Good night! A study on the effects of blue-light filter glasses on sleep quality and cognitive performance in young adults

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Good night!

A study on the effects of blue-light filter glasses on sleep quality and cognitive performance in young adults

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Abstract

In this study the effects of using blue-light filter glasses on sleep quality and vigilance is investigated in 60 young adults, in order to gain more insight in blue-light filter glasses as an effective aid for poor sleep quality. Blue-light filter glasses were expected to have a positive effect on sleep quality and vigilance performance.

This was a single-blind controlled study in which the participants reported their sleep quality on the PSQI and KSS and their vigilance performance was measured with the Psychomotor Vigilance Task. After two weeks of intervention, wearing blue-light filter glasses in the experimental condition and listening to music in the control condition, follow-up measures were registered. Measures of total sleep quality and sleep latency increased and vigilance reaction times decreased over time in the analysis of variances with repeated measures. These changes could not be explained by the use of blue-light filter glasses or the relation between vigilance and sleep quality. The expected positive relation between sleep quality and cognitive performance was not supported by these findings. In conclusion, this study does not provide convincing support for blue-light filter glasses as an effective aid for poor sleep quality. Among others, including objective measures and treatments with longer periods of time are recommended for future research.

Keywords: sleep quality, blue light, cognition, vigilance, filter glasses

Samenvatting

In dit onderzoek zijn de effecten van het gebruik van blauwlichtfilterbrillen op slaapkwaliteit en vigilantie onderzocht bij 60 jongvolwassenen, om meer inzicht te krijgen in blauwlichtfilterbrillen als een effectief hulpmiddel voor een betere slaapkwaliteit. Een positief effect van de blauwlichtfilterbrillen op slaapkwaliteit en prestatie op vigilantie was verwacht. Dit is getest in een enkelblind gecontroleerd onderzoek waarin de participanten hun slaapkwaliteit rapporteerden op de PSQI en KSS. Hun prestatie op vigilantie werd gemeten met de Psychomotorische Waakzaamheidstaak (PVT). Na twee weken interventie, waarin de participanten in de experimentele conditie blauwlichtfilterbrillen droegen en participanten in de controleconditie naar muziek luisterden, werd de nameting uitgevoerd. De metingen van de totale slaapkwaliteit en latentietijd zijn verbeterd en de reactietijd bij de vigilantietaak is verslechterd ten opzichte van de voormeting in de variantieanalyse. Deze veranderingen konden niet verklaard worden door een verschil tussen de condities. De positieve relatie tussen slaapkwaliteit en cognitieve prestatie is niet ondersteund door de bevindingen. Voor toekomstig onderzoek zijn onder andere het gebruik van objectieve metingen van slaapkwaliteit en het langer gebruiken van de brillen aangeraden.

Trefwoorden: slaapkwaliteit, blauw licht, cognitie, vigilantie, filterbrillen

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Introduction

What do the following have in common: higher risk of getting injured in an occupational accident, getting involved in a fatal driving accident and contracting health problems because of reduced immune responses? These are all examples of considerable risk growth in everyday circumstances in the occasion of a lack of sleep quality (Uehli et al., 2014; Swaen et al., 2003; Irwin et al, 1996). More generally, possible consequences are health problems, safety issues, and negative effects on cognitive functioning, mood and quality of life (Naitoh, Kelly & Englund, 1990; Pilcher & Huffcutt, 1996; Strine & Chapman, 2005).

Sleep is a basic need and it may be clear that sleep quality affects everything we do in daily life, so it is important for an individual to have a satisfying quality of sleep. In research, there is not one universal definition for good sleep quality. Sometimes high sleep quality is characterized by sleeping at least 85 percent of the total time spent in bed, a sleep latency of less than 30 minutes, a maximum of one time waking up per night and being awake of maximum 20 minutes during the night (Krystal & Edinger, 2008; Ohayon et al., 2017). Others added depth of sleep, dreams, condition after sleep, effects on daily life and sleep satisfaction (Yi, Shin, Shin, 2006). These measures can be subjectively measured by a questionnaire, or objectively. Examples of objective measures are polysomnography, non-REM spectral analysis, cyclic alternating pattern and actigraphy (Krystal & Edinger, 2008).

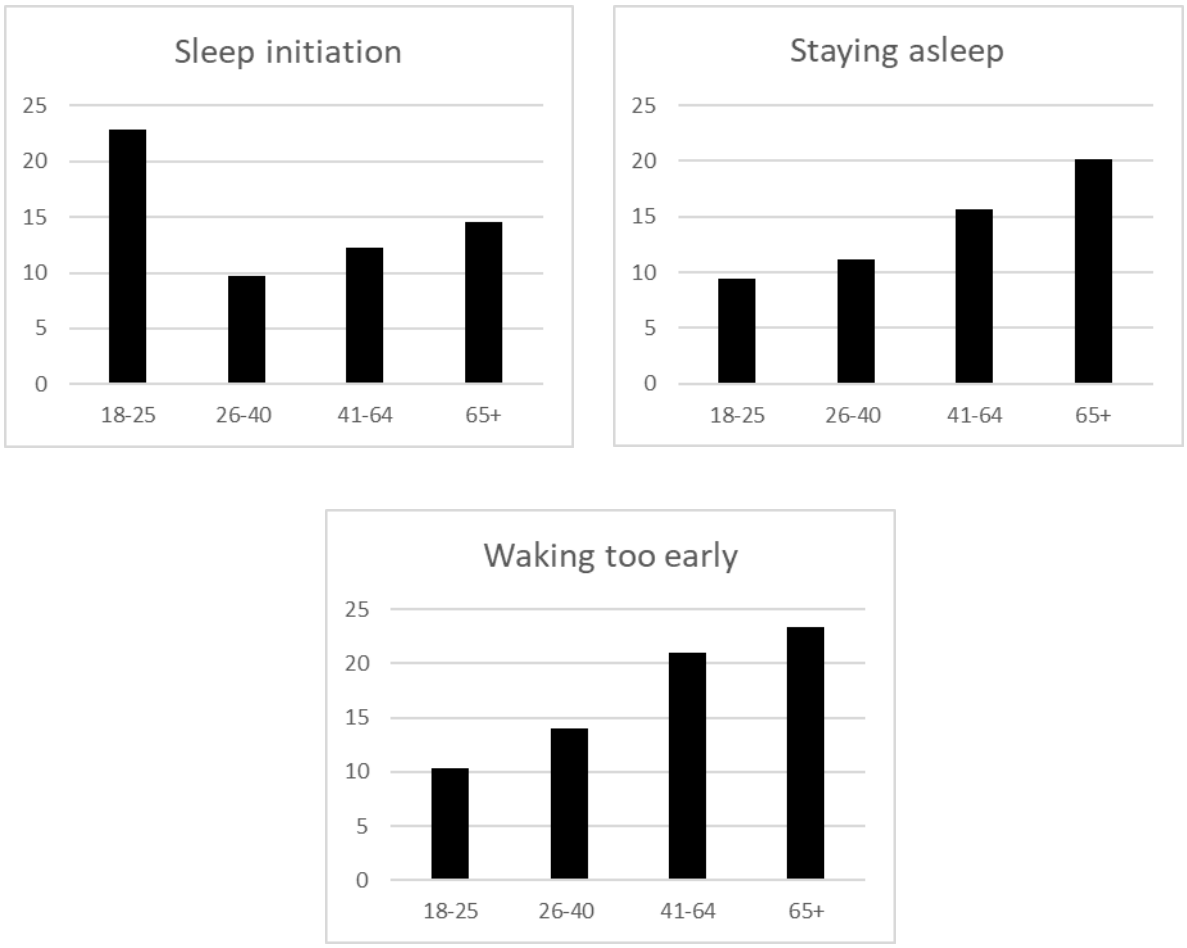
Poor sleep quality

Many factors are found to negatively affect sleep quality, among which are health problems, mental problems, sociodemographic factors and lifestyle. In a study of Central Bureau for Statistics (2020), it was found that in 2018, 23% of the Dutch population of 18 years and older reported sleep problems. In a study of Van Kerkhof (2017), also a quarter of the population under 26 years old had sleep problems and problems with falling asleep. Although all age groups struggle with sleep problems to an equal extent, the type of sleep problem differs per age group.

In accordance with the data of Van Kerkhof (2017) shown in Figure 1, Leone et al. (2018) described that sleep problems related with staying asleep or waking too early, grow with age. This is also the case with sleep initiation, however with one notable exception: the age group of 18-25 years old. It seems that especially young adults have difficulties with sleep initiation. In adults, the highest percentage of problems with sleep initiation (22,9%) is found in the group of 18 to 25 years old (Figure 1).

Figure 1.

Prevalence of symptoms of insomnia



Note. This figure shows the prevalence in percentages of symptoms of insomnia, a) sleep initiation, b) staying asleep, c) waking too early. Based on Hersenstichting (2017).

From the above mentioned factors causing sleep problems, life style seems to be the most important one for the 18 to 25 year old adults, often referred to as young adults. Young adults are active in the evening. They engage, for example, in social activities, they work or study and at least 80% of them are active on a screen device (i.e. computer or smartphone) in the two to four hours before they go to bed (Spitzer, 2016). All these activities, but especially screen use, lead to a decrease in sleep quality (Van der Meijden, 2019). If this continues for a longer time, the young adults in case can develop a chronic partial sleep syndrome.

This can be problematic, because research has shown that low sleep quality affects cognitive functions first. Learning is one of the main activities of individuals in the school age of 18-25, and for this activity, cognitive functions such as vigilance and planning are crucial.

Vigilance is the cognitive function that is considered to be affected most by decreased sleep quality (Alhola, 2007). In short, poor sleep quality could negatively affect the academic performance of young adults (Ahrberg and colleagues, 2012).

The sleep-wake cycle

In young adults, sleep quality is affected particularly by a delay of the sleep-wake cycle, due to evening screen use. A biological description of this delay is given below. During a typical night of sleep, an individual goes through four or five sleep cycles. Each cycle is divided into four stages: 1) REM sleep, which is the onset of a new cycle, 2) the light non-REM sleep and 3-4) the deep non-REM sleep. With each successive cycle, less time is spent in the deeper stages of non-REM sleep and more time is spent in the light non-REM sleep and REM sleep (Hobson, in Gray, 2011).

Each person has a sleep-wake cycle of around 24 hours. This circadian sleep rhythm depends primarily on light. Photosensitive retinal ganglion cells contain melanopsin and are especially sensitive to the blue and blue-green light, with wavelengths under 550 nm. These retinal ganglion cells are connected with the suprachiasmatic nucleus in the hypothalamus. The suprachiasmatic nucleus translates the incoming action potentials from the photosensitive ganglion cells to inhibition of the secretion of melatonin from the pineal gland. Taken together, exposure to light inhibits melatonin secretion. During the day, the inhibited melatonin secretion leads to wakefulness. During the night, the (relative) absence of light causes an increased melatonin secretion, which leads to sleepiness.

Manipulating the sleep-wake cycle

The secretion of melatonin can be manipulated. Since the presence of melatonin is crucial for sleep initiation, exposure to light in the evening delays sleep onset and with that the sleep-wake cycle is delayed (Dumont & Beaulieu, 2007). This can lead to sleepiness feelings in the morning and can even become a chronic problem, leading to sleep disorders or other (health) problems. The circadian rhythm could also be advanced, if an individual is exposed to bright light in the morning or dim light or darkness in the evening.

Many solutions for sleep problems are based on this knowledge. Some examples of interventions are sleep medication or melatonin supplements, but these carry a variety of risks among them, under which cognitive impairment. To overcome this problem, researchers tried non-medical treatments, like complete darkness in the evening hours (Dumont & Beaulieu, 2007; Mortazavi et al., 2018). Despite the positive findings on this solution, the applicability is limited, since students often use the evening hours to study and are not willing to place themselves in complete darkness for the whole evening, which is necessary to ensure optimal

circumstances for sleep. Researchers already found that another treatment, using blue-light filter glasses, could overcome this limitation, because these glasses enable the individual to experience both the physiological effect of darkness and participating in evening activities depending on light, like studying (Burkhart & Phelps, 2009). Moreover, Janků and colleagues (2019) found that filter glasses have larger effects on improvement of sleep quality than only using blue light filters on screens.

Previous studies investigated the effects of blue-light filter glasses on sleep quality, or the effects of sleep quality on cognition. Ahrberg and colleagues (2012) have studied the interaction between sleep quality and academic performance in young adults and found that students who sleep poorly received bad grades, but only when this relation was mediated by stress.

Literature on the effects of blue-light filter glasses on both sleep quality and vigilance in young adults was not found. The current study aims to provide more insights in the effectivity of blue-light filter glasses in enhancing sleep quality and cognitive functions. The research question “What are the effects of blue-light filter glasses on sleep quality and vigilance in young adults?” was examined in a single-blind randomized controlled trial in which baseline sleep quality and vigilance were compared with improved sleep quality and vigilance in people wearing blue-light filtered glasses. These people were also compared to a control group, that listened to a music fragment in the evening.

Music fragment for the control group

The music fragment used in this study consisted of slow electronic tones around the frequency of 528 Hz. The original fragment used binaural beats technology (Licklider, Webster & Hedlun, 1950) by using two tones with slightly different frequencies for each ear. This causes the human brain to create a new tone, with a frequency equal to the difference between the frequencies of the original tones (Oster, 1973). The studies on the effects of binaural beats on sleep quality are promising (Thoma et al., 2013; Shumov et al., 2017, Munoz & Rivera, 2020), but the lowest binaural beats (delta waves of 0,5 Hz to 4 Hz) could possibly help individuals to make the latency time (time needed to fall asleep) shorter (Shumov et al., 2017; Jirakittayakorn & Wongsawat, 2018; Lee et al, 2019). In this study, the original fragment was edited to make sure that the effectivity of the beats was removed. This way the intervention of the control group was a convincing placebo.

Hypotheses

In the current study, the effect of blue-light filter glasses on sleep quality was examined and compared to the effects of music on sleep quality. Based on discussed research on

preventing blue light from reaching the eyes in the hours before going to bed, it is expected that the total reported sleep quality, reported sleep latency and the reported sleepiness feelings will be higher in individuals who used blue-light filter glasses than in individuals who listened to music. These measures of sleep quality will be used as dependent variables in the first hypothesis:

(1) Sleep quality will be higher in individuals who used blue-light filter glasses than in individuals who listened to music.

Based on the found negative effects of poor sleep quality on vigilance, a difference is expected between the group of poor sleepers and the group of good sleepers. The performance on a vigilance task will differ between individuals with poor sleep quality and individuals with good sleep quality. Both pretest and posttest measures of vigilance (reaction times and lapses) will be used as dependent variables in the analyses of the second hypothesis:

(2) Vigilance performance will be higher in individuals with good sleep quality than in individuals with poor sleep quality.

Positive effects on cognitive functions are expected if sleep quality is improved. In the experimental condition an improvement is expected, while in the control condition no improvements are expected. The vigilance performance measures will be used in the analyses of the third and fourth hypothesis:

(3) Individuals who used blue-light filter glasses will have a larger improvement in vigilance scores than individuals who listened to music.

The blue-light filter glasses have been invented as an aid for people with poor sleep quality so it is expected that especially individuals with poor sleep quality show an increase in vigilance measures. This means that a moderation effect of sleep quality is expected. As in the third hypothesis, vigilance measures are used as dependent variables in the analysis of the fourth hypothesis:

(4) The effect of blue-light filter glasses on vigilance performance will be higher in the group of individuals with poor initial sleep quality than in the group of individuals with good initial sleep quality.

Method

Participants

An a priori power analysis was conducted in G*Power ($\alpha = .05$, $1\text{-}\beta = .8$, $f(V) = .4$), which resulted in a required sample size of 52 participants. A total of 67 participants was recruited for this study, of which 60 participants joined. 28 of the participants were first-year students, recruited from the Faculty of Social Sciences (FSS) of Leiden University and 32 participants came from the personal network of the researcher. Four of them did not show up at the follow-up, which results in 56 participants (22 male, 34 female) in the analysis with 26 and 30 participants in respectively experimental and control condition.

All participants were students with an age between 17 and 30 years old ($M = 21.07$, $SD = 2.67$). People were excluded from the study if one of the following criteria applied to them:

- Not a student
- Age outside the range of 16-35 years old
- Clinical sleep problems
- Current or prior history of impaired vigilance due to a mental disorder
- Using any (sleep) medication or drugs in the last month
- Having children combined with a working life

These criteria were expected to prevent to a sufficient extent that participants had a similar lifestyle, so the sleep-wake cycles could be compared.

Participation was on a voluntary basis, but as a compensation the participants could receive the glasses as a gift at the end of the study. In the control group, the original music fragment with binaural beats was shared with people who were interested. The first-year students received 8 study credits as a compensation. In the case of non-completion, no credits were granted. This study was reviewed and approved by the Psychology Research Ethics Committee, approval number CEP19-0924/471. Each participant was aware of their rights, as stated in the informed consent (Appendix A, B).

Measures

All participants were asked to visit the lab twice. During these visits, data was collected via questionnaires and a cognitive task.

Questionnaires

Demographics. The first questionnaire consisted of questions about demographics in order to gain insight in the distribution of age, sex and phone use. This questionnaire was also used to check the criteria applicable to this study (Appendix D).

Perceived Sleep Quality. Before and after the intervention, the participants were asked to answer questions of the Pittsburgh Sleep Quality Index of Buysse et al. (1989). The

questionnaire consisted of 19 items in which the respondents rated their own sleep quality during the previous month or two weeks of intervention (Appendix F). In the latter case, the questions referring to ‘last month’ were replaced by references to ‘last two weeks’. The 19 items can be divided into seven components, for which the participant could score 0, 1, 2 or 3 points. All components count up to a total score of sleep quality within a range of 0 to 21, in which lower scores stand for higher sleep quality.

Sleepiness and fitness. To measure feelings of sleepiness, the Karolinska Sleepiness Scale (KSS) of Miley and Åkerstedt (2016) was used. This is a one-item questionnaire with a 9-point Likert scale with the following steps: (1) extremely alert, (3) alert, (5) neither alert not sleepy, (7) sleepy, but no difficulty remaining awake, (9) extremely sleepy, fighting sleep. The steps in between had a scale value, but no value label

Another one-item 9-point Likert scale was added to this to measure feelings of fitness at wake up time of the participant. The following steps are used: (1) Extremely fit, (3) Fairly fit, (5) Neither fit nor sleepy, (7) Fairly sleepy, (9) Extremely sleepy. The steps in between had a scale value, but no value label. Both measures of sleepiness can be found in Appendix E.

Exit questionnaire. The exit questionnaire was used to check for expectations and attitudes towards this study. Mostly qualitative data was collected to be able to explain found effects. The questions can be found in Appendix G.

Tasks

During this study a cognitive task was used to measure sustained attention, also named vigilance. Both times, the participants performed this task at the Lab of Leiden University.

PVT. The used task was the Psychomotor Vigilance Task for E-Prime 3.0 (Psychology Software Tools, 2020). The stimulus (a red dot) was shown after 2 to 10 seconds of showing a black masking screen. The red dot had a size of 1,5 cm. After the stimulus was shown, the participant responded as quickly as possible by pressing the space bar. No feedback was received on performed trials.

Apparatus and software

Questionnaires. All questionnaires were implemented in Qualtrics and filled out on a computer with Windows 10 in the Lab of Leiden University.

Cognitive Task. The PVT of PSTNet is used and implemented in E-Prime 3.0 (Psychology Software Tools, 2020). The keyboard was used as the reaction device.

Interventions. For the control condition, a binaural beats fragment (US-ALL, 2020) was downloaded and changed from stereo to mono sound. The music fragment was mp3-format, in order to be able to listen to it on both Windows, Android and iOS devices.

The blue-light filter glasses used in the experimental condition were SomnoBlue glasses, offered by KM Human Factors Engineering.

Procedure

Recruitment

All participants were, during their recruitment, asked to participate in an experiment in which interventions for improving sleep quality are researched. The participant was told that two methods would be compared with each other.

Informed consent

The participant was asked to visit the lab at the Faculty of Social Sciences of Leiden University for the pre-test. Each participant took place in a cubicle and after receiving information and asking questions (if there were any), the participant signed the informed consent.

Pre-test

After signing the informed consent, the participant started the cognitive task (PVT) and received the following instructions on screen: “Welcome to the task! You will see a black background for 10 minutes. If a red dot appears on the screen, press SPACE as quickly as possible. Press any key to begin.” After pressing the space bar, the task started instantly and after ten minutes the task stopped automatically. The participant was asked to open the door of the cubicle after which the researcher started the questionnaires about demographics, perceived sleep quality and the sleepiness scale. This took approximately 20 minutes per participant.

Intervention

After the measurements phase, each participant received a personal instruction by the researcher about the intervention. First the participant was told what was expected from him/her and the participant received a schedule for two weeks. The instructions differed between the two conditions.

Experimental condition. Each participant in the experimental condition received the blue-light filter glasses. These participants received the instructions to wear the glasses for one hour or longer, with a starting time of no later than 21:30. The participant was asked to make sure that (1) the glasses fit the skin well so that no light would come through, and that (2) the lights are turned off before the glasses are taken off. Most participants directly set an alarm at 21:30 as a reminder.

Each participant received a checklist, on which the daily requirements could be tracked (Appendix H). The date of the follow-up was also noted on it.

Control condition. Each participant in the control condition received a music fragment. The participant received the fragment via WhatsApp or email. The participant was told to listen to the fragment between 21:30 and bed time, with a minimum of half an hour before going to bed. Each participant used earphones and was allowed to listen while doing the common daily activities. Each participant received a checklist, on which the daily requirements could be tracked (Appendix I). The date of the follow-up was also noted on it.

Follow-up

After ten to fourteen days of intervention, the participant came back to the lab and performed the same task and sleep questionnaires as with the pre-test. In this case, the demographics questionnaire at the beginning was replaced by an exit questionnaire at the end.

Debriefing

The experiment ended with a debriefing (Appendix C) in which the participant was told to which group he was assigned and what was really tested. The meaning of the control group was also explained. The participant who tested the glasses was told that the glasses could be kept as a gift.

Data analysis

After all data was collected the hypotheses were operationalized and analyzed with the program IBM SPSS Statistics 23. Each hypothesis is discussed below.

Hypothesis 1: Sleep quality

The first hypothesis stated that ‘sleep quality will be higher in individuals using blue-light filter glasses than in individuals using music’. This was tested by analyzing the effect of condition and time on five measures of sleep quality with a two-sided ($\alpha = .05$) within subjects analysis of variance with repeated measures. The independent variables used in these analyses are the within-subjects factor Time, consisting of two measures (pretest and posttest), and the between-subjects factor Condition (experimental, control). In the experimental condition the participants used the filter glasses and in the control condition the participants used the music.

The five measures of sleep quality, Total Sleep Quality, Sleep Latency and Latency Time, Sleepiness and Fitness were used as the dependent variables in the analysis. Total Sleep Quality was equal to the total score on the PSQI questionnaire with a range of 0-21. The variable Sleep Latency was the score on one component of this questionnaire, ranging between 0 and 3. Latency Time was the mean reported number of minutes participants needed

to fall asleep. Sleepiness was the score on the KSS scale on the question how sleepy the participant felt at that moment and Fitness was the score on the question how sleepy the participant felt at the moment he woke up.

Hypothesis 2: Sleep quality and vigilance performance

The second hypothesis stated that 'vigilance performance will be higher in individuals with good sleep quality than in individuals with poor sleep quality.' The effect of sleep quality on two measures of vigilance performance as dependent variables is analyzed with a two-sided ($\alpha = .05$) two-way ANOVA. The independent variable used in the analysis is Sleep Quality Group, which are the grouped premeasures on the PSQI questionnaire. This measure was used to create two groups (poor sleeper, good sleeper) based on a median split. Participants with a score of 6 or lower were assigned to the group of good sleepers, the participants with a score of 7 or higher to the group of bad sleepers. The dependent variable Vigilance Reaction Time was equal to the mean reaction time per trial in milliseconds on the PVT task. The other dependent variable. Vigilance Lapses, was equal to the number of lapses during the PVT task. Each trial on which the response time was higher than 500ms was a lapse.

Hypotheses 3 and 4: Blue-light filter glasses, sleep quality and vigilance performance

The third hypothesis stated that 'individuals that used glasses will have a larger improvement in vigilance scores than individuals that used music' and the fourth hypothesis stated that 'The effect of blue-light filter glasses on vigilance is positively moderated by sleep quality.' These hypotheses were tested by analyzing the effect of time, condition and sleep quality on vigilance in a two-sided ($\alpha = .05$) 2x2x2 mixed analysis of variance with repeated measures. The two measures of vigilance (mean reaction time, number of lapses) were used as the dependent variables in this analysis. Time (pretest, posttest), Condition (experimental, control) and Initial Sleep Quality (poor sleeper, good sleeper) were added to this analysis as independent variables.

Results

In the current study, 60 young adults were recruited for the experiment. Four participants did not show up at the post measure, so 56 participants were included in the repeated measures analyses. This group consisted of 22 males and 34 females with an age range of 17 to 33 (M = 21). 43 participants were Dutch, against 13 non-Dutch. 88.4% of all participants uses the smartphone after 22.00, always or almost always. 65% of the participants

indicate that most evenings are filled with relaxing activities with screen use. Another 21.7% indicate that it's their second most done activity in a week.

The participants are divided into two conditions with 26 participants in the experimental condition and 30 participants in the control condition. In Table 1 an overview of the dependent variables is given.

Table 1.

Means and standard deviations of the scores on the dependent variables

	Pretest		**Posttest**	
	Mean	**SD**	**Mean**	**SD**
PSQI	6.53	2.801	7.53	2.72
Sleep latency	30 minutes	29 minutes	21 minutes	18 minutes
Sleepiness	5.41	1.66	5.09	1.74
Fitness	5.80	2.11	5.23	2.02
PVT RT	318.02 ms	43.24 ms	334.05 ms	54.06 ms
PVT Lapses	3.17	4.17	4.23	5.82

Hypothesis 1: Sleep quality

Total. To analyze the effect of Condition (glasses, music) and Time (pretest, posttest) on Sleep quality, a mixed analysis of variance with repeated measures was conducted. The Sleep quality measures added to this analysis were Total Sleep Quality, Sleep Latency and Latency Time. The analysis on Total Sleep Quality used the total scores on the PSQI on pretest and posttest. The reliability of all scale items (n = 14) on PSQI pretest is .652, posttest is .654. The results showed a significant main effect of Time $F (1, 54) = 25.090$, $p < .001$ with an effect size of $\eta_p^2 = .317$. As shown in Figure 2, the pretest PSQI scores ($M = 6.59$, $SD = 2.83$) were significantly higher than the posttest PSQI scores ($M = 5.04$, $SD = 2.72$). The main effect of Condition was not significant in the results, $F (1, 54) = .256$, $p = .615$. Also no significant interaction was found between Time and Condition $F (1, 54) = .152$, $p = .698$. These results showed an increase in sleep quality between the pretest and the posttest, but this effect did not significantly differ between the conditions.

Figure 2.

Scores of the PSQI on the pretest and the posttest in both conditions (experimental, control).

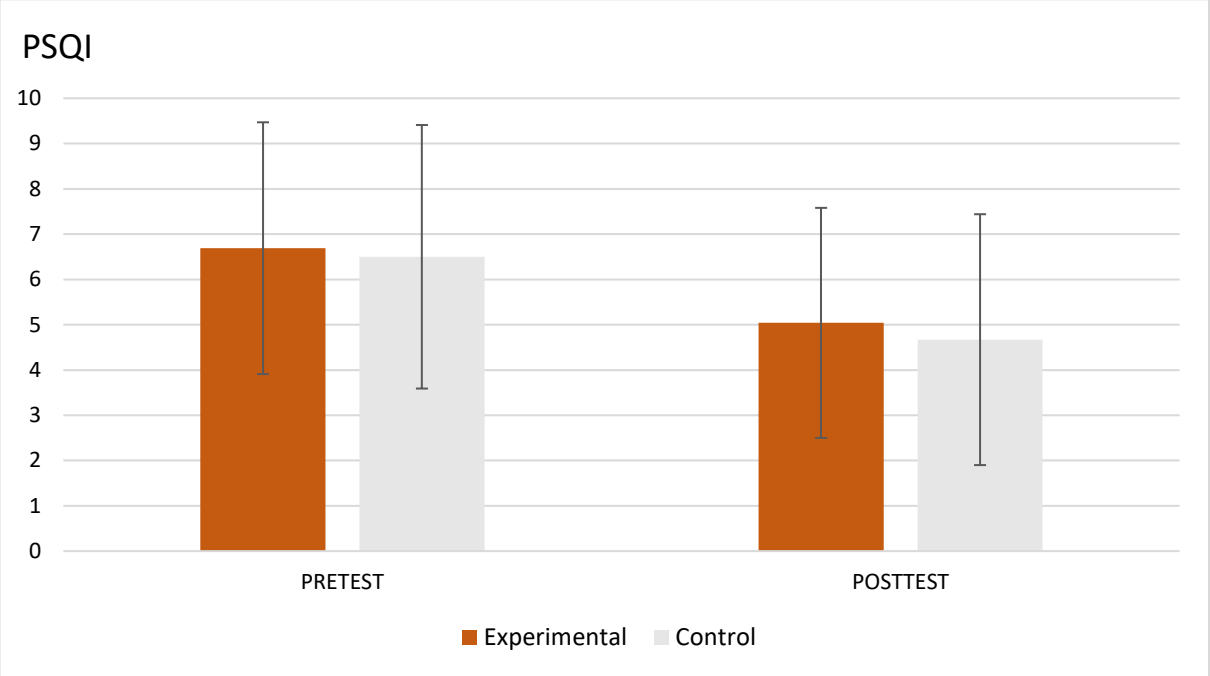
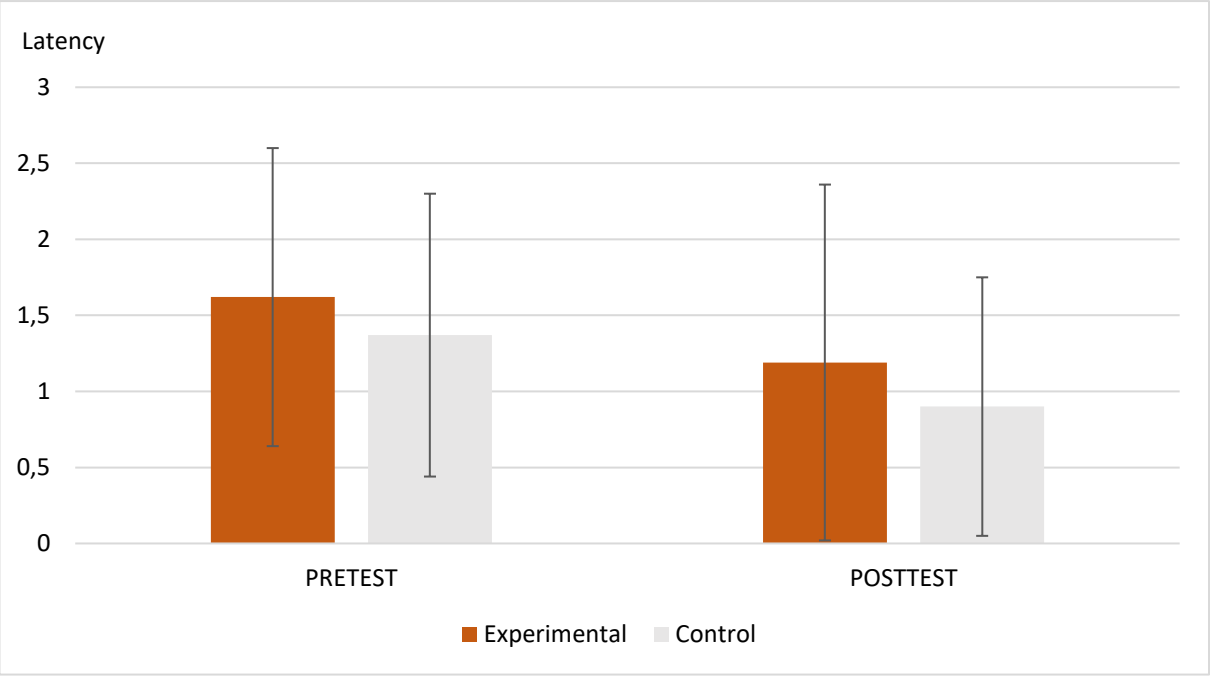


Figure 3.

Scores of Sleep Latency component on the pretest and the posttest

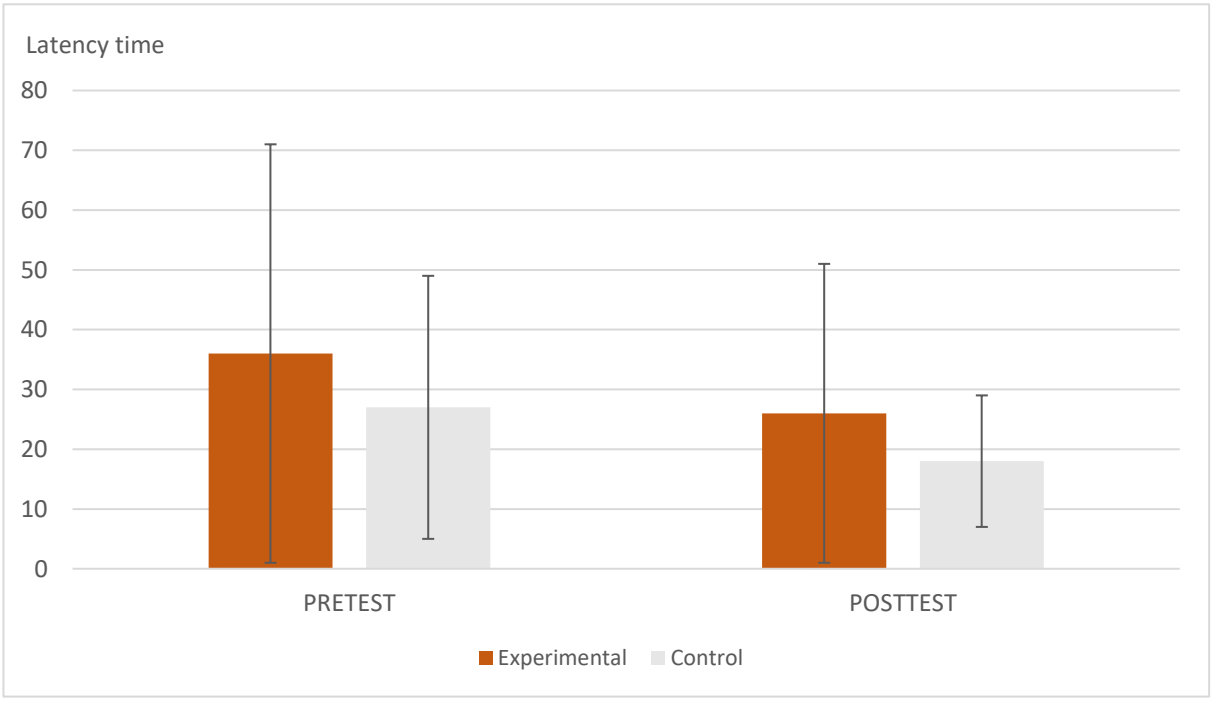


Sleep latency. The scores of the Sleep Latency component on the PSQI were also added to the analysis. This component was significantly correlated with the total PSQI scores ($r = .718$, $p < .001$). The analysis of variance showed that the pretest Sleep Latency scores ($M = 1.48$, $SD = .95$) were significantly higher than the posttest Sleep Latency scores ($M = 1.04$, $SD = 1.01$), with a significant main effect of Time, $F(1, 54) = 18.72$, $p < .001$ and an effect size of $\eta_p^2 = .257$. As shown in Figure 3, the main effect of Condition was not statistically significant with $F(1, 54) = 1.252$, $p = .268$, indicating no differences in sleep latency between both interventions. The interaction effect between Time and Condition was also not significant, $F(1, 54) = .045$, $p = .833$.

The Latency Time participants reported in minutes ("How long has it taken to fall asleep?") was also used as a dependent variable. The analysis of variance again showed a significant main effect of Time. As shown in Figure 4, the pretest Latency Time ($M = 31$ minutes, $SD = 29.37$) was significantly higher than the posttest Latency Time ($M = 22$ minutes, $SD = 18.87$), $F(1, 54) = 10.827$, $p = .002$ with an effect size of $\eta_p^2 = .167$. The main effect of Condition was not significant $F(1, 54) = 2.249$, $p = .140$ and the interaction effect was also not significant $F(1, 54) = .184$, $p = .670$.

Figure 4.

Scores of Sleep Latency time on the pretest and the posttest



Sleepiness and fitness. The reliability of KSS items (n = 2) pretest is .728, posttest is .737. On the scores on Sleepiness, "How sleepy do you feel now?", the analysis of variance showed that the pretest Sleepiness scores (M = 5.41 , SD = 1.66) were not significantly different from the posttest Sleepiness scores (M = 5.09, SD = 1.74), F(1, 54) = 1.016, p = .318. The main effect of Condition was not significant F (1, 54) = .105, p = .747 and also the interaction effect between Time and Condition was not significant, F(1, 54) = .002, p = .968.

On the scores on Fitness, "How sleepy did you feel in the morning?", the analysis of variance showed that the pretest Fitness scores (M = 5.80 , SD = 2.11) were not significantly different from the posttest Fitness scores (M = 5.23, SD = 2.02), F(1, 54) = 1.016, p = .318. The main effect of Condition was not significant F = .057, p = .813 and also the interaction effect of Time and Condition was not significant, F(1, 54) = 1.404, p = .241.

Hypothesis 2: Sleep quality and vigilance performance

Outliers were found on vigilance lapses (25, 14, 12) but they were not deleted, since they were not considered as measurement errors or experimental errors. To test the effect of sleep quality on vigilance, a (two-sided) two-way between-subjects analysis of variance was conducted on the pretest and posttest of vigilance measures (Reaction Time and Lapses) in the poor sleepers (n = 24) and good sleepers (n = 32) group. The sleep groups were based on a median split of the PSQI scores.

Reaction Time. The (two-sided) analysis of variance showed that pretest Vigilance Reaction Time in the group of good sleepers (M = 315, SD = 42.88) was not significantly lower than in the group of poor sleepers (M = 321, SD = 44.39), F(1,58) = .206, p = .651.

The (two-sided) analysis of variance showed that also the posttest Vigilance Reaction Time in the group of good sleepers (N = 43, M = 333 SD = 57.11) was not significantly different than the group of poor sleepers (N = 13, M = 335, SD = 44,43), F(1,54) = .021, p = .886.

Lapses. The (two-sided) analysis of variance showed that pretest Vigilance Lapses in the group of good sleepers (N = 26, M = 2.50, SD = 2.67) was not significantly lower than in the group of poor sleepers (N = 34, M = 4.04, SD = 5.50), F(1,58) = 2.044, p = .158.

The (two-sided) analysis of variance showed that pretest Vigilance Lapses in the group of good sleepers (N = 43, M = 4.44, SD = 6.14) was not significantly lower than in the group of poor sleepers (N = 13, M = 3.54, SD = 4.74), F(1,54) = .238, p = .628.

Hypotheses 3 and 4: Blue-light filter glasses, sleep quality and vigilance performance

To analyze the effect of Time (pretest, posttest), Condition (glasses, music) and Initial Sleep Quality (good sleeper, poor sleeper) on Vigilance, a 2x2x2 (two-sided) mixed analysis of variance with repeated measures was conducted. Vigilance Reaction Time was the

dependent variable and Condition (filter glasses, music) and Initial Sleep Quality (poor sleeper, good sleeper) were independent variables.

Reaction time. The analysis of variance with repeated measures showed that the Reaction Times on the posttest (M = 334 ms, SD = 54.06) were significantly higher than the Reaction Times on the pretest (M = 319 ms, SD = 45.55), F (1, 52) = 7.517, p = .008 with an effect size of η_p^2 = .126. This indicates a slower response on the PVT (Figure 5). As shown in Table 2, the main effect of Condition, the main effect of Sleep Quality and the interaction effect between condition and sleep quality were not significant.

Lapses. The (two-sided) within-subjects analysis of variance with repeated measures showed that the pretest Vigilance Lapses (M = 3.20, SD = 3.74) were not significantly lower than the posttest Vigilance Lapses (M = 4.23, SD = 5.82), F (1, 52) = 1.82, p = .182.
The main effect of Condition showed that the number of lapses between the experimental condition (M = 2.88, SD = 4.93) and the control condition (M = 3.47, SD = 3.739) was not significant, F (1, 52) = .782, p = .381. The main effect of Sleep Quality group showed that the number of lapses in poor sleepers was not significantly different from the number of lapses in good sleepers, F (1,52) = .244, p = .624. The interaction effect of Condition and Sleep Quality was not significant, F (1,52) = .031, p = .861. The interaction effect of Time, Condition and Sleep Quality was also not significant, F (1, 52) = .159, p = .692.

Table 2.

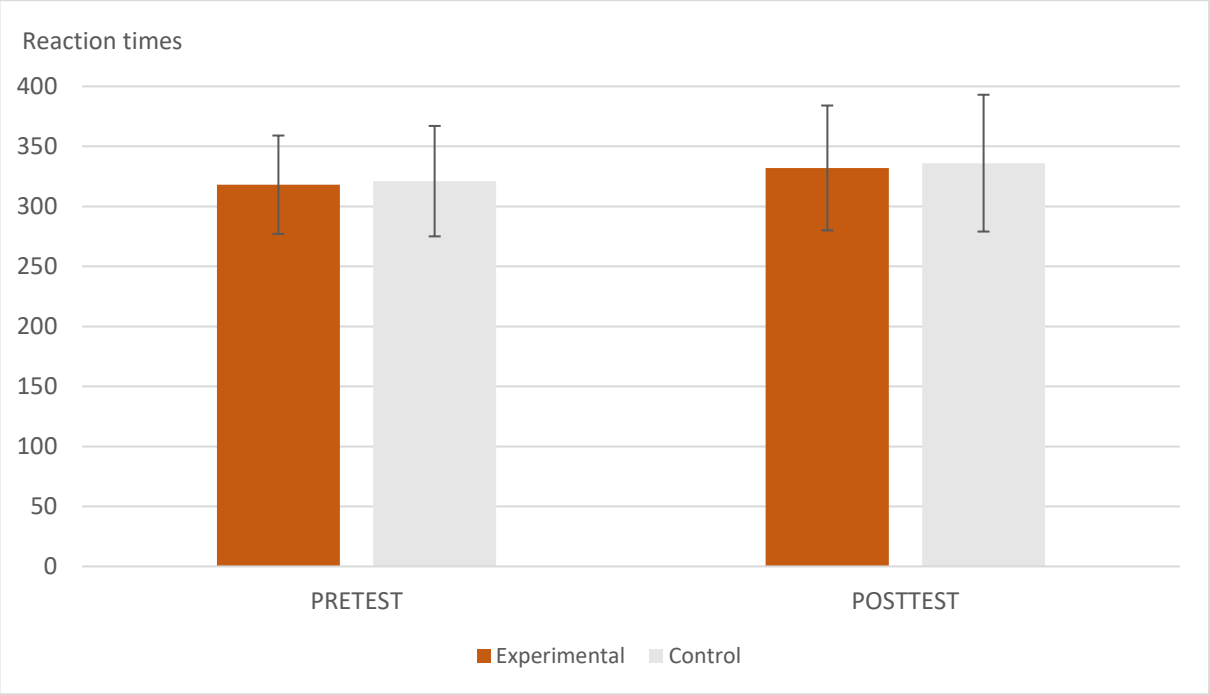
Results of the Analysis of Variance with repeated measures on PVT reaction times

	F	**p**
Condition	.139	.711
Sleep quality	.003	.960
Condition * Sleep quality	.137	.713

Note. Degrees of freedom (1, 52).

Figure 5.

Scores of PVT reaction times on the pretest and the posttest



Discussion

Interpretations

The first hypothesis stated that ‘sleep quality will be higher in individuals who used blue-light filter glasses than in individuals who listened to music’. The main effect of time was positively significant on the total scores of the PSQI, the component sleep latency and the sleep latency in minutes. The main effect of time was not statistically significant on sleepiness and fitness scores. These results indicate an increase in sleep quality between pretest and posttest.

The main effect of the between subjects variable Condition was not statistically significant on any variable and there was no significant interaction effect.
Thus, independent of the condition a participant was assigned to, young adults report higher sleep quality after two weeks of intervention, but did not report less sleepiness. This suggests that sleep quality was improved equally by both interventions, but did not affect their wakefulness during the day.

The second hypothesis analyzed the effect of sleep quality on vigilance and stated that ‘vigilance performance will be higher in individuals with good sleep quality than in

individuals with poor sleep quality'. The participants were divided into two categories, poor sleepers and good sleepers, based on a median split. On both pretest and posttest scores, no significant differences were found between poor and good sleepers regarding to reaction time and number of lapses on the vigilance task. This suggests that vigilance was not affected by sleep quality.

The third hypothesis stated that 'individuals who used blue-light filter glasses will have a larger improvement in vigilance scores than individuals who listened to music.' The main effect of time was positively significant on reaction time, which indicate a significantly worse performance. These results contradicted the expectations that it would improve over time. The main effect of time was not significant on the number of lapses and no interaction effect between time and condition was found. This suggests that the decrease in vigilance reaction times between pretest and posttest could not be explained by the condition an individual was assigned to.

The fourth and last hypothesis stated that 'The effect of blue-light filter glasses on vigilance performance will be higher in the group of individuals with poor initial sleep quality than in the group of individuals with good initial sleep quality'. Since there was no significant interaction found between time, condition and initial sleep quality, the expected moderation of sleep quality was not supported by these findings.

Together, these findings suggest that sleep quality has improved over time, the participants' sleepiness feelings did not change, and their cognitive performance has declined in terms of reaction times. But in all cases, these effects could not be explained by the use of blue-light filter glasses.

Limitations and future research

The conclusions that can be drawn from these results are limited because of several factors: measuring methods, alternative explanations and design limitations.

Sleep quality measures were based on self-report and may therefore not be completely accurate and reliable. Future research could profit from objective measures like dim-light melatonin secretion onset, or the before-mentioned polysomnography, cyclic alternating pattern or actigraphy (Krystal & Edinger, 2008). Although evening light exposure was included in the questionnaire, measuring it objectively could also be a valuable contribution to future research on the effects of blue light on sleep quality. This would be especially interesting because of the genetic differences in sensitivity for blue light between individuals (Chellapa, 2020).

Another limitation is that the effects of the music fragment are uncertain. Although the music fragment was manipulated, it could be that it significantly affected sleep quality as much as the blue-light filter glasses. For further investigation on this topic, a better understanding of the effects of listening music in the evening on sleep is needed, or the control group should no longer listen to music in the evening, but for example in the (early) afternoon.

The differences between pretest and posttest on vigilance reaction times could not be explained by the variables in this study. Future research could use longer periods of wearing glasses in order to investigate whether cognition is affected. Also, other factors could be taken into account, such as mood, stress, depression, self-concept and motivation, because especially stress could have affected the cognitive measures (Ahrberg et al., 2012, Baglioni et al., 2014).

There are also some general limitations for this type of study. It was a single blind study, so although all effort has been made to standardize texts, subtle differences and expectations of the researcher could have affected the outcome that participants expected that the music was the control condition. Fifteen (15) out of 30 (50%) participants in the control condition reported on the exit questionnaire that they had expected that the music fragment would be an effective intervention. In the experimental condition, this was even 19 out of 26 (73%). Future research could benefit from a larger number of participants in order to reach higher power in the analysis, or from a crossover design in which all participants use both interventions in order to serve as their own control group.

Furthermore, the choice was made to let the participants wear the glasses in an uncontrolled condition. One drawback is that environmental differences, such as amount of light or temperature in the room, could have affected the results. Another drawback is that some participants did not fully adhere to the intervention prescriptions or took a pause in the weekends, which could have affected the scores of sleep quality and vigilance. Although the daily activities were normal as much as possible, this could have affected the data. Future studies could set stricter rules for wearing the glasses or exclude the non-adhering participants from analyses.

Implications

This study was the first in which the effects of blue-light filter glasses on both sleep quality and cognitive performance in young adults were investigated. In contrast to previous research, no relation was found between sleep quality and cognitive performance. Sleep quality improved over time while cognitive performance declined in terms of reaction times.

The limitations and recommendations discussed above already give a direction for exploring the relationship between cognition and sleep quality.

More thorough research on the effects of using blue-light filter glasses on both sleep quality and cognition in young adults, in which the discussed recommendations in the Limitations and future research section are taken into account, should be conducted in order to reach more understanding on how sleep quality and cognition are related and how blue-light filter glasses play a role in this.

How do the results contribute to the understanding of how blue-light filter glasses affect poor sleep quality and cognition in young adults? These results support the expectation that blue-light filter glasses could help young adults with difficulties falling asleep, but it seems that with an improved sleep quality the risk of safety problems or (mental) health problems is not automatically reduced.

Conclusion

This study investigated the effects of using blue-light filter glasses on sleep quality and vigilance in young adults, in order to gain more insight in blue-light filter glasses as an effective aid against poor sleep quality. This was done by a single-blind controlled study in which participants reported their sleep quality and performed a vigilance task. After two weeks of intervention, follow-up measures were registered. Although measures of sleep quality increased and vigilance reaction times decreased over time, these changes could not be explained by the use of blue-light filter glasses or the relation between vigilance and sleep quality. The positive relation between sleep quality and cognitive performance was not supported by these findings. Including objective measures and treatments with longer periods of time in future investigations of this topic are recommended for future research. More understanding on this topic could lead to more effective ways of fighting poor sleep quality, and with that, an improvement of quality of life.

References

Ahrberg, K., Dresler, M., Niedermaier, S., Steiger, A., & Genzel, L. (2012). The interaction between sleep quality and academic performance. *Journal of psychiatric research, 46*(12), 1618-1622. Doi: 10.1016/j.jpsychires.2012.09.008

Alhola, P., & Polo-Kantola, P. (2007). Sleep deprivation: Impact on cognitive performance. *Neuropsychiatric Disease and Treatment, 3*(5), 553–567.

Baglioni, C., Spiegelhalder, K., Feige, B., Nissen, C., Berger, M., & Riemann, D. (2014). Sleep, depression and insomnia–a vicious circle?. *Current Psychiatry Reviews, 10*(3), 202-213.

Burkhart, K., & Phelps, J. R. (2009). Amber lenses to block blue light and improve sleep: a randomized trial. *Chronobiology international, 26*(8), 1602-1612. Doi: 10.3109/07420520903523719

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research, 28*(2), 193-213. Doi: 10.1016/0165-1781(89)90047-4

Central Bureau for Statistics. (2020, Octobre 30). Statistics Netherlands: Health and health care use; personal characteristics [Data file]. Retrieved from https://opendata.cbs.nl/#/CBS/nl/dataset/83005NED/table?defaultview&dl=8E86

Chellappa, S. L. (2020). Individual differences in light sensitivity affect sleep and circadian rhythms. *Sleep*, *44*(2). Doi: 10.1093/sleep/zsaa214

Dumont, M., & Beaulieu, C. (2007). Light exposure in the natural environment: relevance to mood and sleep disorders. *Sleep medicine, 8*(6), 557-565. Doi: 10.1016/j.sleep.2006.11.008

Gray, P. (2011). Psychology (6th ed.). Worth, Publishers. *Inc., New York, 247.*

Hersenstichting. (2017, Septembre 18). Genoeg slaap geen garantie voor goede nachtrust [Data file]. Retrieved from https://www.hersenstichting.nl/nieuws/genoeg-slaap-geen-garantie-voor-goede-nachtrust/

Irwin, M., McClintick, J., Costlow, C., Fortner, M., White, J., & Gillin, J. C. (1996). Partial night sleep deprivation reduces natural killer and celhdar immune responses in humans. *The FASEB journal, 10*(5), 643-653. Doi: 10.1096/fasebj.10.5.8621064

Janků, K., Šmotek, M., Fárková, E., Miletínová, E., & Kopřivová, J. (2019). Blue light blocking glasses and CBT-I: effect on subjective and objective sleep quality. *Sleep Medicine, 64*, S174.

Jirakittayakorn, N., & Wongsawat, Y. (2018). A novel insight of effects of a 3-Hz binaural beat on sleep stages during sleep. *Frontiers in human neuroscience, 12*, 387. Doi: 10.3389/fnhum.2018.00387

Krystal, A. D., & Edinger, J. D. (2008). Measuring sleep quality. *Sleep medicine*, *9*, S10-S17. Doi: 10.1016/S1389-9457(08)70011-X

Lee, M., Song, C. B., Shin, G. H., & Lee, S. W. (2019). Possible effect of binaural beat combined with autonomous sensory meridian response for inducing sleep. *Frontiers in human neuroscience, 13*, 425. Doi: 10.3389/fnhum.2019.00425

Leone, S., Van der Poel, A., Beers, K., Rigter, L., Zantinge, E., & Savelkoul, M. (2018). Slechte slaap: een probleem voor de volksgezondheid?. *Trimbos Instituut, Netherlands Institute of Mental Health and Addiction.*

Licklider, J. C. R., Webster, J. C., & Hedlun, J. M. (1950). On the frequency limits of binaural beats. *The Journal of the Acoustical Society of America*, *22*(4), 468-473. Doi: 10.1121/1.1906629

Miley, A. Å., Kecklund, G., & Åkerstedt, T. (2016). Comparing two versions of the Karolinska Sleepiness Scale (KSS). *Sleep and biological rhythms, 14*(3), 257-260. Doi: 10.1007/s41105-016-0048-8

Mortazavi, S. A. R., Parhoodeh, S., Hosseini, M. A., Arabi, H., Malakooti, H., Nematollahi, S., Mortazavi, G., Darvish, L., & Mortazavi, S. M. J. (2018). Blocking short-wavelength component of the visible light emitted by smartphones' screens improves human sleep quality. *Journal of Biomedical Physics & Engineering, 8*(4), 375.

Muñoz, J. P., & Rivera, L. A. (2020). Towards Improving Sleep Quality Using Automatic Sleep Stage Classification and Binaural Beats. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. *IEEE Engineering in Medicine and Biology Society. Annual International Conference, 2020*, 4982–4985. Doi: 10.1109/EMBC44109.2020.9176385

Naitoh, P., Kelly, T. L., & Englund, C. (1990). Health effects of sleep deprivation. *Occupational medicine (Philadelphia, Pa.), 5*(2), 209–237.

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., Dauvilliers, Y., Ferri, R., Fung, C., Gozal, D., Hazen, N., Krystal, A., Lichstein, K.,

Mallampalli. M., Plazzi, G., Rawding, R., Scheer, F. A., Somers, V., & Vitiello, M. V. (2017). National Sleep Foundation's sleep quality recommendations: first report. *Sleep health, 3*(1), 6-19. Doi: 10.1016/j.sleh.2016.11.006

Oster, G. (1973). Auditory beats in the brain. *Scientific American, 229*(4), 94-103. Doi: 10.1038/scientificamerican1073-94

Pilcher, J. J., & Huffcutt, A. I. (1996). Effects of sleep deprivation on performance: a meta-analysis. *Sleep, 19*(4), 318-326. Doi: 10.1093/sleep/19.4.318

Spitzer, M. (2016). *Digiziek: pleidooi voor offline leven.* Atlas Contact.

Swaen, G. M. H., Van Amelsvoort, L. G. P. M., Bültmann, U., & Kant, I. J. (2003). Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht Cohort Study. *Occupational and environmental medicine, 60*(suppl 1), i88-i92. Doi: 10.1136/oem.60.suppl_1.i88

Psychology Software Tools, Inc. [E-Prime 3.0]. (2016). Retrieved from https://www.pstnet.com.

Psychology Software Tools, Inc. (2020, April 7). Psychomotor Vigilance Task (PVT) [30113]. PST Product Service & Support. Retrieved from https://support.pstnet.com/hc/en-s/articles/360008697713-Psychomotor-Vigilance-Task-PVT-30113-

Shumov, D. E., Arsen'ev, G. N., Sveshnikov, D. S., & Dorokhov, V. B. (2017). Comparative analysis of the effect of stimulation with a binaural beat and similar kinds of sounds on the falling asleep process: A brief note. *Moscow University Biological Sciences Bulletin, 72*(1), 33-36. Doi: 10.3103/S0096392517010047

Thoma, M. V., La Marca, R., Brönnimann, R., Finkel, L., Ehlert, U. & Nater, U. M. (2013). The effect of music on the human stress response. *PloS One, 8*(8). Doi: 10.1371/journal.pone.0070156

Uehli, K., Miedinger, D., Bingisser, R., Dürr, S., Holsboer-Trachsler, E., Maier, S., Mehta, A. J., Müller, R., Schindler, C., Zogg, S., Künzli, N., & Leuppi, J. D. (2014). Sleep quality and the risk of work injury: a Swiss case–control study. *Journal of sleep research, 23*(5), 545-553. Doi: 10.1111/jsr.12146

US-ALL. (2020, January 7). 528 Hz [Video]. YouTube. https://www.youtube.com/watch?v=nycmDOGiHgo&list=OLAK5uy_nApbIN6jj0n-

R0i-hThvQJAE473tcZHCU

Van der Meijden, W. P., Stenvers, D. J., van Kerkhof, L., van Nierop, L., van Steeg, H., Bisschop, P. H., van Someren, E. J., & Kalsbeek, A. (2019, May). Restoring the sleep disruption by blue light emitting screen use in adolescents: a randomized controlled trial. *In 21st European Congress of Endocrinology, 63*. BioScientifica. Doi: 10.1530/endoabs.63.P652

Van Kerkhof, L. W. M., Vlaanderen, J. J., Berkhout, A. J. C., Dollé, M. E. T., Vermeulen, R. C. H., & van Steeg, H. (2017). Schermgebruik en blauw licht: Omvang van blootstelling en relatie met slaap. *Rijksinstituut voor Volksgezondheid en Mileu RIVM.*. Doi: 10.21945/RIVM-2017-0106

Yi, H., Shin, K., & Shin, C. (2006). Development of the sleep quality scale. *Journal of Sleep Research, 15(*3), 309-316. Doi: 10.1111/j.1365-2869.2006.00544.x

Appendices

Appendix A: Informed Consent - Experimental condition

Participant Information

Theme of study

In this study we want to investigate the effects of different products on the sleep quality of students. This study takes about 2 weeks in total. In these 2 weeks, your participation demands a total of 4 hours of your time.

The procedure

You will be asked to fill out a questionnaire and do a cognitive task, which will take approximately 45 minutes. After this, you will be asked to do an intervention that is meant to improve sleep quality. You will receive orange glasses to wear during the evening. You will also receive a checklist with which you can check whether you have fulfilled your daily requirements for the study. After the intervention, you come back to the research lab for the posttest of 45 minutes (fill out a questionnaire and do the cognitive task again).
The glasses will block a certain part of the light spectrum to activate sleep hormones. This has no effect on health of your eyes, body and brain. It is completely safe to wear these glasses.

What we ask from you

If you participate in this study, you are expected to come to the university research lab two times for 45 minutes. Besides, you will repeat the intervention for ten days (i.e. wearing glasses or listening to music for ten minutes in the evening). You will receive additional instructions later.

Compensation

For this study, there is no monetary compensation. All first year students are compensated with 8 credits to (partly) fulfill their requirements of the first year course Academische Vaardigheden. Other participants that join voluntarily receive no monetary or study-related compensation.

Confidentiality

Confidentiality is guaranteed and all data is collected and processed in a coded way. Name and other personal data cannot be traced back to the individual. Since this study contains a pretest and a posttest, the answers you give on the questionnaires are first pseudonymized with a respondent number, in order to make it possible that the data from different time points can be coupled. All personal data will be at all times processed according to the GDPR rules. All data will only be used for this study and will not be discussed with anyone.

Participation

Your participation in this study is on fully voluntary basis. You have the right to discontinue participation without giving a reason and without any negative consequence. In case of non-completion, you won't receive credits.

Other information

The coordinator of this study is Guido Band. If you have questions, any remarks or complaints about this study, please contact him via BAND@FSW.leidenuniv.nl or 071-5273998.

Informed Consent

By signing this form, you agree to the following:

o I have read and understood the information about the study and I have had the opportunity to ask additional questions. My questions have been answered adequately. I have had sufficient time to decide whether or not I participate.

O I understand that all data will be collected and processed in a coded way.

O I am aware that I will participate in the study voluntarily. I understand that I can withdraw from participation at all times. I do not need to provide a reason for that.

O I give consent to use my data for the purposes that are mentioned in the information letter.

Name of participant _____

Signature of participant _____ Date _____/_____/_____

Appendix B: Informed consent - Control condition

Participant Information

Theme of study

In this study we want to investigate the effects of different products on the sleep quality of students. This study takes about 2 weeks in total. In these 2 weeks, your participation demands a total of 4 hours of your time.

The procedure

You will be asked to fill out a questionnaire and do a cognitive task, which will take approximately 45 minutes. After this, you will be asked to do an intervention that is meant to improve sleep quality. You will receive a music fragment to listen during the evening. You will also receive a checklist with which you can check whether you have fulfilled your daily requirements for the study. After the intervention, you come back to the research lab for the posttest of 45 minutes (fill out a questionnaire and do the cognitive task again).
The music fragment contains a sound that activates certain brain waves related to sleep and relaxation. This has no effects on health of your ears, body and brain. It is completely safe to listen to this fragment.

What we ask from you

If you participate in this study, you are expected to come to the university research lab two timesfor 45 minutes. Besides, you will repeat the intervention for ten days (i.e. wearing glasses or listening to music for ten minutes in the evening). You will receive additional instructions later.

Compensation

For this study, there is no monetary compensation. All first year students are compensated with 8 credits to (partly) fulfil their requirements of the first year course Academische Vaardigheden. Other participants that join voluntarily receive no monetary or study-related compensation.

Confidentiality

Confidentiality is guaranteed and all data is collected and processed in a coded way. Name and other personal data cannot be traced back to the individual. Since this study contains a pretest and a posttest, the answers you give on the questionnaires are first pseudonymized with a respondent number, in order to make it possible that the data from different time points can be coupled. All personal data will be at all times processed according to the GDPR rules. All data will only be used for this study and will not be discussed with anyone.

Participation

Your participation in this study is on fully voluntary basis. You have the right to discontinue participation without giving a reason and without any negative consequence. In case of non-completion, you won't receive credits.

Other information

The coordinator of this study is Guido Band. If you have questions, any remarks or complaints about this study, please contact him via BAND@FSW.leidenuniv.nl or 071-5273998.

Informed Consent

By signing this form, you agree to the following:

o I have read and understood the information about the study and I have had the opportunity to ask additional questions. My questions have been answered adequately. I have had sufficient time to decide whether or not I participate.

O I understand that all data will be collected and processed in a coded way.

O I am aware that I will participate in the study voluntarily. I understand that I can withdraw from participation at all times. I do not need to provide a reason for that.

O I give consent to use my data for the purposes that are mentioned in the information letter.

Name of participant _____

Signature of participant _____ Date____/_____/____

Appendix C: Debriefing

Debriefing

Thank you very much for participating in this study! Thanks to your effort, we are a step closer in finding solutions to improve sleep quality.

What did we do?

You have participated in an experimental study with two conditions: an experimental condition and a control condition.

If you received the goggles to wear at home, you were in the experimental condition. The effectivity of the goggles is the subject of this study and the aim of this study is to explore the effectivity of filtering blue light in the evening and its effects on sleep quality and cognitive performance.
We predict that the orange glasses will have a positive effect on falling asleep easier and earlier.

If you received the link to the binaural beats music, you were in the control condition. Binaural beats are not found to be convincingly effective in improving sleep quality. With binaural beats, you have stereo music with which the frequency differs between the two ears. The difference between those frequencies activates a certain brain state, which could be relaxing or activating. To ensure that these beats were really not effective, in order to collect data that is as clean as possible, the binaural beats fragment was adjusted from stereo to mono sound. This was a placebo product, which we predict to have no effect on sleep quality.

Why didn't we tell you?

You weren't told beforehand that the binaural beats were part of a control condition to ensure that as much factors as possible are the same across the two conditions. This prevents the data from unequal expectation biases such as 'placebo effects'.
We want to ask you not to tell others about the nature and outcomes of this study.

Your role in this study

In both conditions, you have made an important contribution to this study because your data contains valuable information about the effectivity of both interventions.

Privacy policy

All personal data is disconnected from the research data, to make sure that all research data is processed and saved in a coded way. After the research is finished, personal data will be removed in line with the applicable GDPR rules.

Contact details

The research coordinator of this study at Leiden University is Guido Band. If you have questions, any remarks or if you would like the results of this study, please contact him via email (band@fsw.leidenuniv.nl) or telephone (+31 71 527 3998).

Appendix D: Questionnaire - Demographics

1. Respondent ID
2. What is your age?

   Slider with range between 16-35
3. What is your gender?
   - Male
   - Female
   - Other/Don't want to say
4. What is your nationality?
5. What is the highest degree or level of school you have completed?

   (If currently enrolled, choose the highest degree received)
   - No Schooling Completed
   - Primary School (NL: Basisonderwijsl)
   - Pre-vocational Secondary Education (NL: VMBO)
   - Senior General Secondary Education (NL: HAVO)
   - Pre-university Education (NL: VWO)
   - Secondary Vocational Education (NL: MBO)
   - Higher Professional Education (NL: HBO)
   - University Bachelor
   - University Master
   - PhD
6. Are you currently a student?
   - Yes
   - No
7. Are you currently working more than 10 hours a week?
   - Yes
   - No
8. Do you have children?
   - Yes
   - No
9. Do you have a smartphone?
   - Yes
   - No

10. How much time do you spend daily on your mobile phone on average? Please choose the box that fits best with your situation.
    - Less than 1 hour
    - From 1 to 2 hours
    - From 2 to 3 hours
    - More than 3 hours
11. How often do you use your phone after 22:00 o'clock? Please choose the box that fits best with your situation.
    - Never
    - Once in a month
    - Once in a week
    - Once in a couple of days
    - Almost always
    - Always
12. Which of the following activities do you mostly do before you go to bed?

    Rank them in order with 1 (the most) to 5 (the least).
    - Study
    - Work
    - Sports
    - Relaxing/social activities without screen use
    - Relaxing/social activities with screen (movies, gaming, chatting)
13. Have you consumed alcohol or drugs in the last 24 hours?
    - Yes
    - No
14. Have you consumed coffee (or other nutrients containing caffeine) this morning?
    - Yes
    - No

Appendix E: Questionnaire – Sleepiness and fitness

1. This question is about how you're feeling right now. Please be honest, there is no such thing as a good or bad answer.

	Extremely alert (1)	. (2)	Alert (3)	. (4)	Neither alert nor sleepy (5)	. (6)	Sleepy, but no difficulty remaining awake (7)	. (8)	Extremely sleepy, fighting sleep (9)
Please indicate how alert do you feel?	○	○	○	○	○	○	○	○	○

2. This question is about how you felt when you woke up today. Please be honest, there is no such thing as a good or a bad answer.

	Extremely fit (1)	. (2)	Fairly fit (3)	. (4)	Neither fit nor sleepy (5)	. (6)	Fairly sleepy (7)	. (8)	Extremely sleepy (9)
Please indicate how you felt when you woke up?	○	○	○	○	○	○	○	○	○

Appendix F: Questionnaire - Sleep Quality

In the used follow-up version of this questionnaire, the words "past month" are replaced by the words "past two weeks".

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month.

1. During the past month, at what time have you usually gone to bed at night?
   Please use this time notation: HH:MM
2. During the past month, how long has it usually taken you to fall asleep each night?
   Please give your answer in whole minutes
3. During the past month, at what time have you usually gotten up in the morning?
   Please use this time notation: HH:MM
4. During the past month, how many hours of *actual sleep* did you get at night?
   (This may be different than the number of hours you spend in bed)
5. For each of the remaining questions, check the one best response. Please answer all questions.

A likert scale is used with the following range: (1) Not during the past month, (2) Less than once a week, (3) Once or twice a week, (4) Three or more times a week.

a. Couldn't get to sleep within 30 minutes
b. Woke up in the middle of the night or early morning
c. Had to get up to use the bathroom
d. Couldn't breathe comfortably
e. Coughed or snored loudly
f. Felt to cold
g. Felt to hot
h. Had bad dreams
i. Had pain
j. Other reasons

6. If answered yes on 5j, which other reasons?

7. During the past month, how would you rate your sleep quality overall?
    - Very good
    - Fairly good
    - Fairly bad
    - Very bad

8. During the past month...

A likert scale is used with the following range: (1) Not during the past month, (2) Less than once a week, (3) Once or twice a week, (4) Three or more times a week.

a. How often have you taken medicine (prescribed or over the counter) to help you sleep?

b. How often have you had trouble staying awake while driving, eating mails, or engaging in social activity?

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?
A likert scale is used with the following range: (1) No problem at all, (2) Only a very slight problem, (3) Somewhat of a problem, (4) A very big problem.

10. Do you have a bed partner or roommate?
    - No partner or roommate
    - Partner/roommate in other room
    - Partner in same room, but not same bed
    - Partner in the same bed

Appendix G: Questionnaire – Exit

1. Before you started with the intervention, did you expect that the intervention would be effective?
2. To what extent do you think that your expectancies affected the effectivity of the intervention? (0 = not at all, 10 = totally)

Please answer these questions about the intervention you had during the two testing weeks.

A likert scale is used with the following range: (1)Strongly disagree, (2) Disagree, (3) Somewhat disagree, (4) Neither *agree nor disagree, (5) Somewhat agree, (6) Agree, (7) Strongly agree.*

3. The intervention was fun
4. The intervention was frustrating
5. The intervention asked too much of my time
6. The intervention was helpful
7. The intervention was easy to implement in my daily life
8. The intervention was effective for improving my sleep quality

9. Do you have any other remarks about the intervention?
10. Which intervention were you assigned to?
    - Blue light blocking glasses (experimental)
    - Music fragment (control)

The following question was only answered by the participants in control group

11a. How often have you listened to the whole fragment?
- Always (10 times)
- Most of the time (7-9 times)
- About half the time (4-6 times)
- Sometimes (1-3 times)
- Never (0 times)

The following question was only answered by the participants in control group

11b. How often have you worn to the glasses for a minimum of 1 hour?
- Always (10 times)
- Most of the time (7-9 times)
- About half the time (4-6 times)
- Sometimes (1-3 times)
- Never (0 times)

12. Have you any other remarks or questions about this study?

Appendix H: Checklist for participants – Experimental condition

Checklist

Draw a (✓) to track your daily requirements.

Advice: set an alarm at 21:30!

ID # .....

Day	Task	Date	>60 min	<60 min
1	Introduction (LAB)	/	✓	✓
2	Intervention day 1	/		
3	Intervention day 2	/		
4	Intervention day 3	/		
5	Intervention day 4	/		
6	Intervention day 5	/		
7	Intervention day 6	/		
8	Intervention day 7	/		
9	Intervention day 8	/		
10	Intervention day 9	/		
11	Intervention day 10	/		
12	Follow-up (LAB)	/		

Appendix I: Checklist for participants – Control condition

Checklist

Draw a (✓) to track your daily requirements.

Advice: set an alarm at 21:30!

ID # .....

Day	Task	Date	
1	Introduction (LAB)	/	✓
2	Intervention day 1	/	
3	Intervention day 2	/	
4	Intervention day 3	/	
5	Intervention day 4	/	
6	Intervention day 5	/	
7	Intervention day 6	/	
8	Intervention day 7	/	
9	Intervention day 8	/	
10	Intervention day 9	/	
11	Intervention day 10	/	
12	Follow-up (LAB)	/	