three-level model as described above, no significant models were constructed. The researchers were unable to determine if this was due to model fit being worse or the sample size decrease leading to these results.

Effect of chronotype on alertness

Following previous analysis, the effect of chronotype on alertness was investigated. Midpoint of sleep on free days corrected (MSFsc) for sleep debt was calculated for each person. From the graph in Figure 2, it can be seen that most of the participants have their midpoint of sleep (MSF) between 3am and 6am. One participant is slightly later (around 6:30) and one participant is extremely late, around 9 am (M=4:48, SD=00:39). The lowest MSFsc was 3:52 and the maximum at 8:50.

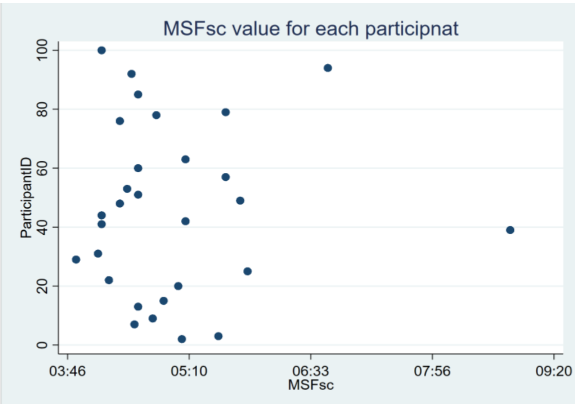

Figure 2 Scatterplot of MSFsc of each participant

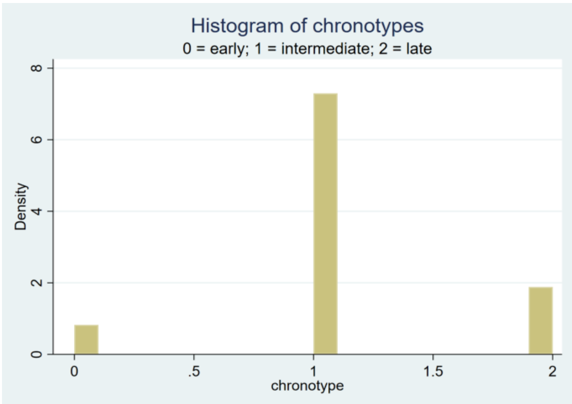

Figure 3 Histogram of chronotype distribution

Participants were divided into chronotypes groups based on following formula:

$$\text{Late} = MSFsc \geq \underline{MSFsc} + \sigma_{MSFsc} \qquad \text{Early} = MSFsc \leq \underline{MSFsc} - \sigma_{MSFsc}$$

$$\text{Intermediate} = \underline{MSFsc} - \sigma_{MSFsc} \leq MSFsc \geq \underline{MSFsc} + \sigma_{MSFsc}$$

The most prevalent is the intermediate chronotype (Figure 3). 2 participants have early chronotype, 20 have intermediate and 7 participants have late chronotype. Chi2 test was used to find whether there is a significant relationship between these two variables. The results show a significant relationship between them X^2 (16, N = 425) = 26.64, p = 0.046.

Chronotype as well as alertness are person dependent, with alertness being also dependent on day and the time of the day. Therefore, a multilevel analysis with three levels was conducted for those participants which answered the questions every day of the study. A mixed model with alertness as the dependent variable and chronotype and part of the day (morning, noon, evening, night) as independent variables, participant ID and date as random intercepts was created.

The model showed that there is a statistically significant difference between early chronotype ($p < 0.001$) and other chronotypes in terms of influence on alertness. Morning chronotypes feel more alert throughout the day. There was no statistical difference between late and intermediate chronotype. The time of day was not a significant predictor of alertness. Inclusion of interaction between chronotype and continuous time variable showed that there is a significant effect between alertness of early chronotypes throughout the day and other types of chronotypes. The direction of this relationship is negative, meaning that with later hours, late and intermediate chronotypes feel more alert than early chronotypes. The interaction effect can be also seen in the graphs in Figure 4; early chronotypes feel between 9 am and 4.30 mostly alert, or at least fairly alert and that their alertness decreases in the evening whereas other chronotypes do not show such a trend.

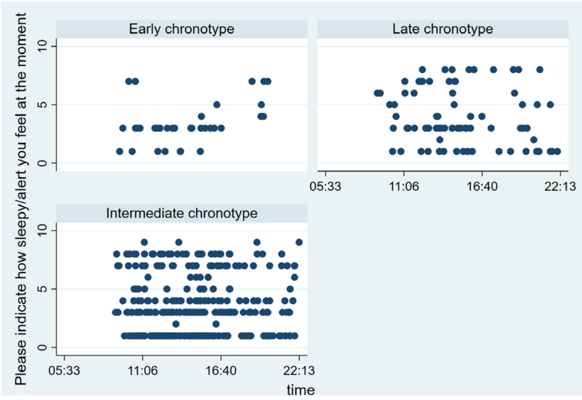

Figure 4 Scatterplot of alertness throughout the day for each chronotype

Use of categorical predictors instead of continuous predictors also increased the significance of the model, since when the model with continuous MSFsc showed that chronotype is not significant. The software used for this analysis did not provide any way of getting the value of R2 that would represent the model-fit of the 3-level model.

Discussion

The analysis of the influence of light on the alertness throughout the day provided no significant models. Attempts were made to use only the more complete measurements from the datasets, which excluded participants who had days without responses, but this did not give any significant results. Reasons for this could be the small size of the dataset which, with the aforementioned selection method, only had 11 participants instead of the original 29. Additionally, the varying time of day at which the alertness questionnaires were sent made this analysis harder, as no single day had the same measurements at the same time, and the small number of questionnaires made it impossible to sketch a graph of the changes in alertness throughout the day. However, more questionnaires would be too disruptive throughout the regular days of participants. In future studies, sending the questionnaires at fixed moments throughout the day could make for a more coherent and more comparable analysis and possibly different results.

While this study remains inconclusive, literature has shown illuminance as one of the main influencers of alertness (Badia et al., 1991). Specifically, if the light tends towards the blue spectrum, the effect is very pronounced (Cajochen et al., 2000). The used light loggers did not measure the spectral distribution of the light that they detected, making the specific effect of the light harder to analyse. During data gathering, participants took off their light loggers when going to bed, thus the light effect of smartphone or e-book usage in bed could not be effectively logged, while this could also have influenced their sleep as emitted blue light suppresses melatonin production.

It is important to mention that the sample size and its distribution across the different chronotype groups was not equal, and therefore results concerning chronotype cannot be considered with too much reliability. The time of day was a significant predictor of this alertness, but the difference was only in evening hours, which is in line with the expectations.

In the future, focus could be put on the specific effect of going outside on alertness, thus being exposed to sunlight, at specific times during the day. For example, is there a difference in perceived alertness when one is outside in the morning or in the afternoon? And how does this differ for different chronotypes? The results could lead to recommendations on how one can increase their alertness throughout the day by taking walks at specific times based on their chronotype.

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