The Effect of Blue Light Exposure on Cognitive-Distraction-Induced Alpha Perturbation in Night-time Simulated Driving Task

Andi Nadhila Prameswari✉ • Lulu Lusianti Fitri • Suprijanto

✉ School of Life Sciences and Technology, Institut Teknologi Bandung (ITB)
Jalan Ganesha No. 10 Bandung 40132 Indonesia
e-mail: andinadhila@gmail.com

Abstract *The effect of driver cognitive distraction is specified by a perturbation in brain wave which results in alpha band synchronization (power raise), thus indicating an attentional shift to top-down processing and the inhibition of sensory information. At night, the inhibition typically raises due to melatonin secretion which reduces driver arousal. Blue light (wavelength: 446-477 nm) is known to be effective in stimulating arousal, therefore is expected to suppress the ongoing effect of cognitive distraction. The objective of this study was to firstly evaluate the effect of cognitive distraction on alpha perturbation in night-time simulated driving task and to further evaluate the effect of blue light exposure towards the cognitive-distraction-induced perturbation. The study was conducted towards five male participants using a driving simulator. Data collection was held at night in two conditions: no lighting (dark) and blue light exposure, for five minutes each. On the third minute in each condition, a question was given to the participant to induce cognitive distraction. The question was modified from RVCB (2002) and had to be answered verbally in 2 minutes. Alpha waves from channels F3 and F4 were recorded using EMOTIV EPOC EEG Neuroheadset to observe cognition activity. The results showed that in the dark: (1) right hemisphere was more dominant than left hemisphere before and after distraction onset (P<0,05), (2) distraction onset resulted in synchronization in both channels (P<0,05), and (3) there was no statistically significant difference in synchronization percentage between F3 and F4. Whereas upon blue light exposure: (1) right hemisphere was more dominant than left hemisphere before and after the onset of distraction (P<0,05), (2) there was no statistically significant alpha perturbation, and (3) there was no statistically significant difference in perturbation percentage between F3 and F4. The aforementioned results indicate that blue light exposure doesn't affect alpha power directly, however it is able to reduce alpha synchronization significantly in both channels. It can be concluded then, that: (1) the onset of cognitive distraction results in alpha synchronization and (2) blue light exposure reduces the cognitive-distraction-induced alpha synchronization.*

Keywords Blue light, Cognitive Distraction, Brain wave, Electroencephalograph, Driving simulation

Background

Driving is a complex activity requiring extraction and integration processes from multiple sources in the brain in order to gain maximum control of the vehicle safely and efficiently [1]. The process involves high concentration in the visual and cognitive fields [2]. Thus, safety has become one of the main points in the development process of manufacturing transportation technology. The role of software in enhancing safety, comfortability, and economic value has also raised significantly [3]. Along with the advancement of information and communication technology, most vehicles are now equipped with In-Vehicle Information System (IVIS) to assist drivers by providing informations related to driving activity. Other than that, wireless technology and voice command also allow drivers to receive or make calls without any hand and/or eye movement so that they will not have to divert their eyes from the road. Broy [4] stated that since 30 years ago, transportation technology has grown exponentially and is predicted to keep growing for the next 20 years.

The rapid progress has made it natural to assume that road safety will, too, increase. However, that is not the case. Based on BPS data [5], in the term of 2009-2013, there was an increase in the number of traffic accidents for 12.29% per year in Indonesia. It leads to the presumption that there might be a correlation between the growth of technology and the rate of traffic accident. One thing which may link the two of them is driver distraction. The possibility of it has long been considered [1]. The vast amount of facilities which were firstly aimed to help drivers has raised the usage rate and in turn, lessen drivers' attention to the road instead. Stutts [6] stated that as long as wireless technology and IVIS keep growing, traffic accident rate due to distraction is predicted to increase, also. Furthermore, 78% of traffic accidents are caused by driver inattention [7]. The highest proportion of it happens because of driver distraction due to additional task other than driving [7].

Generally, operating IVIS requires visual attention to input or retrieve the needed information [1]. It is also required everytime a driver receives or makes calls by using cellular phone. Those tasks divert driver's gaze from the road to other object (eyes-off-the-road) which results in visual distraction. Among some methods thought to be effective in overcoming the issue are voice recognition and Text-to-Speech. Both enable a driver to keep his/her eyes on the road while operating the navigation or audio system, listening to emails, and receiving or making calls [8]. Nevertheless, the interaction mechanism does involve cognitive function which contributes to driver's work load [1]. The increased work load will further result in cognitive distraction and affect driver's behaviour [1].

Despite the fact that it does not generate eyes-off-the-road phenomenon, cognitive distraction such as receiving calls (hands-free) and communicating with other passenger will give rise to inattention (mind-off-the-road). This type of distraction is unlikely to affect vehicle control, but will decrease object detection due to attentional shift to certain thoughts in mind [9]. The result is selective information filtering based on the expectation of the thought instead of the real-life event (looked-but-did-not-see) [9]. That phenomenon prevents the retrieved visual information from being processed by the brain and in the end will compromise driver's safety [10]. For instance, when the driver is on the crossroads but unaware of other object getting close from another direction.

Research regarding cognitive distraction effect on driver's behaviour has been conducted by Burns [11]. He compared between the effect of cellular phone conversation and legal dose of alcohol consumption in England (80mg/100 ml). The results showed that drivers tended to drive slower than the instructed speed, reaction times decreased and were slower, and traffic signs were frequently missed than that of alcohol. Similar study [12] also concluded that the onset of cognitive distraction while driving (interacting with IVIS) lowered drivers' performance significantly, compared to legal consumption of alcohol in England. In addition, driver cognitive distraction is specified by a perturbation in brain wave which results in alpha synchronization in the frontal lobe [13][14]. However, those studies were not conducted to figure out methods to reduce or minimize distraction effect.

The appearance of alpha synchronization indicates an attentional shift to internal attention in the brain (top-down) and inhibition of sensory information [14]. The inhibition is presumed to raise at night due to melatonin secretion which reduces arousal [15]. Therefore, it is further presumed that melatonin effect suppression or, in other words, arousal increase, will possibly be a good method to minimize distraction effect.

One way to do that is by using blue light (wavelength: 447-480 nm). Earlier finding [16] have suggested that blue light exposure would generate the most sensitive response on circadian rhythm and neuroendocrine regulation. The research concluded that 460 nm was the most effective wavelength in suppressing melatonin production. Other research using EEG was done by Phipps-Nelson [17]. The results showed that blue light exposure reduces delta and theta power. Moreover, blue light exposure for 5 minutes also increased beta power in the cognitive area [18]. With the increased arousal caused by blue light exposure, distraction effect is presumed to be minimized, supposedly shown by the reduction of alpha synchronization.

This study was conducted by simulating driving activity at night to (1) evaluate the effect of cognitive distraction on alpha perturbation in night-time simulated driving task and to (2) further evaluate the effect of blue light exposure towards the cognitive-distraction-induced perturbation. The suppression of melatonin effect due to blue light exposure is expected to reduce the distraction effect, indicated by the reduction of alpha synchronization.

Methods

Participants

The research was conducted towards five male participants studying in Institut Teknologi Bandung. The criteria used in selecting the participants were as follows: able to drive manually; owns a certified driving license; not color-blind; normal-sighted or lens-corrected; has slept for at least 8 hours on the previous night before the test takes place; under no influence of caffeine, drugs, and alcohol; male; and 22 year-old.

Driving Simulation

Driving task was simulated by using driving simulator device Logitech G27 along with the pedal and gear set. The program used was Gran Turismo 5, operated within Sony PlayStation® 3 and shown in LG LED TV 40”. The track chosen was Clubman Stage Route 5 to simulate driving activity in city at night. The task was done continuously without any stop due to traffic lights.

Blue Light Stimulus

The blue light stimulus was generated by using two Philips goLITE BLU lamps (peak wavelength: 468nm). Each lamp were placed in each participant’s right and left sides forming an angle of 45^{o}. The placement of the lamps can be seen in Figure 1.

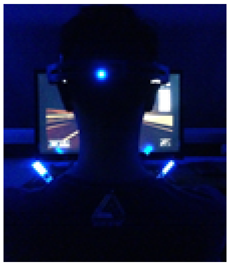


Figure 1. Blue light stimulus positioning

Cognitive Distraction Stimulus

Cognitive distraction onset was done in no lighting (dark) and blue light condition in the form of verbal questions using a recording. Before the task took place, each participan was instructed to answer the question verbally and continuously for 2 minutes. The answer was then recorded using a headset. The questions given referred to Rosenbaum Verbal Cognitive Test Battery [11] to represent the cognitive activity happening when a driver receives a call while driving. They referred question was “M5: *Animals beginning B*” which was then modified into “Mention all animals whose names begin with B” and ““Mention all animals whose names begin with K”. The order of those questions were alternated in each condition for each participant.

Electroencephalograph (EEG)

The EEG device used was EMOTIV EPOC EEG Neuroheadset which had 128 Hz sampling rate. Data from channels F3 (left) and F4 (right) were taken to observe brain activity in the frontal lobes. The electrodes were first poured by saline multipurpose solution to enhance the conductivity

Test Procedure

Data sampling was held in Laboratorium Instrumentasi Medik Program Studi Teknik Fisika, Institut Teknologi Bandung. It began with the preparation of the simulator set at 19.30 WIB and continued with EEG electrodes placement on the participant’s head. The trial (stimulus adaptation) was done at 20.00 WIB. Data sampling was done from 20.10 to 20.20 WIB. For each participant, the order of dark and blue light condition was alternated randomly to

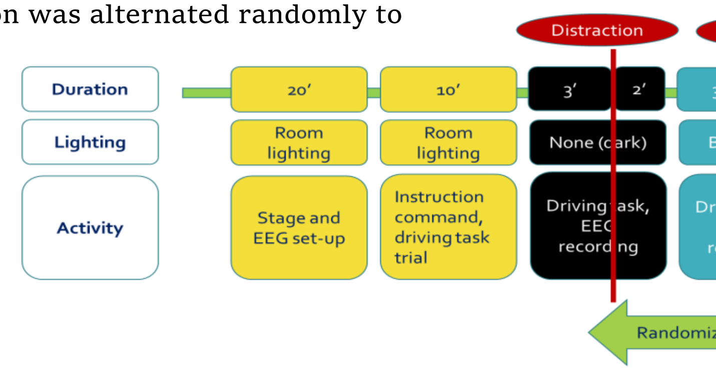


Figure 2. Data sampling procedure

prevent carry-over effect. Distraction onset was done on the third minute in every condition. The detailed scheme of data sampling procedure can be seen in Figure 2.

Data Processing

Raw data was processed using MATLAB, integrated with EEGLAB, to filter and generate alpha wave (frequency: 8-13 Hz). The data was then categorized based on two variables: lighting (dark and blue light) and distraction order (after and before distraction onset). Statistical analysis was conducted using Two-way Repeated Measures in SPSS to test whether there was any interaction between those variables. The test was then continued with Paired T-test to figure out detailed differences between variables.

Results and Discussion

The resulted data from each participant is 128 datas per second for 4 minutes in dark condition and 4 minutes in blue light condition. They contribute to a total of 307.200 datas from 5 participants.

In order to analyze the responses generally, data processing was done by averaging the datas from 5 participants per second. To evaluate the effect of cognitive distraction (variable: distraction order), analysis was done by comparing the power differences between after and before (baseline) distraction onset in dark condition and then quantified it in the form of perturbation percentage in dark condition. On the other hand, to evaluate the effect of blue light (variable: lighting) towards cognitive distraction effect (variable: distraction order), a former analysis was done by comparing power differences between after and before (baseline) distraction onset in blue light condition. The results were quantified in the form of perturbation percentage in blue light condition, then compared with the perturbation percentage in dark condition (baseline). Overall, statisticl analysis using Two-way Repeated Measures showed that there was a significant interaction (P<0,05) between the two variables. Therefore, a further test was held using Paired T-test to observe the detailed effect of each variable with the following order: (1) 'distraction order' variable in dark condition, (2) 'distraction order' variable in blue light condition', (3) 'lighting' variable before distraction onset, and (4) 'lighting' variable after distraction onset.

The Effect of Cognitive Distraction in Dark Condition

The mean alpha power in dark condition is shown in Figure 3. Before performing analysis towards 'distraction order' variable in dark condition, a former statistical analysis was done towards 'channel' variable to compare power differences between channels F3 and F4 by using Paired T-test. The results showed that in dark conditions: (1) before distraction onset, alpha power in F4 was significantly higher than F3 (P<0,05) and (2) after distraction onset, alpha power in F4 was still significantly higher than F3 (P<0,05). Those results suggested that in dark condition, cognitive distraction does not affect the lateralization of frontal lobe hemispheres. The dominant right hemisphere is presumed to be caused by spatial working memory usage while driving [19]. Due to the significant differences between F3 and F4, the next statistical analysis was conducted individually.

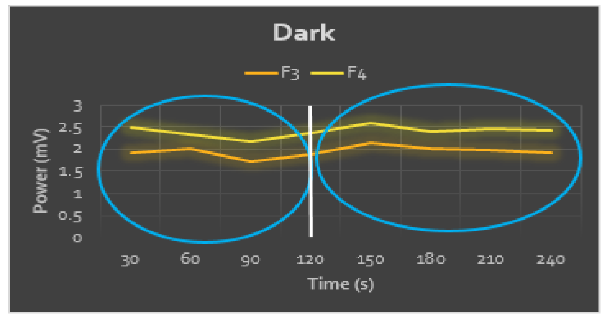
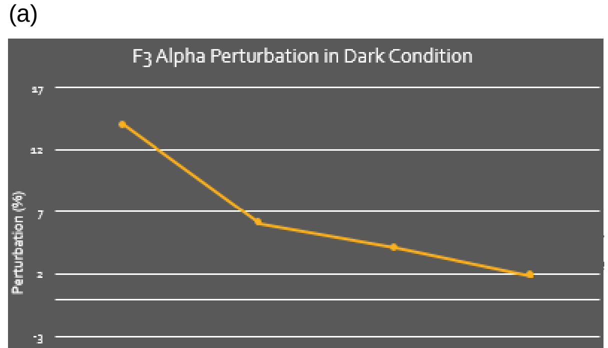


Figure 3 Alpha power in dark condition (white line marks distraction onset)

Paired T-test towards variable 'distraction order' in dark condition showed that: (1) in the channel F3, alpha power after distraction onset was significantly higher than before (P<0,05) and (2) similar with F3, in F4, alpha power after distraction onset was also significantly higher that before (P<0,05). Those results suggested that in dark condition, cognitive distraction onset generated perturbation in the form of alpha synchronization in frontal lobes. The resulting synchronization was quantified in percentage and is shown in Figure 4. It can be seen from the figure that in respect to the baseline, there is a significant synchronization in channels F3 (4 (a)) and F4 (4 (b)). Despite that, Paired T-test showed no significant differences between the synchronization in F3 and F4.

(a)



(b)

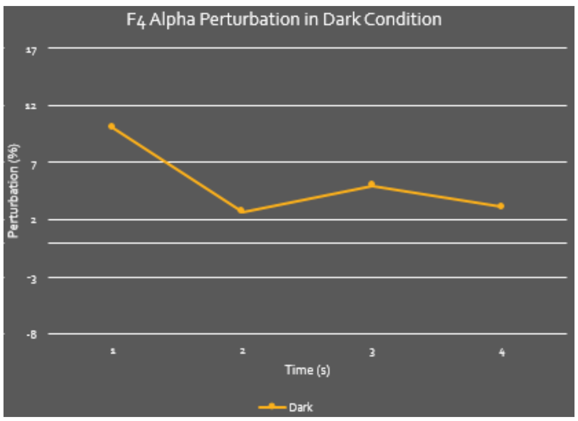


Figure 4 Alpha perturbation percentage in dark condition in F3 (a) and F4 (b)

In the frontal lobe area of selective attention processing (prefrontal cortex), attentional shift happens so that the attention will be focused on stimulus relevant to the main activity [20]. Prefrontal cortex is a part of our brain which functions in regulating stimulus filtering and goal-directed responses as an internal attention control, coordinating task order, and coordinating with superior parietal lobes in mapping the sensory information and motor responses needed when performing multi-tasking activity [21]. In this case, attentional shift happened by focusing driver's main attention to cognitive distraction stimulus. The consequences of the shift was the degrading response towards visual stimulus retrieved while driving. That result suggested that when drivers make conversation while driving, that conversation can become the main task, instead of driving. The selection of conversation as the main task can be caused by former instruction before the simulation which obligated the driver to answer the questions given. That phenomenon supported Stutts' [6] theory which stated that there is a factor of willingness which is likely to play a role everytime a distraction is given.

Attentional shift towards cognitive distraction is specified by alpha synchronization after distraction onset. The resulting alpha synchronization indicated that there is an attentional shift in cognitive area, that is, a change from bottom-up attention to top-down attention. Bottom-up attention focuses on external information processing and happens spontaneously without any voluntary control. On EEG, bottom-up attention is indicated by alpha desynchroniation [22]. This type of attention is used in the retrieval of sensory information. In this study, bottom-up attention happens when drivers retrieve visual information regarding the road situation while driving. On the other hand, top-down attention focuses on internal information processing to achieve certain goals and is done voluntarily [22]. The process usually happens due to the imagination of the stimulus instead of the visualization, thus requires working memory and long-term memory [22]. Klimesch [23] stated that internal attention conrol is indicated by alpha synchronization. The statement supports a similar one from Cooper *et al.* [24] which stated that alpha power tends to raise upon focused attention towards internal information processing and when work load increases.

The resulted top-down attention is presumed to be evoked by the question which required recall process of long-term memory. In top-down processing, sensory information is inhibited due to selective attention filtering in prefrontal cortex. It is supported by the increasing alpha activity in memory retention, which indicates top-down control towards the formerly saved information by inhibiting retrieval of irrelevant information [23]. Moreover, Klimesch [23] stated that top-down process kept attention focused on certain task by using inhibition to prevent interference from information processing system irrelevant to the main task.

Prefrontal cortex holds important role in inhibiting irrelevant information [23]. Afferent and efferent in prefrontal cortex filter segments of information considered to be important temporarily [14]. Alpha synchronization in the prefrontal cortex represents inhibition of stimulus irrelevant to the current attention focus or sensory information inhibition [14]. The inhibition caused attention to be focused to internal stimulus and is shown by synchronization of low-frequency wave (relative in fully awake condition) which suggested low temporal resolution (relative to beta). Furthermore, when responding to external stimulus, alpha power will reduce, compared to responding to internal stimulus [24]. The theory is supported by Klimesch [23] which stated that alpha power was higher when performing tasks with high internal demand (top-down attention control) compared to the task in which sensory information information processing happens automatically through bottom-up process. The resulted external stimulus inhibition is predicted to cause looked-but-did-not-see and mind-off-the-road phenomenon, leading to traffic crash.

At night, the absence of blue light which is a part of visual light spectrum makes it hard for Intrinsically Photosensitive Receptor Ganglion Cell (ipRGC) in the retina to produce action potential [25]. Therefore, melatonin secretion increases [25]. The increase of melatonin is presumed to give rise to external stimulus inhibition. It is due to the existence of melatonin receptor MT1 in suprachiasmatic nucleus (SCN). After binding with the receptor, K^+ conductance in SCN increases, thus inhibits the action potential in neurons (firing neuron) [26]. SCN has projections to paraventricular nuclei (PVT) in thalamus which is the centre of arousal and further to infralimbic cortex which is a part of prefrontal cortex [27]. Therefore, the ongoing sensory information inhibition in prefrontal cortex is presumed to raise due to inhibition in SCN. This is supported by Sonnleitner [14] which stated that interactions between thalamus and cerebral cortex held important role in attentional shift. In addition, Sonnleitner [14] also stated that alpha power recorded in cortex not only came from thalamo-cortical interaction, but was also regulated by interactions between thalamic relay cells and thalamic reticular nucleus. It suggested that regulation of attention through arousal projection from thalamus to cortex is essential in selective attention processing.

The Effect of Blue Light towards Cognitive Distraction

The mean alpha power in blue light condition is shown in Figure 5. Before performing analysis towards 'distraction order' variable in blue light condition, a former statistical analysis was done towards 'channel' variable to compare power differences between channels F3 and F4 by using Paired T-test. The results showed that in blue light condition: (1) before distraction onset, alpha power in F4 was significantly higher than F3 ($P<0{,}05$) and (2) after distraction onset, alpha power in F4 was still significantly higher than F3 ($P<0{,}05$). Those results suggested that in blue light condition, cognitive distraction does not affect the lateralization of frontal lobe hemispheres. Similar to the dark condition, the dominant right hemisphere is presumed to be caused by spatial working memory usage while driving [19]. Due to the significant differences between F3 and F4, the next statistical analysis was conducted individually.

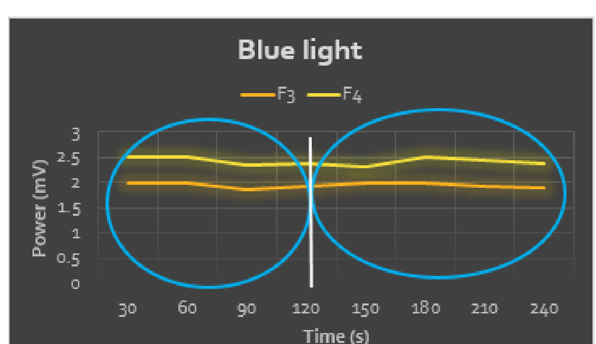
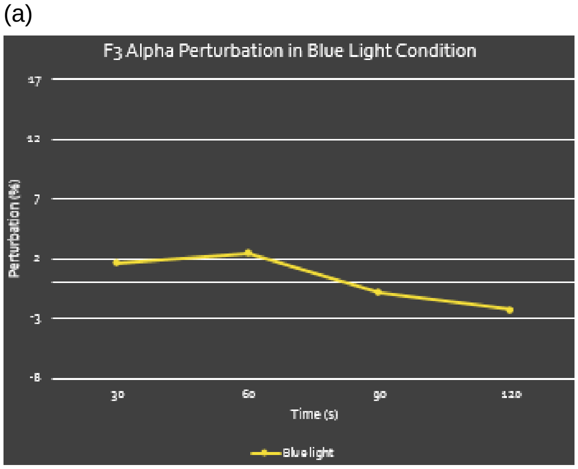


Figure 5 Alpha power in blue light condition (white line marks distraction onset)

Paired T-test towards variable 'distraction order' in blue light condition showed that: (1) in F3, there was no statistically significant differences between powers after and before distraction onset; and (2) similar with F3, in F4, there was also ni statistically significant differences between powers after and before distraction onset. Those results suggested that in blue light condition, cognitive distraction onset did not generate significant alpha perturbation. The perturbation was quantified in percentage and is shown in Figure 6. It can be seen from the figure that relative to the baseline, there are alpha desynchronizations in channels F3 (6 (a)) and F4 (6 (b)), nevertheless, are not significant. Furthermore, Paired T-test showed no significant differences between the perturbation in F3 and F4.

(a)



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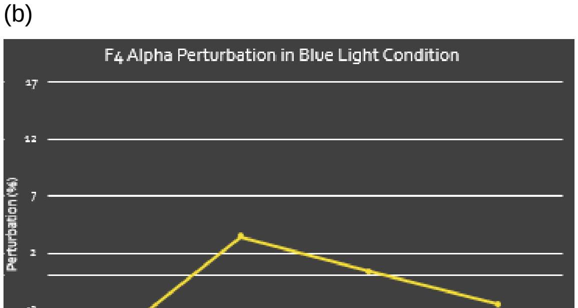
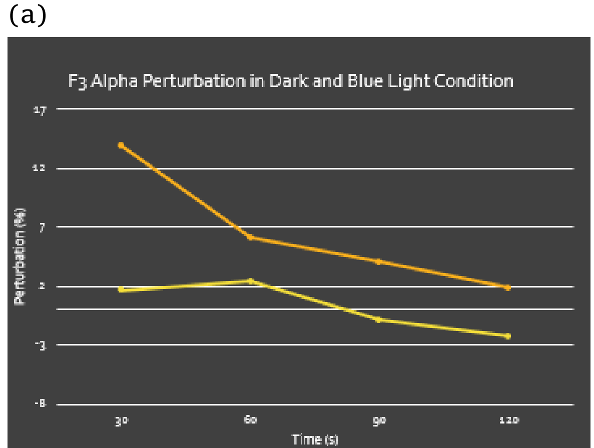


Figure 6 Alpha perturbation percentage in blue light condition in F3 (a) and F4 (b)

The next analysis using Paired T-test towards variable 'lighting' before distraction onset suggested that: (1) in F3, there was no statistically significant differences between powers in dark condition and blue light condition; and (2) in F4, there was also no statistically significant differences between powers in dark condition and blue light condition. The analysis towards variable 'lighting' after distraction onset also generated similar result as follows: (1) in F3, there was no statistically significant differences between powers in dark condition and blue light condition; and (2) as with F3, in F4, there was also no statistically significant differences between powers in dark condition and blue light condition. The findings suggested that blue light exposure did not directly affect alpha power neither after nor before distraction onset. However, Paired T-test towards perturbation percentage indicated that in both channels, F3 and F4, perturbation percentage in blue light condition was lower than dark condition and was statistically significant ($P<0,05$). Figure 7 shows the difference between perturbation percentages in dark condition and blue light condition in F3 (a) and F4 (b).

(a)



(b)

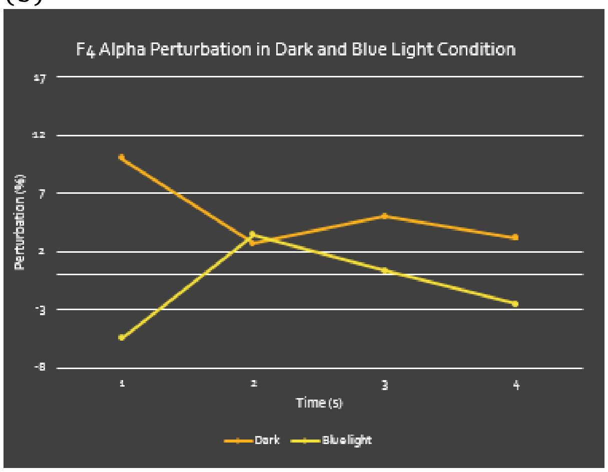


Figure 7 Alpha perturbation percentage in dark and blue light conditions in F3 (a) and F4 (b)

The decrease of alpha synchronization in blue light condition indicates a higher external stimulus processingin prefrontal cortex [23][24]. However, it is not known whether the increase of external stimulus processing will in return inhibit top-down processing. The faster alpha desynchronization in F4 is assumed to indicate faster response towards external stimulus due to its function in spatial working memory relevant to driving activity [19].

The aforementioned external stimulus processing is presumed to raise due to arousal projection from PVT, which is a further projection from SCN [27]. As it occurred, it is assumed that there was a decrease in firing neuron inhibition in SCN. Related to blue light exposure, the decreased inhibition may be caused by melatonin suppression or SCN modulation by ipRGC. Upon exposure to blue light, ipRGC depolarizes and generates action potential projected to SCN and further to pineal gland, thus suppressing melatonin secretion [25].

Along with the suppression of melatonin, the bindings between melatonin and MT1 receptor will in turn decrease, resulting in the reduction of K^+ conductance and prevention of the inhibition of firing neuron, which will finally contribute to the ongoing inhibition in prefrontal cortex [26][27]. Earlier study by Brainard *et al.* [16] showed that blue light exposure for 90 minutes could reduce maltnin production. Despite that, since melatonin level was not measured, it cannot be concluded that melatonin suppression has occurred by 4 minutes of exposure.

In regards to that, it is assumed that the decrease in external stimulus inhibition occurred due to SCN modulation by ipRGC. After being depolarized, ipRGC projection to SCN causes the inhibition of firing neuron in the SCN, reduces the inhibition in PVT which raises arousal and lastly reduces visual information inhibition in ILC in prefrontal cortex [26][27]. The effect of blue light on driver arousal has been studied before [18]. The results showed that there was an increase in driver arousal by 5 minutes of exposure, which was indicated by beta power raise. With the increase of arousal which further reduces visual information inhibition in selective attention processing, the occurrence of looked-but-did-not-see and mind-off-the-road phenomenon may decrease, thus the number of traffic crashes is expected to lower.

Conclusions

Based on the findings, it can be concluded that (1) in dark condition, cognitive distraction onset resulted in significant alpha synchronization (P<0,05) in F3 and F4; (2) upon exposure to blue light, the onset did not result in significant alpha perturbation; and (3) blue light exposure reduces cognitive distraction effect, indicated by significantly lower alpha synchronization percentage ($P<0,05$) in blue light condition, in F3 and F4.

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