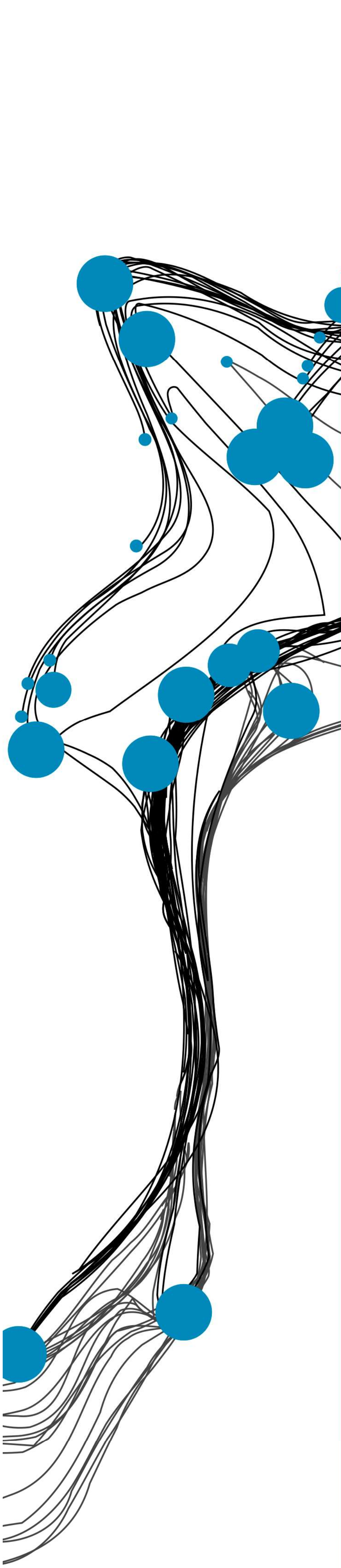

MASTER THESIS

THE VIGILANT BRAIN

ROLES OF EARLY ERP COMPONENTS ON VIGILANCE STATE MONITORING

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The Vigilant Brain: roles of early ERP components on vigilance state monitoring

Master Thesis

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Date: August 2018

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Abstract

The role of C1 and P1 component as the early event-related potential (ERP) that emerges from the striate cortex at 60ms to 150ms after stimulus onset has not widely studied for vigilance state monitoring. In this study, we developed a new radar-like display that consists of a white and red moving triangle that appears in the upper and lower visual display as a target and non-target stimulus. The task performance was measured with signal detection theory (SDT) and reaction time, the electroencephalography (EEG) data that was recorded during the task was analyzed with Event-Related Lateralization's (ERLs). Statistical results showed that the vigilance decrement occurred as the effect of the block in d-prime, beta and reaction time. However, the modulation of ERLs activity in three different time windows (60-90ms, 90-120ms, and 120-150) were not affected by the block. There was no significant effect of the stimuli position, and there was no interaction effect between the block and the stimuli. Therefore, further studies with improved methods and optimized stimuli are required before C1 and P1 component can be used for real-time vigilance state monitoring.

Keywords: vigilance, electroencephalography, event-related potentials, lateralization, signal detection theory

1. Introduction

Development of autonomous system allowed shifted role of the human operator from an active manual task function to systems supervisory role where the operator only need to take corrective actions when problems occur (Sheridan, 2012). Operational problems arise in intermediate automation levels where humans are expected to monitor the automated system (Casner, Hutchins, & Norman, 2016). Assessment of operator readiness is critical for safe operations to avoid loss of control during a transition phase from automation to manual control (Cabrall, Happee, & de Winter, 2016). The research on vigilance has increased with the widespread implementation of automation in human-machine systems (Parasuraman & Riley, 1997). Previous studies revealed that several incidents occurred as a result of the vigilance failures of human operators in semiautomated systems (Molloy & Parasuraman, 1996).

Vigilance can be described as sustaining an individual's attention while performing a cognitively non-challenging task for an extended period of time (Langner & Eickhoff, 2013; Martel, Dähne, & Blankertz, 2014). Laboratory research that was carried out after the military suspected that during the World War II era, the radar operators tended to miss important signals near the end of their shift. The study revealed that individual performance gradually declined over time in the task (Mackworth, 1948). Since then, the vigilance research usually focused on detection of a performance decline over time, a result that is known as the vigilance decrement (Warm, Parasuraman, & Matthews, 2008). A performance decrease characterizes the vigilance decrement over time and an increment of response time for detection (Parasuraman, Warm, & See, 2000). The increment of reaction time with very long fore-period has been attributed to a difficulty in maintaining the vigilance state beyond the optimal fore-period (Awh et al., 2000).

A critical aspect in studying vigilance decrement was the vigilance task. There are numbers of different tasks have been designed by the previous researcher to investigate the vigilance decrement, for example, Mackworth Clock test, Psychomotor Vigilance Task (PVT), Continuous Performance Task (CPT), AX-CPT, Conners' CPT, Sustained attention to response task (SART) (Langner & Eickhoff, 2013). However, the most commonly used task type in vigilance research was the go/no-go task (Warm et al., 2008). The go/no-go task was usually very simple to minimize the cognitive load of the participant during the experiment (Langner & Eickhoff, 2013). In the go/no-go task, the target stimuli infrequently occur in order to resemble the real-world condition; participants withhold the response to non-target stimuli while sustains attention throughout the experiment (Eichele, Juvodden, Ullsperger, & Eichele, 2010; Mackworth, 1948; Martel et al., 2014).

A rare stimuli occurrence may cause an expectancy bias problem. Expectancy bias resulting in the observer tends not to give a response since the expectancy of the target stimuli occurrence was very low (Craig, 1987). In order to minimize the bias, the performances of the observer can be rated using the signal detection theory (SDT) approach during the experiment. SDT rate the observer performance in the condition where the observers as decision maker are trying to optimize performance when facing random variability (Craig, 1987; see Macmillan & Creelman, 2004; Swets, 1977). SDT viewed that the absence of the response during the task not only based on the perceptual factors but could also be upon decision factors that involved in the detection goals, expectations about the stimuli, and the potential consequence about the correctness of the responses (Parasuraman et al., 2000). SDT research on vigilance indicates that the vigilance decrement accompanied by a decreased portion of false detections as a result of either change in the observer's decision criterion beta (β) and loss of sensitivity to signals d-prime (d') (Liu & Uang, 2018; Parasuraman et al., 2000; Swets, 1977).

Next to objective behavioral measure of task performance, vigilance research usually also uses individual subjective measures (Eichele et al., 2010; Martel et al., 2014). Subjective measures such as the sleepiness indicators were correlated with the performance on the vigilance task (Kaida, Åkerstedt, Kecklund, Nilsson, & Axelsson, 2007). Back in 1972, Hoddes, Dement, and Zarcone developed Stanford Sleepiness Scale which can be used to evaluate sleepiness at a specific moment in the time such as during a vigilance task (Shahid, Wilkinson, Marcu, & Shapiro, 2011). Participants are asked to rate their sleepiness with a Likert scale rating from 1 to 7. Combining self-report scale with behavior performance implies a complete data-set that includes both objective and subjective aspects of performance.

On the other hand, despite the importance of task types and measures in vigilance research's, researchers introduced various approach in term of the vigilance study. Notable methods aside from task type were; investigating perceived mental workload, neural measures of resource demand in vigilance, and task-induced stress (Warm et al., 2008). From all mentioned methods, only the neural measures approach benefits from its direct measurement that unveil how the vigilance process occurs and what factor is related to the cognitive process that happens in the brain when a person perceives a stimulus (Eichele et al., 2010; Martel et al., 2014). Researchers need to acquire the brain signal in order to be able to conduct a neural measure. The brain signal acquisition method distinguished into invasive, semi-invasive and non-invasive, with the electroencephalography (EEG) as most pronounce method for non-invasive (Elsayed, Zaghloul, & Bayoumi, 2017). According to Berka et al. (2007), EEG result is the only physiological signal that accurately reflects changes in alertness, attention, and workload that can be identified and quantified on a millisecond basis. EEG is a reliable tool that allows direct measurement of brain activity in almost instantaneously with the signal consists of multidimensional information such as; time, space, frequency, power, and phase (see Cohen, 2014).

The earlier neural measure on the vigilance research revealed that theta waves dropped significantly before the error occurred but stable during the usual responses, and alpha waves in that time window could not be used to identify errors (Daniel, 1967). By contrast, the research from O'Hanlon & Beatty (1977) suggested that there was a consistent relationship between arousal and vigilance with the percentages of theta, alpha, and beta waves in the EEG recording. In general vigilance research indicates that the EEG amplitude shifted from higher to lower frequencies over the course of vigilance tasks (Parasuraman et al., 2000). Nowadays, the application of the Fast Fourier Transform (FFT) technique suggests that alpha activity plays a significant role in the vigilance attention. As reported by O'Connell et al. (2009) there was a positive modulation of the alpha activity starting 20s before the lapse of attention. Martel et al. (2014) found supporting evidence that the alpha-activity observed emerging and gradually accumulating 10s before a missed target. Based on the previously mentioned findings can be concluded that EEG measurements can be used to measure the vigilance state.

In term of the EEG signal processing method, one of the most commonly used methods is computing event-related potentials (ERP). ERP is calculated by summing all the voltage at each time point over trials then divided the results by the number of trials (see Cohen, 2014). As a result of the technique, the ERP waveform appears on the scalp as a series of positive and negative deflections that vary in polarity, amplitude, and duration over time (Kappenman & Luck, 2012). Several advantages of the ERP are fast and straightforward to compute, require few analysis assumptions or parameters, high temporal precision and accuracy, extensive and decades-long literature of ERP finding, and provide a quick and useful data quality of single-subject data (Cohen, 2014; Luck, Woodman, & Vogel, 2000; Woodman, 2010). As ERP has been used in the various line of cognitive research, ERP also has been used to study the vigilance. ERPs enable researchers to examine whether the vigilance decrement was related to amplitude decreased of evoked brain activity or only specific ERP components changes associated with vigilance (Parasuraman et al., 2000).

Regarding the use of visual stimuli in vigilance research, early studies demonstrated that visual evoked potential elicited different ERP components (Luck et al., 2000). The ERP component that occurred as a result of visual stimuli were C1 components which flip polarity based on the upper or lower position of the stimulus, P1/N1 component that followed as information propagates through visual system and perceptual analysis performed, then the component associated with categorization of the visual stimulus N2/P3 components (see Woodman, 2010). C1 component typically onset latency between 40ms to 70ms then peaked between 60ms to 100ms, P1 component onset latency 65ms to 80ms then peaked around 100ms (Mangun, 1995).

From all the visual evoked component, P3 component that usually peaks around 250-300ms were relatively the most quickly to be observed with a limited amount of trials since it is relatively slow and has a large amplitude (Woodman, 2010). Several ERP study has highlighted the importance of P3 on vigilance attention. Wickens et al. (1983) found that P3 component can be related to resource allocation of attention. O'Connell et al. (2009) suggest that P3 changed four to five seconds before a lapse of attention. Eichele et al. (2010) stated stimulus-locked peaks in the N2, and P3 latency range indicated that expected compatibility and error-related modulations, and Martel et al. (2014) concluded that P3 component significantly gradually attenuated starting 5s before the misses.

Unlike the popularity of P3 component in the vigilance research, currently, no research examines how the vigilance state is affected by the modulation of the early ERP components such as C1 and P1. Even though C1 component known to reflects the initial response of the primary visual cortex to a stimulus (Di Russo, Martínez, Sereno, Pitzalis, & Hillyard, 2002; Mangun, 1995). Kelly et al. (2008) found that attention can enhance the amplitude of the initial visual evoked response in the primary visual cortex (V1) starting at around 50–60ms after stimulus onset. Other than that, the amplitudes of the early ERP components such as C1, P1, or N1 components were known to be related with sensory and perceptual processing that sensitive to stimuli different (Woodman, 2010). Rauss et al. (2009), stated that C1 could be modulated by the attentional load which means initial inputs associated with C1 were sensitive to attentional influences. Similar to C1 component, P1 component was also known as an early measure of visual stimuli related to index spatial processing (Mangun, 1995). P1 and N1 were known to be more sensitive to differentiation of visual stimuli, depending on the stimuli position, and whether the stimuli was attended or un-attended (Mangun, 1995; Woodman, 2010). P1 component amplitude was also sensitive to spatial information provided by the peripheral cues (van der Lubbe & Woestenburg, 1997). P1 amplitude was larger for stimuli presented at relevant locations compared to irrelevant locations (Boksem, Meijman, & Lorist, 2005).

Previous studies discovered that C1 and P1 component were sensitive to stimuli different. The polarity and scalp distribution of C1 is dependent on where the stimulus presented, P1 amplitude maximum is over the lateral occipital scalp, approximately right over the ventrolateral prestriate cortex, contralateral to the visual field where the stimuli presented (Mangun, Hillyard, & Luck, 1993). C1 component is positive if the stimulus is presented in the lower hemifield and reverses its polarity over certain parts of the scalp when the stimulus is presented in the upper hemifield (Butler et al., 1987). C1 for lower quadrants was maximally positive over mid-line parieto-occipital scalp regions, slightly contralateral to the visual field of the stimulus (Di Russo, Martínez, Hillyard, & Martinez, 2003). Mangun (1995) indicated that the left visual field stimuli produce right occipital maximum, and right field stimuli produce left occipital maximum. Several mentioned findings provide adequate evidence that the modulation of C1 and P1 component as the earliest visual evoked potential can be changed as a result of attention.

In this research, a visual stimulus was developed to elicit a different ERP component based on the stimuli position. Unlike the previous study from Eichele et al. (2010) and Martel et al. (2014) that used static stimuli, in this research a moving stimulus was being used. The movement effect expected to mimic a real-world situation where the stimulus usually dynamic rather than static. The stimuli were designed to evoke a different contralateral activity on the striate cortex by presenting the stimuli on eight different positions on the visual field similar to the previous study from Butler (1987), Mangun (1995), and (Di Russo et al., 2003). Based on Luck et al. (2000), when processing visual attention a different brain hemisphere would be activated depending on the stimuli position when attention shifted from the left visual field to the right visual field, the ERP component shifted from right hemisphere to left hemisphere. Therefore, the potential difference between the hemisphere will be used to measure the vigilance state.

A method that commonly used to investigate how different part of hemisphere behave to specific stimuli on one side of the visual field is by applying double extraction technique known as event-related literalization's (ERLs) (Van der Lubbe & Utzerath, 2013; Wascher & Wauschkuhn, 1996). Visual ERLs are computed as the difference in activity over the hemispheres contralateral and ipsilateral to laterally presented stimuli (Wiegand et al., 2018). Research that examined ERLs over posterior-occipital sites suggested that this ERLs related to visual selection (Luck et al., 2000). The ERLs activity reflects the brain's contralateral activity will be fluctuated based on whether the stimulus was attended or not.

The present research goal was to investigate how ERLs modulation of the early ERP component related to vigilance state. The vigilance state derived from the behavior performance measures which was calculated with signal detection theory and reaction time. A subjective measure was also compared to the behavior performance measures. We proposed that the stimuli and experiment block triggered the vigilance decrement effect on behavior performance as well as triggered the modulation of ERLs activity of C1 and P1 component. We expect that the modulation of the early ERP component correlated with the vigilance decrement that occurred as a result of time on task. However, since the nature of this study was fundamental research, the result served as a step to determine the most appropriate EEG measure on vigilance state monitoring. The research outcome if all hypotheses confirmed were the early ERP component could be used for further research of developing a real-time vigilance state monitoring. Further study will be required before the result can be implemented to applied research on real-time vigilance state monitoring in a real-world situation.

2. Method

a. Participants

Seventeen participants took part on a voluntary basis from SONA test subject pool system and *Persatuan Pelajar Indonesia Enschede* (Enschede Indonesian Student Association) for the experiment. All participants were students at the University of Twente or Saxion University. The group consists of 11 males and six females, age range from 19 to 33 (M = 23.39, SD = ± 4.09), all participants were right-handed. However, the problem with amplifier battery caused six participants' data were removed due to incomplete experiment block. Eleven participants' data remains in the final dataset, age ranges of the participants from 19 to 30 years old (M = 23.61, SD = ± 3.59), consists of eight males and three females. All participant completed Freiburg visual Acuity test (Bach, 2007) to validate their self-report about normal or corrected-to-normal vision. Online Ishihara color identification test (Colblindor, 2018) performed to validate that no participant has color blindness. No participant reported having neurological or psychiatric disorders, and none of them consumed alcohol or drugs 12 hours before the study. The ethical board of the University of Twente has reviewed and approved the study before the start of the experiment. All participant informed about the experimental procedure and signed an informed consent form before the experiment.

b. Apparatus

Presentation software (Neurobehavioral System, 2018) was installed on a computer with Intel core i5 7th Gen and 8Gb RAM. Stimuli presented on AOC monitor with a resolution of 1024 x 890 pixels and 140 Hz screen refresh rate. Behavioral responses and EEG data were recorded using BrainVision Recorder software (Brain Products, 2018). EEG signal was acquired using 49 channels electrodes attached on ActiCap with 10-20 system, reference electrode placed on AFz channel, horizontal EOG attached on the face near right and left eye, vertical EOG channel connected on vertically aligned position with left eye pupil above and under the eye. Ground electrodes channel placed on the forehead and attached to the ground aux port. The signal was amplified using BrainProduct Amplifier powered by BrainPower amplifier battery.

c. Design

The study was focused on the behavior performance monitoring and measurement of EEG activity on prolonged sustained attention vigilance task to find the occurrence of the vigilance decrement effect and the stimuli related ERLs activities modulation of the early ERP component. Therefore, the experiment was designed with a long duration with continuous behavior performance and EEG measurement. The experiment consisted of five blocks with ten minutes duration per experiment block. Each experiment block consisted of 44 target stimuli and 384 non-target stimuli 192 non-events. The stimuli were divided equally to appear in the upper and lower position of the horizontal axis of the visual display. The stimuli order of target/non-target and position appearance were randomized, and no group intervention was given to the participant.

d. Stimuli

The visual display used for the experiment was a circular radar-like display with eight different segments. The stimuli consisted of a white moving triangle (RGB: 255, 255, 255) as non-target stimuli and a red moving triangle (RGB: 255, 0, 0) as target stimuli, during non-event only radar screen with no moving object were presented.

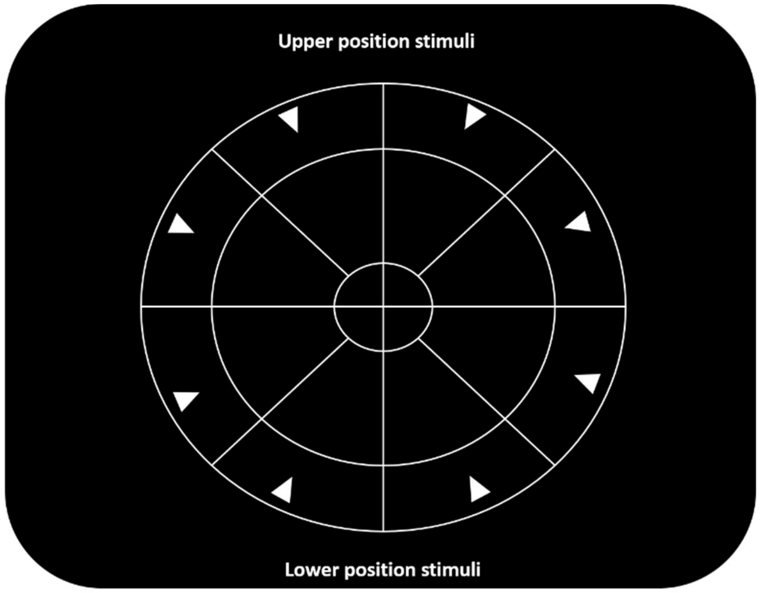

Figure 1. The white triangle represents eight different starting position of the target and non-target stimuli. The stimuli were moving from starting position to the center of the radar-like display with 500ms duration. The stimuli order and position were randomized. The experiment consisted of 5 blocks with an equal number of 24 targets and 192 non-targets for upper and lower position stimuli.

The non-target and target stimuli appeared randomly from eight different starting positions with 481pt distance from the center of the display (Figure 1). The stimuli moved diagonally (22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5° and 337.5° from horizontal axis) starting from the outer periphery to the center of the visual display with 500ms duration. Stimuli were grouped as upper stimuli position and lower stimuli position based on the position compared to the axis line; both groups consisted of four target stimuli and four non-target stimuli

e. Measures

Measures in this study consisted of EEG measure, a subjective measure, and behavior performance measure. EEG measure was recorded from 49 Ag/AgCl ring electrodes located at AF3, AF4, AF7, AF8, Fz, F3, F4, F5, F6, FCz, FC3, FC4, FC5, FC6, Cz, C1, C2, C3, C4, C5, C6, T7, T8, CPz, CP1, CP2, CP3, CP4, CP5, CP6, Pz, P1, P2, P3, P4, P5, P6, P7, P8, PO, PO3, PO4, PO7, PO8, PO9, PO10, O1, O2, and Oz. EEG data were processed offline after the recording to derived the ERP of the non-target stimuli.

The subjective measure used in this study was a paper and pencil method of Stanford Sleepiness Scale (SSS) that need to be filled in by the participant before the experiment started, after the trial block and immediately after completing each of experiment blocks. The behavioral measure was derived from the speed of response to the target stimuli (reaction time in milliseconds) and correct/incorrect detection and discrimination of both target and non-target stimuli. The responses to target stimuli were labeled as a ‘hit’ when the button pressed was occurred within 500ms after stimuli onset and labeled as a ‘miss’ when no button was pressed or when it was pressed more than 500ms after stimuli onset. Reaction time as a measure of behavioral performance was calculated based on the average reaction time of the hit responses. No button responses to the non-target stimuli were labeled as ‘correct rejection,’ a button response to non-target stimuli was labeled as ‘false alarm.’ Based on the number of classifications, the proportion correct rejections of the non-target stimuli (correct rejection rate), the proportion of hits (hit-rate) for all target-stimuli, and the basis of bias measure (criterion) were calculated for each block. Following that d-prime and beta were calculated as a measure of performance (Macmillan & Creelman, 2004). The sensitivity of this measure reflects the ability to discriminate between signal and noise, with a higher sensitivity leading to more hits and correct rejections and less false alarms and misses.

f. Task and procedure

The experiment was conducted during daytime in the closed laboratory room with darkened illumination. Participants were seated on the chair in front of the display monitor at a viewing distance of approximately 85 cm, the center of the display was set on the participant’s eye level.

Participants instructed to fixated their eye to the center of the display at all time during the experiment while attending appearing and moving stimuli from the outer ring of the visual field to the center of the display with duration 500ms (Figure 2). At the beginning of the experiment, the participant pressed the button to begin the practice block. The instruction that appeared on the screen before the practice block started was; “Fixated to the center of the display at all time, attend to the moving triangle, press spacebar as quickly as possible if red colored triangle appears.” Participants were asked whether they fully understand the or further explanation was required after the instruction was presented on the screen.

Participant started the practice block immediately after they clearly understood the instruction. Performance feedback was given during the practice block to ensure that the participant performed the task as required by the procedure. After completing the practice block, the participant begins the experiment.

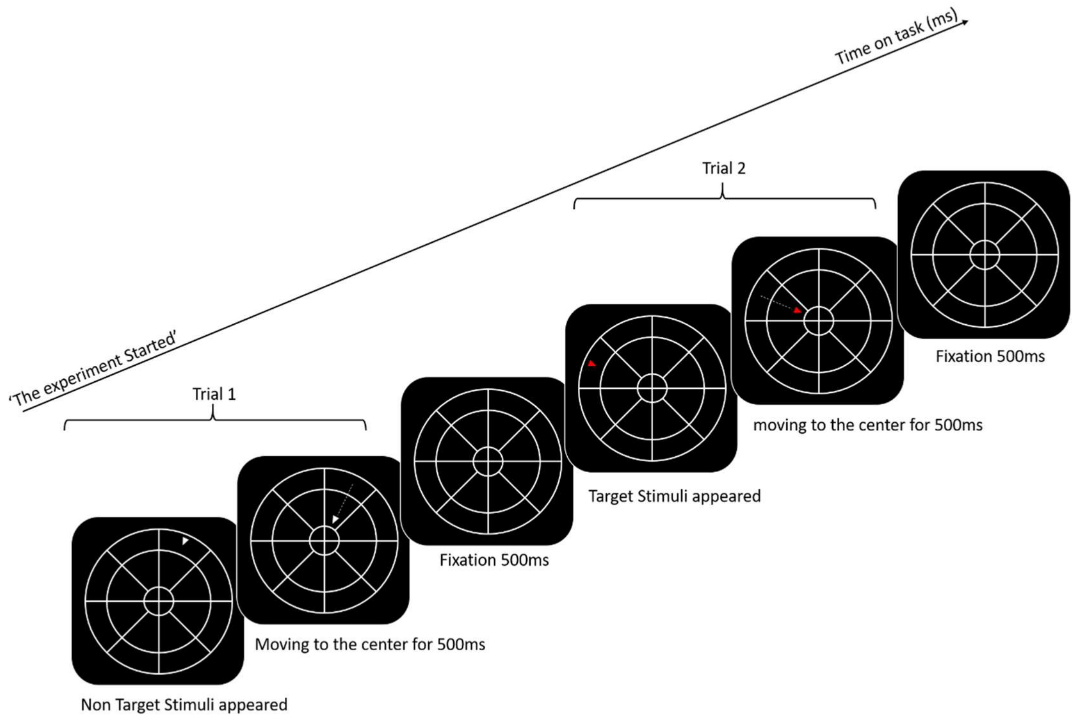

Figure 2. Participants press the button to start the experiment. Target and non-target stimuli appeared in randomized order. Participant had to press the space bar as quickly as possible when a target stimulus appears. Stimuli moved from the outer periphery to the center of the visual display with duration 500ms.

During the experiment, the participant had to press the spacebar button as quickly as possible when the target stimuli appeared. Stimuli were presented with the interval of 500ms between stimuli. A static radar display with no moving object was presented in this interval. After each block of the experiment, the participant had to fill in the sleepiness scale and was given a maximum of two minutes break, after the break a new block immediately started.

g. EEG analyses

EEG raw data were analyzed with Brain vision analyzer version 2.1 (Brain Products GmbH, 2014). A low cut-off filter of 0.16 Hz was applied followed by a high cut-off filter of 20 Hz to remove a muscular movement and artifacts. Level trigger with threshold negative -60 and positive 60 from hEOG channel was applied to identified eye movement. Raw EEG data segmented per non-target stimuli for overall experiment block and per blocks segment. Following that baseline correction was set from -100 to 0 ms. Artifact rejection was set to automatic with gradient criteria of allowed voltage steps 100 µV/ms, minimum and maximum allowed amplitude of +/- 150 µV and a low activity criterion of 0.5 µV with an interval length of 100 ms. The ocular correction independent component analysis (ICA) was selected with a semi-automatic mode for horizontal and vertical eye movements correction with 30% parameter. The baseline was adjusted from -100 to 0 ms, then the data was segmented per non-target stimuli and processed with a grand average per non-target stimuli to generate the ERP.

Raw data were segmented into upper left/right and lower left/right based on non-target markers with the setting -500 before and 500ms after stimuli onset. The grand average of ERP non-target stimuli of all participants was created. Following that, lateralization of upper and lower position stimuli was calculated with the following formula:

$$ERLs = \frac{(Ipsilateral - Contralateral) - (Contralateral - Ipsilateral)}{2}$$

The ERLs grand average of all participant left upper and left lower stimuli position were created. The mirroring channels activities value were calculated by timing the activity value of the left side ERLs with -1. Following that, a topographic map of both channels was created to visualize the ERLs activity for upper stimuli position and lower stimuli position. The topographic maps were divided into three different time-window (60-90ms, 90-120ms and 120-150ms) and presented as back, left and right of the head view.

Following that, the ERLs activity of P1-P2, P3-P4, P5-P6, P7-P8, PO7-PO8, and PO9-PO10 in the three different time-windows (60-90ms, 90-120ms and 120-150ms) was extracted. Data were examined to find out which electrodes pairs were the most active with the highest lateralized activity (highest deviation from zero) in this three different time-windows. The electrode pairs with highest lateralized activity were selected, and the data were extracted for further statistical analyses.

h. Statistical analyses

Dataset consists of eleven participants' data on five experiment blocks, two stimuli position (upper and lower), continuous dependent variable of all behavior performance measure (d-prime, beta, and reaction time), Stanford Sleepiness Scale, and continuous dependent variable of ERLs activities from three different time-windows (60-90ms, 90-120ms, and 120-150ms). Data were examined with a descriptive statistic to get a better understanding of the data structure.

The average score of Stanford sleepiness scale as a subjective measure was compared to the average result of all behavior performance measurement for upper and lower stimuli to examine whether the subjective rating was correlated with the behavior performance. Spearman correlation was chosen for this analyses since this method was robust in dealing with not normally distributed data. Further statistical analyses were performed to examines whether the vigilance decrement effect occurred as reflected by performance decreased and increment of reaction time over time on task. ERLs activity in the three different time windows was compared to examine the modulation as the effect of blocks. The final goal of the data analyses was to examines whether the ERLs modulation was related to behavioral performance.

All ERLs activities and behavior measure were continuous dependent variables, blocks and stimuli were the within-subject factors. Therefore, A two-way repeated measures ANOVA for three different time windows of ERLs activity (60-90ms, 90-120ms and 120-150ms) and all behavior measure (d-prime, beta, and reaction time) were performed with blocks and stimuli position as a within-subject factor. All values of behavior performance measures and ERLs activity measures were set as dependents variable, five experiment blocks and two stimuli position were set as a within-subject factor. Mauchly's test of sphericity was used in all ANOVAs analyses to validate the equal variance of the difference between levels to avoid interpretation bias. Greenhouse-Geisser corrected value was used for result interpretation of all significant result of Mauchly’s test of sphericity. Data outlier were not checked since the outlier will not be removed. Data normality were also not checked since a two way repeated measure were robust to abnormality.

Additional statistical analysis with R (R Core Team, 2018) was performed. All the dependents variables were plotted with the GGplot2 package from CRAN library (Wickham et al., 2018) to see the correlation between variables. Following that, all the dependent variable were plotted to see how the stimuli and block effects on the variables. Because the experiment effect began as the experiment started, the intercept was set in the first block of the experiment. An analysis with the multilevel linear model was performed using Brms package from CRAN library (Bürkner, 2018). A multi-level model was built with d-prime, beta, reaction time and ERLs activity in three different time windows as a dependent variable. The five experiment blocks and two stimuli position were used as a covariate predictors variable. All dependent variable was connected to predictors in one multi-response model. However, the interpretation of the results carried out separately per variable. The model contains population level and participant level effect. Since the intercept for the model was a low number of repetitions hence slope random effects were unable to be created. The result was presented as fixed effect table with lower and upper confident interval 95%.

3. Results

a. *EEG ERL*

ERLs activities of the upper and lower position stimuli from all electrode channels on the visual cortex were extracted from the grand average of ERLs activity. The value that set as an absolute number deviation from zero in three different time-window can be seen in Figure 4. The histogram chart indicates that the highest lateralization for the upper position stimuli for 60-90ms and 90-120ms time windows were on P7-P8 channel, meanwhile, for the time window 120-150ms highest lateralization was on P5-P6 channel (Figure 4a). Nevertheless, P7-P8 channel was selected for consistency of the analysis. On the other hand, PO7-PO8 selected for lower position stimuli as this channel consistently shown the highest activity across three different time windows (Figure 4b).

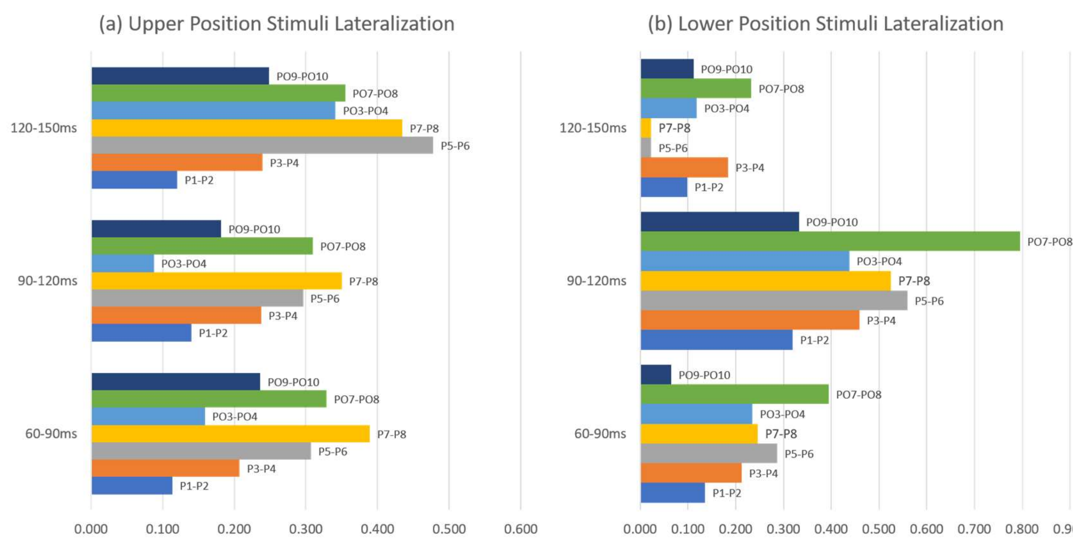

Figure 4. ERLs activities chart of all electrodes pair on the visual cortex. The value was presented as an absolute deviation from zero. The higher the value, the more active the channel. P7-P8 and PO7-PO8 were selected for upper stimuli position and lower stimuli position respectively.

ERLs activity of P7-P8 channel for upper position stimuli and PO7-PO8 for lower position stimuli peaked around 90-110ms after stimuli onset (Figure 5). The upper position stimuli reach its positive peak earlier compared to the lower position stimuli, after its peak, both activities were modulated to the negative direction. The peak amplitude of lower position stimuli was higher positive compared to upper position stimuli in 90-110ms time-window.

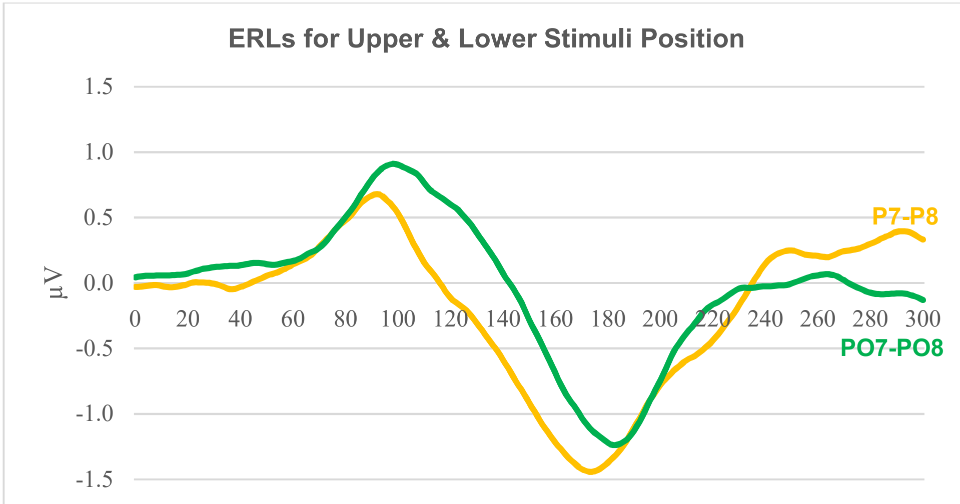

Figure 5. ERLs activity of P7-P8 channel for upper stimuli position and PO7-PO8 for lower stimuli position after stimulus onset until 300ms. Both ERLs were peaked at around 90-110ms after stimuli onset, PO7-PO8 have higher positive amplitude compared to P7-P8 channel.

The topographic map of both channel pairs in the three different time windows (60-90ms, 90-120ms and 120-150ms) was created and displayed in Figure 6. The topographic map of upper stimuli position (Figure 6a) and lower stimuli position (Figure 6b) divided into three time-window and presented as a back, left and right of the head view. The display was set with the discrete color mode, and manual scaling with minimum -0.70 to maximum 0.70 μV, the red color represents a positive ERLs, and the blue color represents a negative ERLs, the denser the color, the higher the activities.

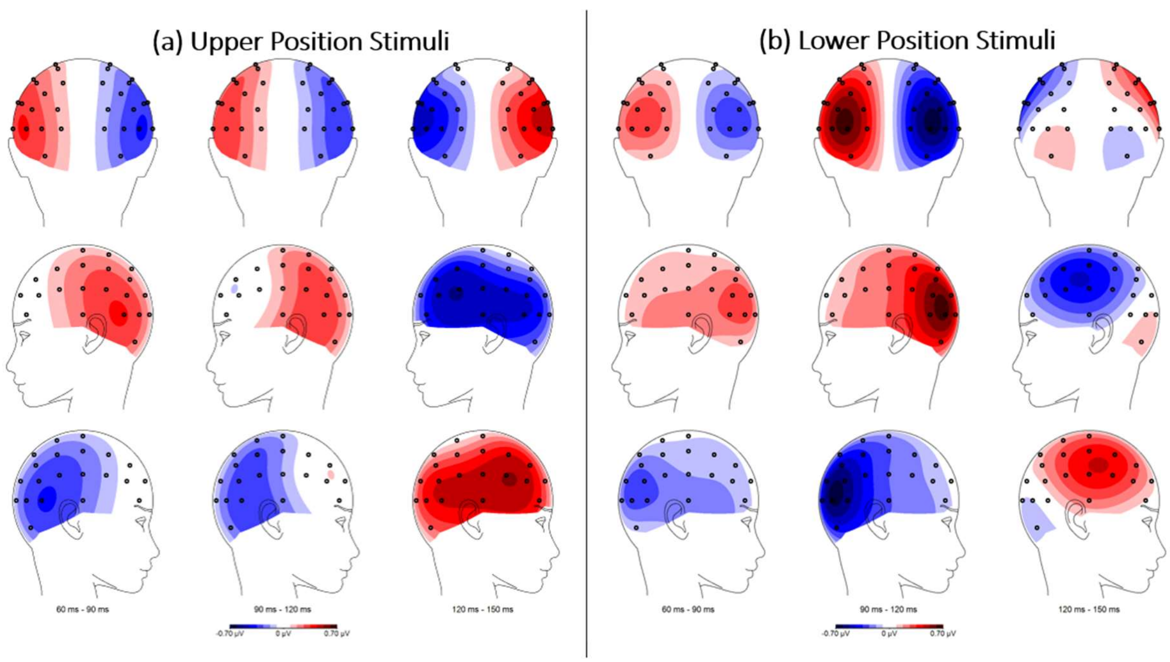

Figure 4. Topographic map of ERLs activities for upper and lower position stimuli projected to the left hemisphere reflects the contra-ipsilateral power difference; the right hemisphere reflects the ipsi-contralateral difference.

Based on visual inspection of the topographic map can be seen that lower position stimuli induced a higher ERLs activity compared to upper position stimuli. Contralateral activities of the stimuli were negative; therefore, the ipsilateral activities were positive. Power difference in the activities can be seen in both upper and lower stimuli position.

b. Descriptive Statistic

Descriptive statistics analyses of all variables across experiment block for all participants were presented in Table 1.

Descriptive Statistics				
Variable	Min	Max	Mean	Std. Dev
Stanford Sleepiness Scale	1	6	3.67	1.240
D-prime	2.243	4.831	3.982	.733
Beta	1.815	49.542	17.270	13.981
Reaction time	354.167	484.571	405.198	29.599
ERLs in time window 60-90ms	-1.082	3.272	.392	.646
ERLs in time window 90-120ms	-1.920	3.871	.573	.832
ERLs in time window 120-150ms	-3.217	2.748	-.101	1.117

Table 1. Descriptive statistic of all the variable

Mean of Stanford sleepiness scale was 3.67 with a standard deviation of 1.240, this value was approximately in the middle between min value of 1 and max value of 6. Mean of D-prime was 2.243 with a standard deviation of .733, this value was close to the maximum value of 4.831 that reflects the overall group performance of the stimuli identification was good with a high number of hit and only limited number of miss. On the other hand, mean of beta was 17.270 with standard deviation 13.981; this value was close to a minimum value which means the performance bias was low with a high number of correct rejections and a low number of false alarms. Reaction time mean was 405.198 with standard deviation 29.599, this value was close to the center with the minimal value of 354.167 and the maximum value of 484.571 that reflects the distribution was close to normal distribution. Mean of ERLs in the 60-90ms was .392 with a standard deviation of .646, this value was closer to the minimum value of -1.082 compared to the maximum value of 3.272. Mean of ERLs in the 90-120ms was .573 with a standard deviation of .832, this value was closer to the minimum value of -1.920 compared to the maximum value of 3.871. Mean of ERLs in the 120-150ms was -.101 with a standard deviation of 1.117, this value was closer to the center between the minimum value of -3.217 and the maximum value of 2.748.

c. Spearman correlation

Correlation between subjective measure and behavior measure was presented in Table 2. According to Spearman correlation results, there was no significant correlation between subjected measure with the behavior measure for both upper and lower position stimuli.

Correlation of Subjective Measure with Performance Measure			
		Rs	*P*
Upper Stimuli Position	D-prime	-.387	.240
	Beta	.145	.671
	Reaction Time	.103	.764
Lower Stimuli Position	D-prime	-.252	.455
	Beta	.056	.870
	Reaction Time	.103	.764

Table 2. Spearman correlation indicates that there was no significant correlation between the average Stanford Sleepiness Scale with d-prime, beta and reaction time for both upper and lower stimuli position.

d. Two-way Repeated Measures ANOVA

The results of two-way repeated measures ANOVA for all behavior performance (Table 3.) shown that no statistically significant interaction effect of stimuli and block can be found on behavior measures. The results suggested that no significant difference between the group mean of d-prime, beta and reaction time in different stimuli position and different block. The main effect of stimuli was also not statistically significant on all behavior measures, meaning that different stimuli did not cause different behavior measures. However, the main effect of block on all behavioral measures was found out to be statistically significant. Overall, from the result can be seen that the experiment block has a significant effect on all behavior measure.

Results of Two-way repeated measures ANOVA of Behaviour Measure					
Dependent Variable	Effect	df1	df2	F	*p*
d-prime	stimuli*block	4	40	1.482	.226
	Stimuli	1	10	.004	.951
	Block	4	40	3.273	.021*

Results of Two-way repeated measures ANOVA of Behaviour Measure

Beta	stimuli*block	2.335	23.353	.331	.754
	Stimuli	1	10	.961	.35
	Block	4	40	3.07	.027*
reaction time	stimuli*block	4	40	.28	.889
	stimuli	1	10	.792	.394
	block	4	40	4.899	.003**

*the effect is significant $p < .05$

** the effect is significant $p < .01$

Table 3. A two-way repeated measures ANOVA of all behavior measures indicates that the block has a statistically significant main effect on all behavior measure. No statistically significant results were found either in the interaction effect between stimuli and block or main effect of stimuli.

The interaction between the stimuli and block to all behavior measure were presented in Figure 3. The figure showed that both upper (stim 1) and lower stimuli (stim 2) have a similar effect to behavior measure over the experiment block. In general, d-prime for upper and lower stimuli position decreased over the experiment block (Figure 3a). However, d-prime for upper stimuli position in the last experiment block was increased compared to the previous block. Meanwhile, d-prime for lower stimuli position in the third block was increased from the previous block before decreased again until the last experiment block. Beta for upper and lower stimuli position increased over the experiment block (Figure 3b). However, beta for upper and lower stimuli position was decreased in the last experiment block compared to the previous block. Reaction time (Figure 3c) steadily increased over the experiment block both for upper and lower stimuli position. Detail comparison of the mean value of d-prime, beta and reaction time can be seen on the table B5 in the appendix.

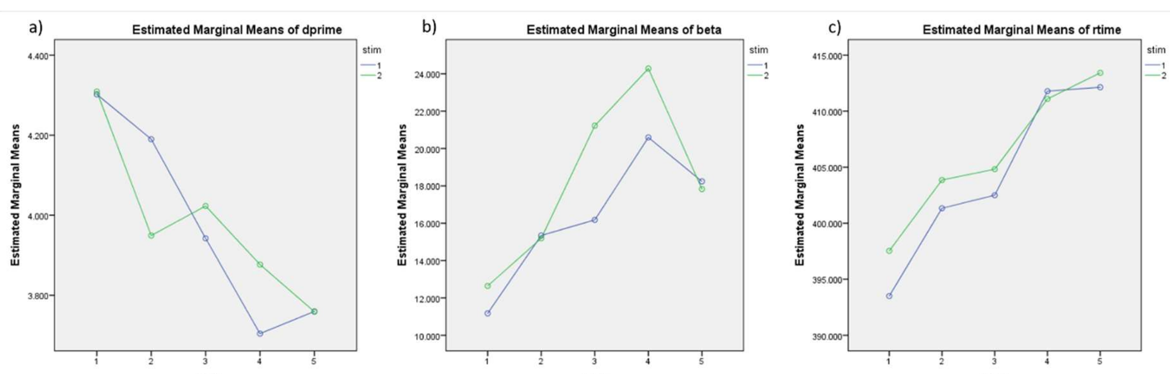

Figure 3. Interaction effect of stimuli and block on a) d-prime, b) beta, and c) reaction time. In general, d-prime were decreased over time during the experiment, beta was increased overtime until block four before dropping in the last block of the experiment, reaction time was gradually increased from the beginning to the end of the experiment.

The results of two-way repeated measures ANOVA for all ERLs activity in three different time windows (Table 4) indicated that were no statistically significant interaction effect of stimuli and block. The results suggested that there was no significant difference between the groups mean of ERLs in 60-90ms, 90-120ms and 120-150ms time windows for different stimuli position and different block. However, the main effect of stimuli was statistically significant in 90-120ms time-window. The results mean that the different stimuli caused a significantly different ERLs activity on P7-P8 for upper stimuli and PO7-PO8 for lower stimuli in 90-120ms time-window. The main effect of the block on all ERLs activity in three time-windows was also not significant. Overall, from the result can be concluded that the ERLs were significantly different for upper and lower position stimuli in the 90-120ms time-window. However, the ERLs activity was not affected by the time on task.

Results of Two-way repeated measures ANOVA of ERLs activity

Dependent Variable	Effect	df1	df2	F	*p*
time windows 60-90ms	stimuli*block	4	40	.249	.908
	stimuli	1	10	.007	.937
	block	4	40	.238	.478
time windows 90-120ms	stimuli*block	4	40	1.173	.337
	stimuli	1	10	5.388	.043*
	block	4	40	.867	.492
time windows 120-150ms	stimuli*block	4	40	2.262	.079
	stimuli	1	10	3.807	.8
	block	4	40	1.217	.319

*the effect is significant $p < .05$

Table 4. A two-way repeated measures ANOVA of ERLs activity on three different time windows indicated that the stimuli have a statistically significant main effect on all ERLS activity on time windows 90-120ms. No statistically significant interaction effect between stimuli and block, no statistically significant main effect of the block.

The interaction between the stimuli and block to ERLs in three different time-windows can be seen in Figure 4. The figure illustrates that both the upper (stim 1) and lower stimuli (stim 2) have fluctuated over the experiment block in 60-90ms time-window (4a), 90-120ms time-window (Figure 4b), and 120-150ms time-window (Figure 4c). Detail comparison of the mean value of ERLs activity in the three different time windows can be seen on the table B5 in the appendix.

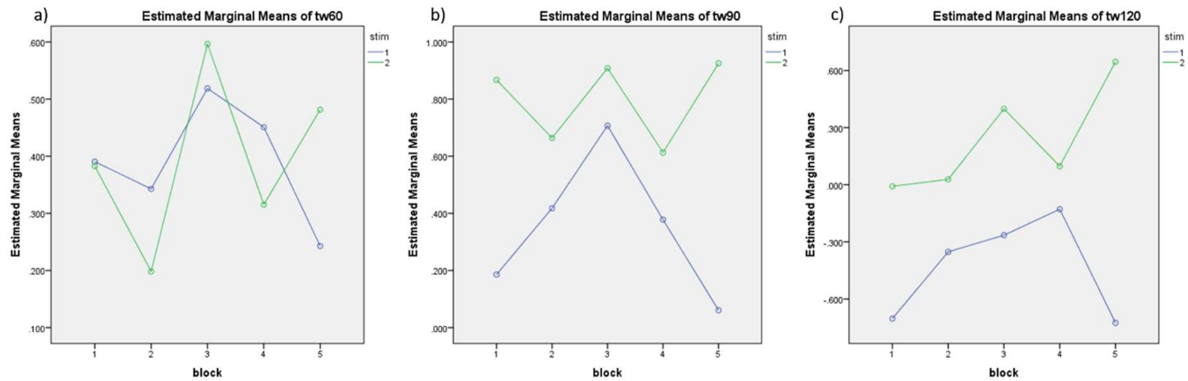

Figure 4. Interaction effect of stimuli and block on ERLs activity on time-window a) 60-90ms, b) 90-120ms, and c) 120-150ms. In general, the ERLs activity in three different time-windows fluctuated over the experiment block with no apparent pattern, which means that the experiment block did not affect the ERLs activity.

The statistical result suggests that there was no interaction effect between experiment block and stimuli position can be found in the behavior results and ERLs activities. However, the performance (d-prime, beta and reaction time) over time were affected by the experiment block. D-prime was decreased over time, beta and reaction time were increased over time. The effect of the experiment block on the ERLs activity in the three different time windows was not statistically significant. No significant difference of performance measure can be found between the different stimuli, only the ERLs in 120-150ms time windows were statistically different for a different stimulus. Based on these results, further analyses to examine whether the ERLs activity related to the behavior performance did not need to be performed.

e. Multilevel Linear Model

The correlation plot shows that all behavioral performance measurements have a reasonably high correlation between variables, while ERLs activities have a low correlation between variables (Table 5). D-prime has a negative correlation with beta and reaction time, while beta has a positive correlation with reaction time. The correlation between behavior performance measure with ERLs activity was quite low. The plot of the interaction effect of stimuli and block to all dependent variable can be seen in the APPENDIX A2 to A7.

	d-prime	beta	rtime	60-90ms	90-120ms	120-150ms
d-prime		-.721	-.744	-.209	-.201	-.120
beta	-.721		.713	.129	.13	.059
rtime	-.744	.713		.169	.135	.052
60-90ms	-.209	.129	.169		.562	.376
90-120ms	-.201	.13	.135	.135		.656
120-150ms	-.120	.059	.052	.052	.656	

Table 5. Correlation between all the dependent variables

Multilevel linear model analyses used a stimulus as a fixed effect and block as a covariate in a group level. The result in Table 6 shown that average d-prime for lower position stimuli was 4.352, this estimate was precise with high certainty. The experiment block has a negative effect to lower position stimuli, with high certainty each experiment block decreased d-prime as much as -.117. The upper position stimuli have a higher average compared to a lower position with .119 difference. However, this estimate has a considerable uncertainty with a wide range; the actual difference could be higher in a positive or negative direction. The experiment has a more detrimental effect to upper position stimuli compared to lower position stimuli; however, the actual value might be much greater towards negative or positive since the uncertainty of this estimate was also considerable in both positive or negative direction. The interaction effect showed that the experiment block has a negative effect on decreasing d-prime value, while the stimuli difference does not cause a difference d-prime value. Additionally, the results in Table 7 also show that the individual variation in d-prime was considerably high with .556, although with the level of uncertainty regarding its real value was considerable.

DV	fixef	center	Lower	upper
Dprime	Intercept	4.352	3.930	4.788
	stimUpper	0.119	-0.278	0.501
	block	-0.117	-0.203	-0.034
	stimUpper:block	-0.041	-0.158	0.079
Beta	Intercept	12.008	3.745	20.141
	stimUpper	-1.979	-11.064	7.303

DV	fixef	center	Lower	upper
	block	1.937	0.005	3.864
	stimUpper:block	0.002	-2.786	2.757
Rtime	Intercept	393.222	377.191	409.487
	stimUpper	-4.601	-14.835	5.703
	block	3.898	1.631	6.103
	stimUpper:block	0.881	-2.256	3.974
tw60ms	Intercept	0.141	-0.411	0.691
	stimUpper	0.030	-0.085	0.146
	block	-0.049	-0.215	0.112
	stimUpper:block	0.141	-0.411	0.691
tw90ms	Intercept	0.780	0.266	1.302
	stimUpper	-0.335	-0.987	0.302
	block	0.007	-0.127	0.139
	stimUpper:block	-0.037	-0.229	0.158
tw120ms	Intercept	-0.163	-0.926	0.602
	stimUpper	-0.307	-1.113	0.492
	block	0.136	-0.028	0.299
	stimUpper:block	-0.121	-0.361	0.114

Table 6. Multilevel model analyses result of all dependent variable with the stimuli and block as covariates with 95 percent confident interval

The average beta for lower position stimuli was 12.008, but this estimate has a considerable uncertainty about the real magnitude that can be much lower or higher (Table 6). The experiment block has a considerable effect to lower position stimuli; each experiment block increases beta by almost as much as 2 points. Although the effect of the block to lower position stimuli was almost certainly positive, there was considerable uncertainty regarding the actual magnitude. The upper position stimuli have a smaller average compared to a lower position with -1.979 difference. However, this estimate has a considerable uncertainty with a wide interval. Therefore, the difference can be higher in a positive or negative direction. The experiment block has an almost identical effect to upper and lower position stimuli; however, the actual value might be much greater towards negative or positive direction with up to 2.7 difference. The interaction effect showed that the experiment block has a positive effect on increasing beta value, while the stimuli difference does not necessary causing beta difference. Also, the results of the analysis also showed that the individual variation in beta was quite remarkable reaching 8.702, although with a considerable level of uncertainty regarding its real value (Table 7).

The average reaction time for lower position stimuli was 393.222; this was a precise estimate with high certainty level (Table 6). The experiment block has a positive effect to lower position stimuli; there was considerable certainty that with each block of the experiment the reaction time was decreased up to almost 4ms. The upper position stimuli have a faster average reaction time compared to lower position stimuli with -4.601 difference. However, this estimate has a high uncertainty with a wide interval to negative and positive direction. The effect of block was higher positive to upper position stimuli compared to lower position stimuli; however, the actual value might be less positive, or event negative since the uncertainty of this estimate was also high in both directions. The interaction effect showed that the experiment block has a positive effect on increasing reaction time, while the stimuli difference does not cause a notable reaction time. The results of the analysis also showed that the individual variation in reaction time was considerably high with 25.01 with considerable certainty about the estimate (Table 7).

Parameter	center	lower	upper
sd_part__dprime_Intercept	0.557	0.371	0.911
sd_part__beta_Intercept	8.702	5.761	13.738
sd_part__rtime_Intercept	25.010	17.879	37.786
sd_part__tw60ms_Intercept	0.244	0.053	0.541
sd_part__tw90ms_Intercept	0.426	0.179	0.816
sd_part__tw120ms_Intercept	0.794	0.447	1.588

Table 7. Participant level effect of multilevel linear model reflected the variability of means

The average ERLs activity for lower position stimuli in 60-90ms time window was .304 (Table 6). However, this estimate could also be possible to be higher or even lower to negative value since there was high uncertainty in both directions. The experiment block has a positive effect to lower position stimuli. Each experiment block increased the ERLs activity by .03. However, the value could also be higher positive or lower negative since the estimate comes with considerable uncertainty. The upper position stimuli have a higher ERLs activity in 60-90ms time window compared to lower position stimuli with .141 difference. However, this estimate has a high uncertainty with a wide interval to negative and positive direction. The effect of block was negative to upper position stimuli with -.049 difference compared to lower position stimuli; however, the actual value might also be higher from this estimate since there was also considerable uncertainty to negative and positive direction. The interaction effect showed that there was considerable uncertainty for the effect of stimuli and block to ERLs activity in 60-90ms. The individual variation in reaction time was considerably high with .244, although this estimate has considerable uncertainty (Table 7).

The average ERL activity for lower position stimuli in the 90-120ms time window was .78. Experimental blocks have relatively small effects for lower position stimuli; each block increases the ERL activity by .007 (Table 6). However, both of these estimates have considerable uncertainty with the actual value which may be higher towards the positive or lower towards the negative. Upper position stimuli have a lower ERL activity in the 90-120ms time window compared to lower position stimuli with a difference of -.335. The effect of the block on the upper position stimulation is negative at -.037. However, these two estimates also have a remarkable uncertainty. Therefore, the actual value may also be higher towards the positive or lower towards the negative. The results of the analysis shown that there was considerable uncertainty to determine the interaction effect of stimuli and blocks on ERL activity within 90-120ms time window. From the results also known that individual variations in reaction time were notable high with .426, although this estimate also has considerable uncertainty (Table 7).

The average ERL activity for lower position stimuli in the 120-150ms time window was -.163. Experimental blocks have relatively small effects for lower position stimuli; each block increases the ERL activity by .136 (Table 6). However, both of these estimates have considerable uncertainty with the actual value which may be higher towards the positive or lower towards the negative. Upper position stimuli have a lower ERL activity in the 120-150ms time window compared to lower position stimuli with a difference of -.307. The effect of the block on the upper position stimulation was negative at -.121. However, these two estimates also have a remarkable uncertainty. Therefore, the actual value may also be higher towards the positive or lower towards the negative. The results of the analysis shown that there was considerable uncertainty to determine the interaction effect of stimuli and blocks on ERL activity within 120-150ms time window.

Furthermore, the results also showed that individual variations in reaction time were notable high with .794, although this estimate also has considerable uncertainty (Table 7).

4. Discussion and Conclusion

Technology advancement encourages the implementation of an automation system that may take over human function as an operator in the future. However, problems arise in the interaction between the automation system and human operator, sometimes transition between automated control to manual control does not switch smoothly. The operator readiness to take over the control in a critical moment and the vigilance state was the issue in the task that requires the operator to sustains attention for an extended period with of inactivity. This research was conducted to investigate the possibility of a real-time vigilance state monitoring based on neural activity that measured with the EEG. The primary research question was whether the individual vigilance state could be predicted by modulation of the early ERP components that appear after stimuli onset. This study was designed using a moving visual stimulus that appeared at a different starting position to trigger different C1 and P1 component. These two ERP components were known to be the first occurred visual evoked potential and were sensitive to a stimulus difference. ERP components were analyzed with ERLs technique to find out contralateral activity difference between left and right hemisphere depending on the stimuli position.

ERLs result shown that the upper and lower position stimuli triggered different activation in occipital cortex area. The upper position stimuli elicit the highest activity on the P7-P8 channel in 60-90ms and 90-120ms time-window, before switching to P5-P6 channel in 120-150ms time-window. Meanwhile, the lower position stimuli elicit the highest activity on the PO7-PO8 channel in all three different time windows. ERLs activities for both upper and lower position stimuli peaked at around 90-100ms after stimuli onset. ERLs activities were higher on PO7-PO8 compared to P7-P8. These activity difference indicate that the stimuli in the lower visual field triggered higher activity in the occipital area compared to the stimuli in the upper visual field. ERLs activities from both channels were peaked at around 90 to 110ms after the stimuli onset. P7-P8 reached the peak first then followed by PO7-PO8. However, the amplitude was higher on PO7-PO8 compared to P7-P8.

ERLs activity on both electrodes pairs was extracted at three different time-window to investigate how ERLs modulation on both channels fluctuated throughout the experiment as an effect of time on task from experiment block and stimulus difference. A two-way repeated measures

ANOVA of ERLs activity in both channels shown that there was no significant interaction effect between stimulus position and experiment block on ERLs modulation. The result suggests that there was no significant difference between the ERLs activity modulation on P7-P8 for upper position stimuli and PO7-PO8 for lower position stimuli in the different experiment block. The result of analyses also shown that the main effect of the stimulus was only significant for 90-120ms time windows, which explained that the upper and lower position stimuli ERLs activities only differ in 90-120ms time-window and did not in another time windows. The main effect of block on ERLs activity was also not statistically significant in all three different time windows, which explain that during the experiment the time on task did not significantly affect the ERLs activity in the three different time windows. Examination of the ERLs activity graph for both stimuli at three different time-windows illustrates that P7-P8 and PO7-PO8 have fluctuated regardless the experiment blocks.

Multilevel linear models' analyses also provided similar results. The interaction effect of block and stimuli to ERLs modulation in both channels do not have a reliable magnitude to establish the precise estimate and has a considerable uncertainty since the credibility levels that were too wide. The stimuli difference also has a substantial uncertainty to explain the effect of the modulation of the ERLs activity. As well as the block effect that also has a considerable uncertainty to the changing of ERLs activity as the effect of time on task. Therefore, it was difficult to precisely determine whether the stimuli nor the block influences ERLs activity. The results of further processing explain that individual difference plays an essential role in the variance of the ERLs activity in the three different time windows.

This study used signal detection theory as a measure of behavior performance, instead of only relying on the calculation of hit and miss. The implementation of d-prime and beta as provides a more accurate result of the performance by provides information about the sensitivity of the observer and decision criteria (Macmillan & Creelman, 2004). D-prime which were calculated based on a portion of hit-miss to the total target stimulus reflects the participant ability in identifying the target stimulus. During the experiment, d-prime decreased over time on task in each experiment block for both upper and lower position stimuli. Another aspect of SDT was Beta which was calculated based on a correct rejection of non-target stimuli or false alarm response to non-target stimuli. Beta was used as bias criterion. The results showed that beta increased over time for both stimuli until the fourth experiment block then decreased in the last experiment block. Reaction time as another performance measure shown that the participant response consistently slowed down from time to time during the experiment both for upper and lower position stimuli.

A one-way repeated measure ANOVA of all behavior performance measure shown that there was a significant main effect of block on all behavior performance measure. The result from multilevel model analysis also confirms the changed of d-prime, beta and reaction time from time to time. D-prime was decreased from time to time. Meanwhile, beta and reaction time was increased from time to time. The effect of block was precise with high certainty in all the behavioral measure. However, the variance of individual differences was also remarkable in the d-prime, beta and reaction time.

Statistical analyses have shown that there was no significant correlation between subjective measure with all performance measure both for upper and lower position stimuli. The results explain that the subjective scale did not accurately reflect the changes in individual performance. The statistical result also has shown that upper and lower position stimulus did not cause a different behavioral performance, but the behavior measure was affected by the block as a factor of time on task. However, the similar effect of the block did not occur on the modulation of ERLs activity in three different time windows. Therefore, without performing further analyses based on the result can be concluded that the vigilance decrement was not related to early ERP component modulation which was the focus of this present study. In addition, also known also that individual factors play a major role in the difference in behavioral performance measure and ERLs activities.

There were several limitations in regard of study design as well as the nature of C1 and P1 ERP component that needs to be addressed related to the present study. Related to study design, the laboratory experiment method that was chosen because until recently the fundamental concept of neural measure on vigilance state still needed to be developed before it can be tested in the field study or applied domain. Nevertheless, stimulus developed for this research was designed to replicates a real-world task in a radar-like monitoring experiment form. In this experiment, the stimuli in the form of a moving triangle is a new approach, unlike previous studies that only used static visual objects. The effect of moving stimuli was expected to provide a result that resembles a real-world situation. However, the ratio of target stimuli that was very low compared to non-target stimuli. As a result, one missed response to target stimuli has a more significant effect on the d-prime changes compared to one false alarm response to beta changes. In addition, the number of target stimuli that was very low makes it difficult to analyze the target stimuli so that the analysis is carried out on non-target stimuli.

C1 and P1 component polarity were very small compared to another ERP component that occurs afterward such as P3 component. Therefore C1 and P1 component are sensitive to noises during the recording. According to Woodman (2010) to get a good measure of C1 and P1 component from individual participant it can take around 300-1000 trial per condition. The number of trials in the present study for non-target stimuli was 384 per block; the number already complied with a minimum number of trials based on Woodman suggestion. However, a completely noise-free recording situation for a vigilance task where the task was monotonous and cognitively nonchallenging was difficult to achieve. During the experiment, participants were observed often moves or blinks when their alpha wave in the EEG recording increased. This observed behavior was a signal that when participants started to get drowsy, the noises increased as well. Therefore, ideal recording situation to achieve signal to noise ratio condition were difficult to achieve with a minimum number of trials.

Related to existing research, the current result that higher ERLs value for lower stimuli was projected to PO7-PO8 support the finding from Butler et al. (1987), that the stimuli presented to lower hemifield more positive compared to stimuli presented on the upper hemifield. ERLs also provided information that different stimuli position on the left or right of visual field projected on contralateral hemisphere supporting the previous finding from Butler et al. (1987), Mangun et al. (1993), and Di Russo et al. (2003). C1 and P1 ERP component occurred in the striate cortex as a response to visual stimuli. The results have shown that the modulation of early ERP components such as C1 and P1 were affected by the attention (Boksem et al., 2005; O'Connell et al., 2009; Rauss et al., 2009; van der Lubbe & Woestenburg, 1997). The result contradicts with the study by Fu et al. (2010) that C1 component was insensitive to the attention manipulation no significant effect of attention on C1 amplitude.

Previous EEG studies found out that cortical arousal is functionally related to the vigilance but not to the vigilance decrement, multiple brain area plays a different role in vigilance such as; noradrenergic brainstem reticular formation, the intralaminar thalamic nuclei, and the right prefrontal cortex (Parasuraman et al., 2000). This study focuses on the visual cortex to see changes in ERP components that appear in the visual cortex and how they affect vigilance performance. The result that there was no significant effect of block on ERLs activity confirms that visual arousal not related with the vigilance decrement effect that occurred during the experiment. Visual evoked ERP modulation only related to visual stimuli attention but did not explain how the modulation was related to the behavior performance change over time.

The result showed that individual performance has decreased over time. The performance decrease over time characterized by a decreased of d-prime, an increase of beta, and a slowed down of reaction time. The result confirmed the vigilance decrement effect that occurs when participant need to sustain attention while doing a simple and monotonous task for an extended period of time (Langner & Eickhoff, 2013; Mackworth, 1948; Martel et al., 2014; Parasuraman et al., 2000). Different stimuli did not significantly cause performance differences, but block experiments as a time factor in the task had a significant effect on the work. However, time on task did not have a significant effect on the fluctuation of ERLs in the three different time-windows. Therefore, can be concluded that the ERLs modulation of early ERP components was not related to task performance. Further research is required to examine the effect of stimuli on EEG activity and performance measures to provide more information about the nature of C1 and P1 components before these two components can be used for a vigilance monitoring.

The current research findings provide several opportunities for improvements in order to acquire a better result. For example, related to the effectiveness of stimulus that designed for this study, although the newly developed stimuli proved to be able to cause accuracy reduction effects. The stimulus duration for this study was 500ms; this duration was long enough to reduce the possibility of errors. The effect of stimuli duration can be seen from the mean of d-prime that skewed high and the mean of beta that skewed to low. By reducing the stimulus duration, it is expected that the number of errors will increase so that the vigilance decrement effect will be more visible. Adding more target stimuli to increase the ration of target and non-target. Changing mediating display in between stimuli event from static radar-like display to a blank screen and prolonged duration between trial to reduce noise in the measurement baseline. Add multiple events at one time-window to add complicity of the stimuli event to mimic a real-world situation where multiple stimuli might occur at once. Prolong the experiment duration and adding experiment block to increase the vigilance decrement effect.

In the aspect of data analyses, the improvement can be made by comparing the ERLs activity between the hit and missed or a false alarm and correct rejection. By making this comparison will be precisely known the neuroactivity differences in between the errors and the correct response. This study uses the ERLs methods on the early ERP component, if the research focus is still on the visual arousal, then a technique other than ERP ERLs can be considered. However, if the focus of the research is more on how the neurobehavior on vigilance decrement then the studies related to how the modulation of EEG signal from another part of the brain that may affect the vigilance state will also be required to provides more inclusive view about the vigilance state.

Finally, an implementation of real-time vigilance monitoring system based on the neural activity is still too early to do. However, by continuously conducting fundamental research to investigate the neural activity that arises when individuals perceive and process stimuli, we will be able to explain the neural activity underlying vigilance decrement. Following that, the research can be stepped up into an applied study of vigilance monitoring in a real-world situation once the neural activity is known and the accurate measurement method can be developed. Only after all the thing can be sorted out, we can begin developing a device that able provides an early warning when neural activity shows signs of error and provide a preliminary alarm before the actual error occur to prevent an accident. That is when the all of the research in the real-time vigilance become fruitful with the state-of-the-art vigilance monitoring device as a final result.

5. References

Awh, E., Baylis, G. C., Cantwell, D., Clark, V. P., Courtney, S. M., Davidson, M. C., … Donnell, B. F. O. (2000). *The Attentive Brain*.

Bach, M. (2007). The Freiburg Visual Acuity Test-Variability unchanged by post-hoc re-analysis. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *245*(7), 965–971. https://doi.org/10.1007/s00417-006-0474-4

Berka, C., Levendowski, D. J., Lumicao, M. N., Yau, A., Davis, G., Zivkovic, V. T., … Craven, P. L. (2007). EEG Correlates of Task Engagement and Mental Workload in Vigilance, Learning, and Memory Tasks. *Aviation, Space, and Environmental Medicine*, *78*(5), B231–B244. https://doi.org/10.1016/j.biopsycho.2011.03.003

Boksem, M. A. S., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research*, *25*(1), 107–116. https://doi.org/10.1016/j.cogbrainres.2005.04.011

Brain Products. (2018). BrainVision Recorder.

Bürkner, P.-C. (2018). Package 'brms.' Retrieved from http://discourse.mc-stan.org

Butler, S. R., Georgiou, G. A., Glass, A., Hancox, R. J., Hopper, J. M., & Smith, K. R. H. (1987). Cortical generators of the CI component of the pattern-onset visual evoked potential. *Electroencephalography and Clinical Neurophysiology/ Evoked Potentials*, *68*(4), 256–267. https://doi.org/10.1016/0168-5597(87)90046-3

Cabrall, C. D. D., Happee, R., & de Winter, J. C. F. (2016). From Mackworth's clock to the open road: A literature review on driver vigilance task operationalization. *Transportation Research Part F: Traffic Psychology and Behaviour*, *40*, 169–189. https://doi.org/10.1016/J.TRF.2016.04.001

Casner, S. M., Hutchins, E. L., & Norman, D. (2016). The challenges of partially automated driving. *Communications of the ACM*, *59*(5), 70–77. https://doi.org/10.1145/2830565

Cohen, M. X. (2014). Analyzing Neural Time Series Data: Theory and Practice. *MIT Press*, (1), 1–5. Retrieved from http://www.amazon.com/Analyzing-Neural-Time-Series-Data/dp/0262019876/

Colblindor. (2018). Ishihara Color Test. Retrieved from https://www.color-blindness.com/ishihara-38-plates-cvd-test/

Craig, a. (1987). Signal detection theory and probability matching apply to vigilance. *Human Factors*, *29*(6), 645–652. https://doi.org/10.1177/154193128502900103

Daniel, R. S. (1967). Alpha and Theta EEG in Vigilance. *Perceptual and Motor Skills*, *25*(3), 697–703. https://doi.org/10.2466/pms.1967.25.3.697

Di Russo, F., Martínez, A., Hillyard, S. a, & Martinez, A. (2003). Source Analysis of Event-related Cortical Activity during Visuo-spatial Attention. *Cerebral Cortex*, *13*(5), 486–499. https://doi.org/10.1093/cercor/13.5.486

Di Russo, F., Martínez, A., Sereno, M. I., Pitzalis, S., & Hillyard, S. A. (2002). Cortical sources of the early components of the visual evoked potential. *Human Brain Mapping*, *15*(2), 95–111. https://doi.org/10.1002/hbm.10010

Eichele, H., Juvodden, H. T., Ullsperger, M., & Eichele, T. (2010). Mal-adaptation of event-related EEG responses preceding performance errors. *Frontiers in Human Neuroscience*, *4*(August), 1–9. https://doi.org/10.3389/fnhum.2010.00065

Elsayed, N., Zaghloul, Z. S., & Bayoumi, M. (2017). Brain Computer Interface: EEG Signal Preprocessing Issues and Solutions. *International Journal of Computer Applications*, *169*(3), 975–8887.

Fu, S., Fedota, J. R., Greenwood, P. M., & Parasuraman, R. (2010). Dissociation of visual C1 and P1 components as a function of attentional load: An event-related potential study. *Biological Psychology*, *85*(1), 171–178. https://doi.org/10.1016/j.biopsycho.2010.06.008

Kaida, K., Åkerstedt, T., Kecklund, G., Nilsson, J. P., & Axelsson, J. (2007). Use of Subjective and Physiological Indicators of Sleepiness to Predict Performance during a Vigilance Task. *Industrial Health*, *45*(4), 520–526. https://doi.org/10.2486/indhealth.45.520

Kappenman, E. S., & Luck, S. J. (2012). ERP Components: The Ups and Downs of Brainwave Recordings. In *The Oxford Handbook of Event-Related Potential Components*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0014

Kelly, S. P., Gomez-Ramirez, M., & Foxe, J. J. (2008). Spatial attention modulates initial afferent activity in human primary visual cortex. *Cerebral Cortex*, *18*(11), 2629–2636. https://doi.org/10.1093/cercor/bhn022

Langner, R., & Eickhoff, S. B. (2013). Sustaining attention to simple tasks: A meta-analytic review of the neural mechanisms of vigilant attention. *Psychological Bulletin*, *139*(4), 870–900. https://doi.org/10.1037/a0030694

Liu, C.-L., & Uang, S.-T. (2018). An efficient fuzzy alarm system for improving human performance in supervisory task. *Proceedings - 2017 2nd International Conference on Cybernetics, Robotics and Control, CRC 2017*, *2018–Janua*, 66–70. https://doi.org/10.1109/CRC.2017.21

Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, *4*(11), 432–440. https://doi.org/10.1016/S1364-6613(00)01545-X

Mackworth, N. H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology*, *1*(1), 6–21. https://doi.org/10.1080/17470214808416738

Macmillan, N. A., & Creelman, C. D. (2004). *Detection Theory: A User's Guide: 2nd edition*. *Detection Theory: A User's Guide: 2nd edition* (Second Edi). Lawrence Erlbaum Associates Publishers. https://doi.org/10.4324/9781410611147

Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology*, *32*(1), 4–18. https://doi.org/10.1111/j.1469-8986.1995.tb03400.x

Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. *Attention and Performance XIV*. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=1993-97600-009&site=ehost-live

Martel, A., Daḧne, S., & Blankertz, B. (2014). EEG predictors of covert vigilant attention. *Journal of Neural Engineering*, *11*(3). https://doi.org/10.1088/1741-2560/11/3/035009

Molloy, R., & Parasuraman, R. (1996). Monitoring an Automated System for a Single Failure: Vigilance and Task Complexity Effects. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *38*(2), 311–322. https://doi.org/10.1177/001872089606380211

Neurobehavioral System. (2018). Presentation. Retrieved from https://www.neurobs.com/

O'Connell, R. G., Dockree, P. M., Robertson, I. H., Bellgrove, M. A., Foxe, J. J., & Kelly, S. P. (2009). Uncovering the Neural Signature of Lapsing Attention: Electrophysiological Signals Predict Errors up to 20 s before They Occur. *Journal of Neuroscience*, *29*(26), 8604–8611. https://doi.org/10.1523/JNEUROSCI.5967-08.2009

O'Hanlon, J. F., & Beatty, J. (1977). Concurrence of Electroencephalographic and Performance Changes During a Simulated Radar Watch and Some Implications for the Arousal Theory of Vigilance. In *Vigilance* (pp. 189–201). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4684-2529-1_11

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *39*(2), 230–253. https://doi.org/10.1518/001872097778543886

Parasuraman, R., Warm, J. S., & See, J. E. (2000). Brain System of Vigilance. In R. Parasuraman (Ed.), *the attentive brain* (pp. 221–256). MIT Press.

R Core Team. (2018). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Rauss, K. S., Pourtois, G., Vuilleumier, P., & Schwartz, S. (2009). Attentional load modifies early activity in human primary visual cortex. *Human Brain Mapping*, *30*(5), 1723–1733. https://doi.org/10.1002/hbm.20636

Shahid, A., Wilkinson, K., Marcu, S., & Shapiro, C. M. (2011). Stanford Sleepiness Scale (SSS). In *STOP, THAT and One Hundred Other Sleep Scales* (pp. 369–370). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4419-9893-4_91

Sheridan, T. B. (2012). Human Supervisory Control. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (Fourth Edi, pp. 990–1015). New Jersey: John Wiley & Sons, Inc. Retrieved from https://onlinelibrary-wiley-com.proxy.findit.dtu.dk/doi/pdf/10.1002/9781118131350.ch34

Swets, J. A. (1977). Signal Detection Theory Applied to Vigilance. *Vigilance: Theory, Operational Performance and Physiological Correlates*, 705–718.

Van der Lubbe, R. H. J., & Utzerath, C. (2013). Lateralized power spectra of the EEG as an index of visuospatial attention. *Advances in Cognitive Psychology*, *9*(4), 184–201. https://doi.org/10.2478/v10053-008-0144-7

van der Lubbe, R. H. J., & Woestenburg, J. C. (1997). Modulation of early ERP components with peripheral precues: A trend analysis. *Biological Psychology*, *45*(1–3), 143–158. https://doi.org/10.1016/S0301-0511(96)05226-X

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance Requires Hard Mental Work and Is Stressful. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *50*(3), 433–441. https://doi.org/10.1518/001872008X312152

Wascher, E., & Wauschkuhn, B. (1996). The interaction of stimulus- and response-related processes measured by event-related lateralizations of the EEG. *Electroencephalography and Clinical Neurophysiology*, *99*(2), 149–162. https://doi.org/10.1016/0013-4694(96)95602-3

Wickens, C. D., Kramer, A. F., Vanasse, L., & Donchin, E. (1983). Performance of concurrent tasks: A psychological analysis of reciprocity of information processing resources. *Science*, *221*(1968), 1080–1082.

Wickham, H., Chang, W., Henry, L., Pedersen, T. L., Takahashi, K., Wilke, C., & Woo, K. (2018). Package 'ggplot2.'

Wiegand, I., Napiórkowski, N., Töllner, T., Petersen, A., Habekost, T., Müller, H. J., & Finke, K. (2018). Event-related Electroencephalographic Lateralizations Mark Individual Differences in Spatial and Nonspatial Visual Selection. *Journal of Cognitive Neuroscience*, *30*(4), 482–497. https://doi.org/10.1162/jocn_a_01221

Woodman, G. F. (2010). A brief introduction to the use of event-related potentials (ERPs) in studies of perception and attention. *Attention and Perceptual Psychophysiology*, *72*(8), 1–29. https://doi.org/10.3758/APP.72.8.2031.A

Appendix A. Figure

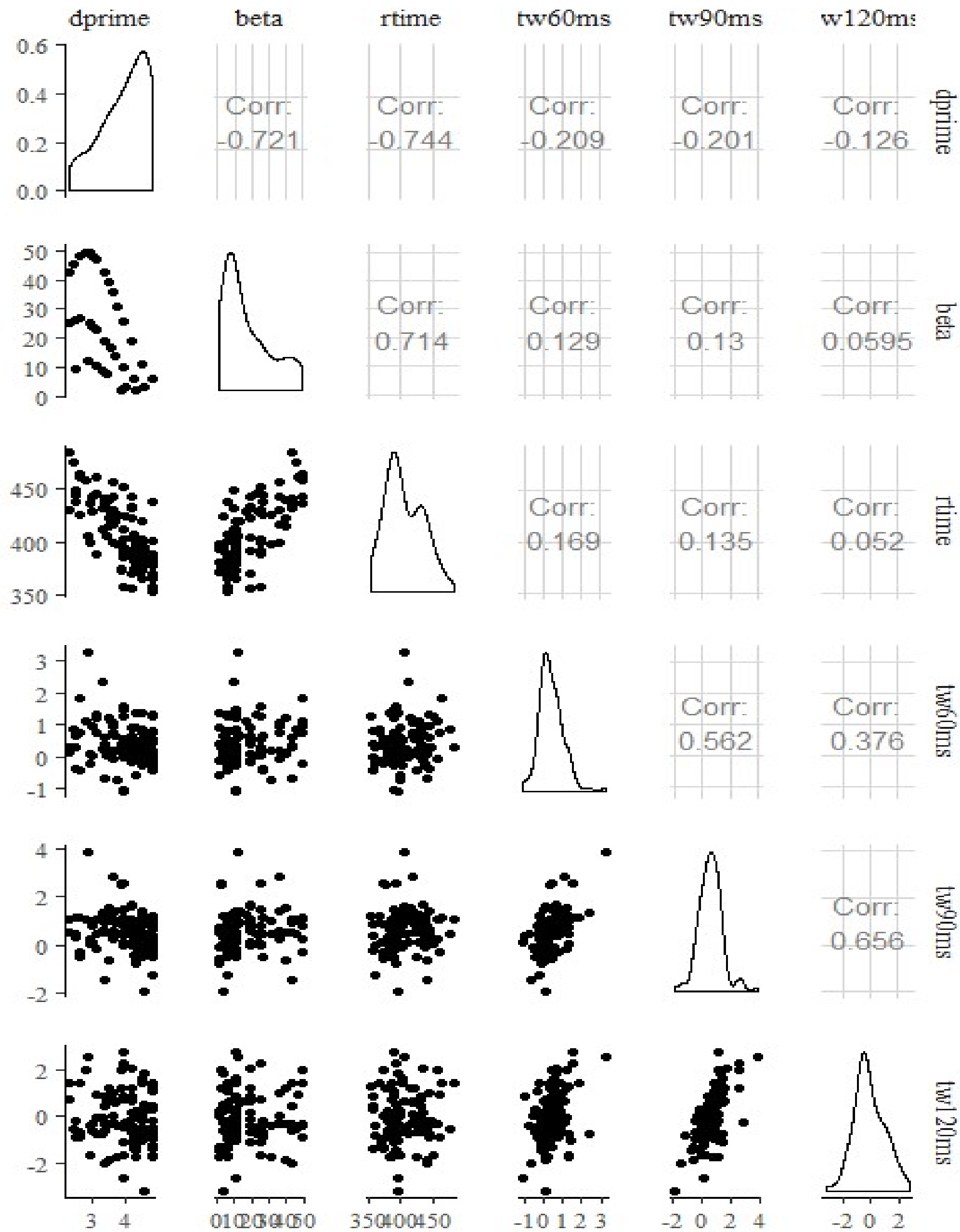

Figure A1. GGpairs plot correlation of all dependent variable

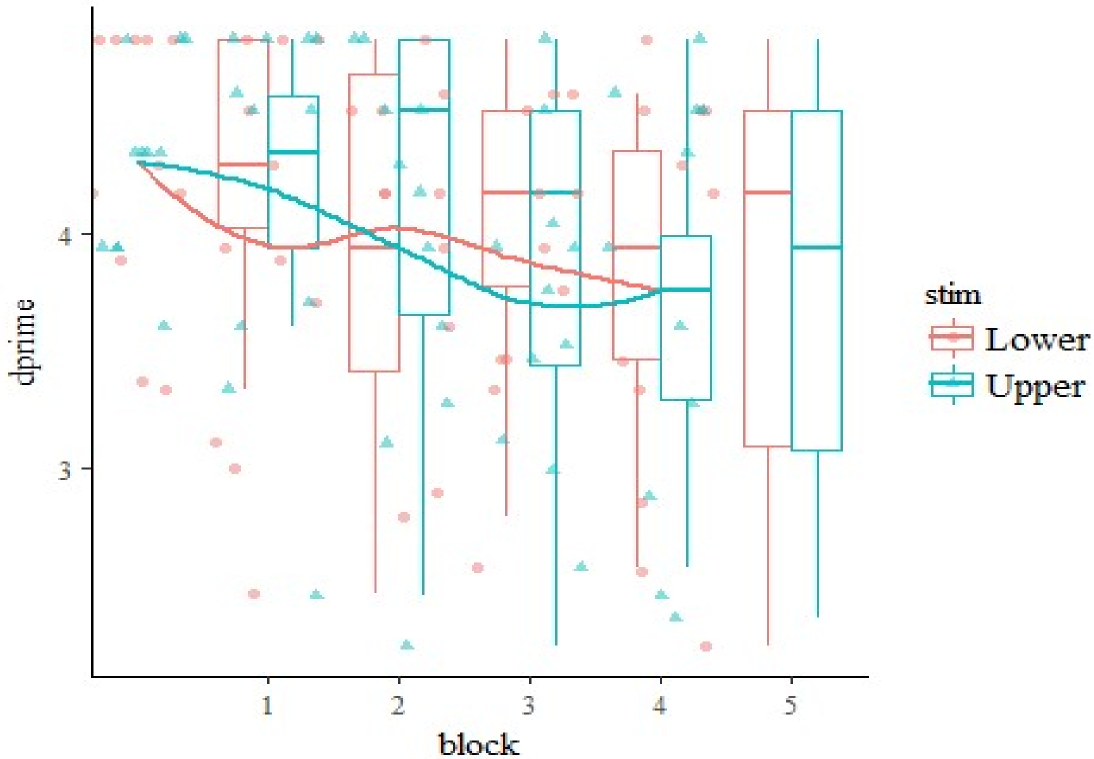

Figure A2. D-prime per block for upper and lower stimuli.

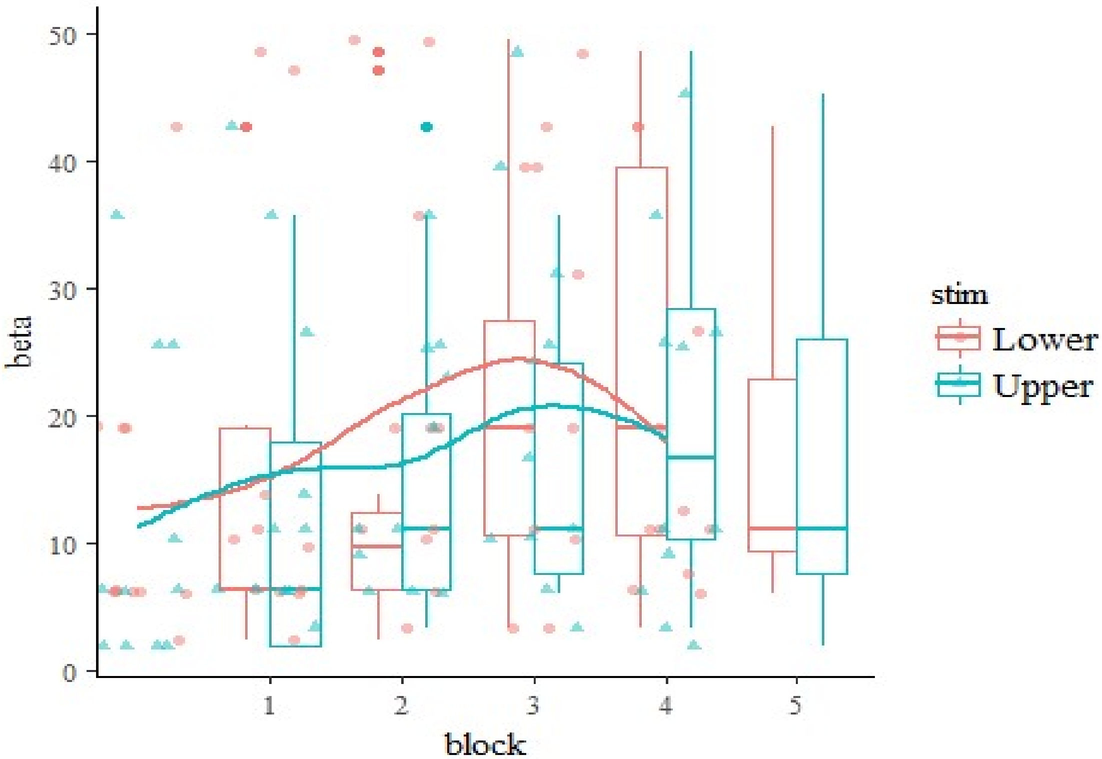

Figure A3. Beta per block for upper and lower stimuli.

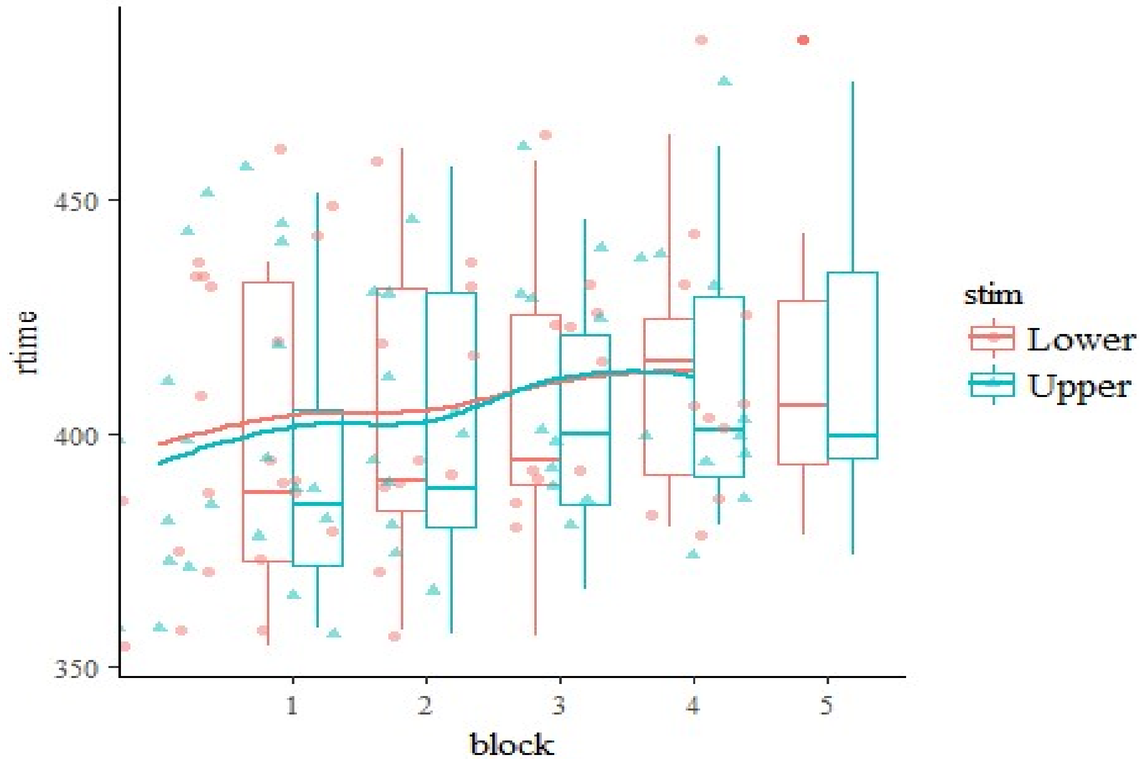

Figure A4. Reaction time per block for upper and lower stimuli.

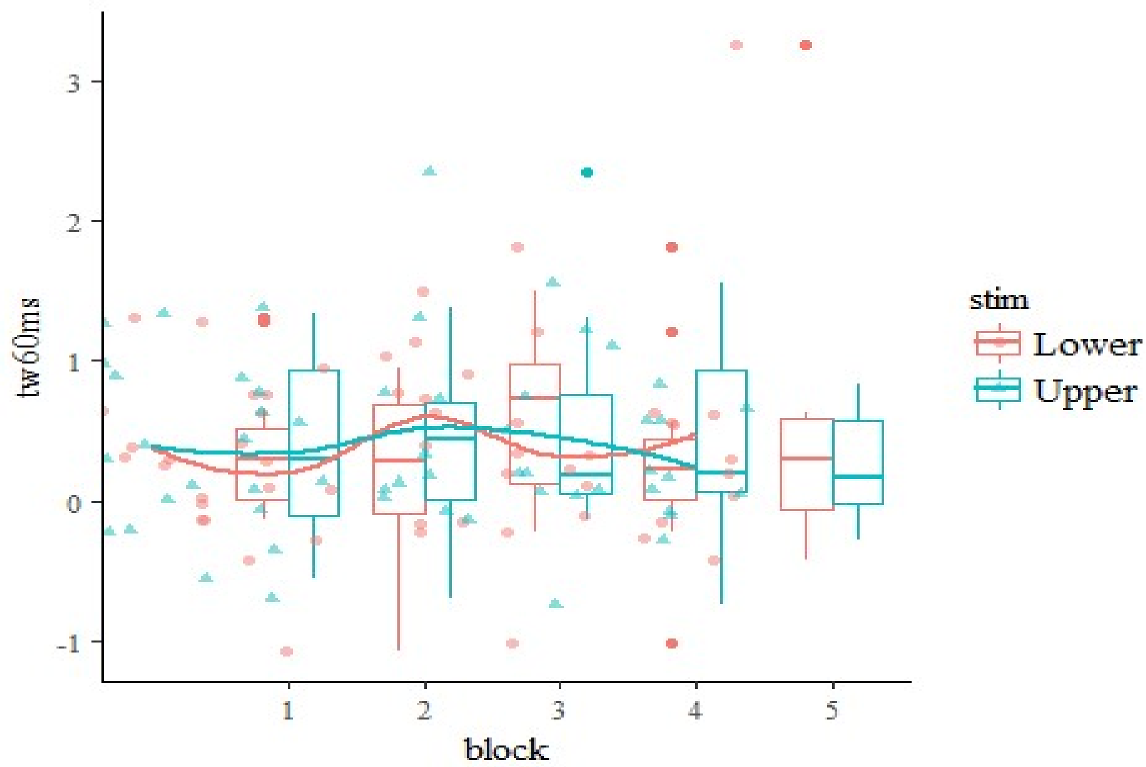

Figure A5. ERLs 60-90ms per block for upper and lower stimuli.

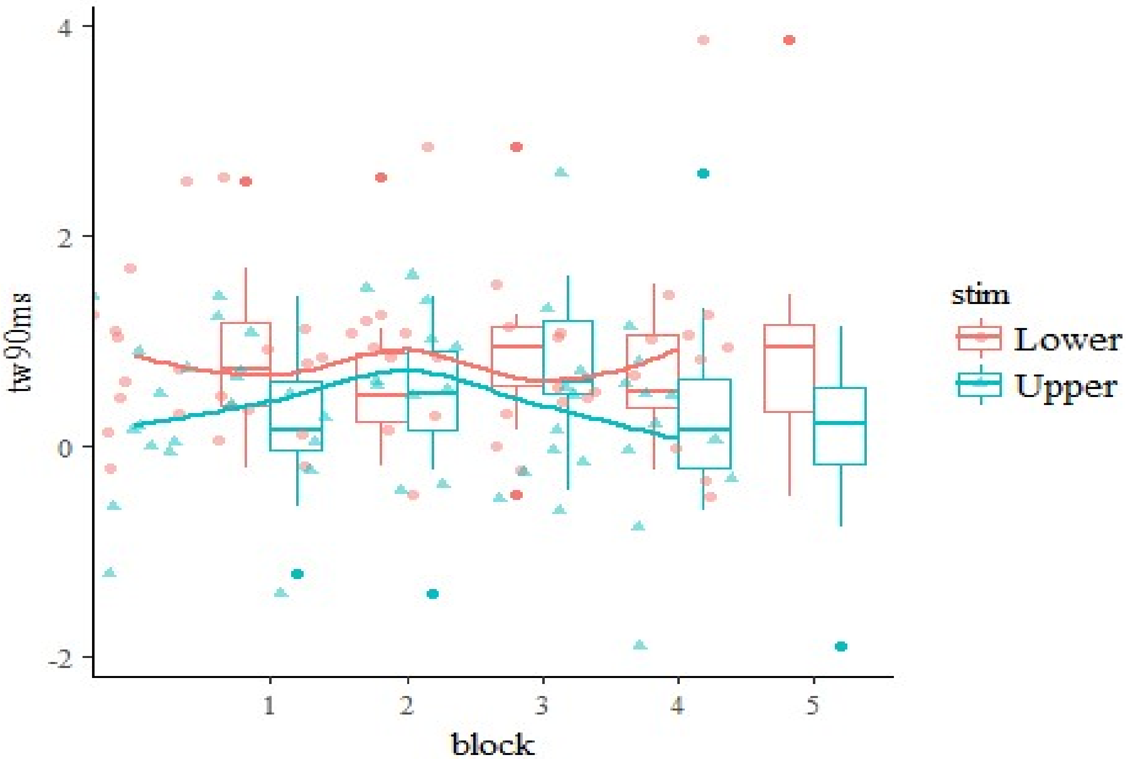

Figure A6. ERLs 90-120ms per block for upper and lower stimuli.

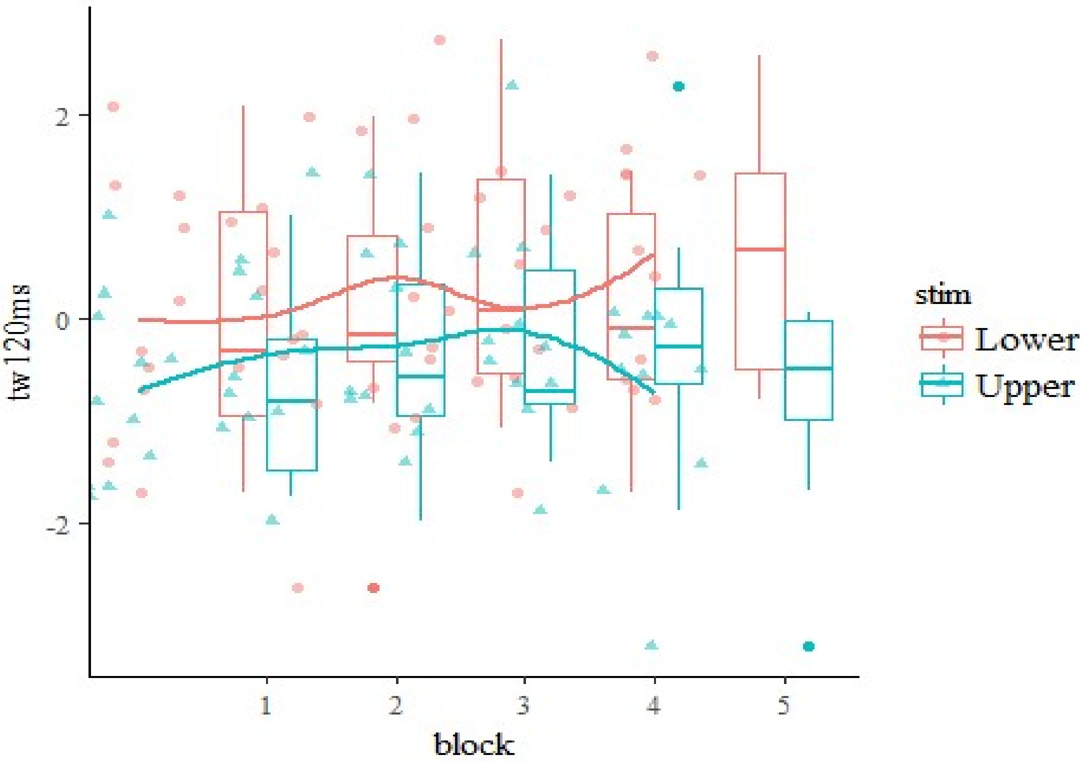

Figure A7. ERLs 120-150ms per block for upper and lower stimuli.

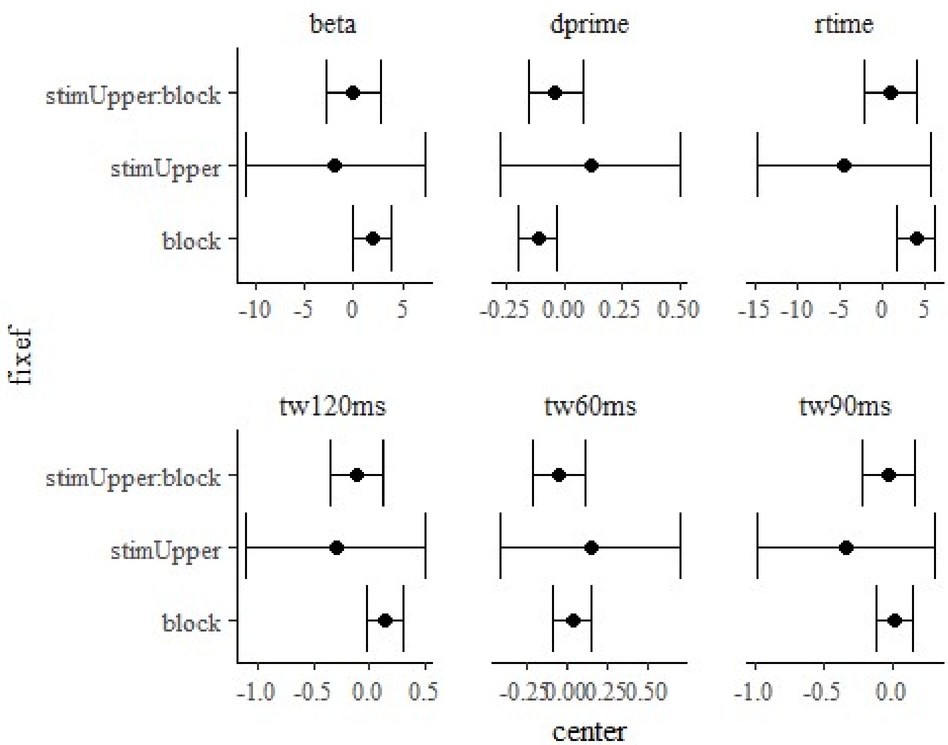

Figure A8. Fixed Effect interaction plot.

Appendix B. Table

Correlations

			avg_subjective sleepiness
Spearman's rho	avg_up_d	Correlation Coefficient	-0.387
		Sig. (2-tailed)	0.24
		N	11
	avg_up_b	Correlation Coefficient	0.145
		Sig. (2-tailed)	0.671
		N	11
	avg_up_rt	Correlation Coefficient	0.103
		Sig. (2-tailed)	0.764
		N	11

Table B1. Spearman's Rho Correlation of Stanford Sleepiness Scale with all behavior measure and ERLs activity for upper stimuli position

Correlations			
			avg_subjective sleepiness
Spearman's rho	avg_lo_d	Correlation Coefficient	-0.252
		Sig. (2-tailed)	0.455
		N	11
	avg_lo_b	Correlation Coefficient	0.056
		Sig. (2-tailed)	0.870
		N	11
	avg_lo_rt	Correlation Coefficient	0.103
		Sig. (2-tailed)	0.764
		N	11

Table B2. Spearman's Rho Correlation of Stanford Sleepiness Scale with all behavior measure and ERLs activity for lower stimuli position

Mauchly's Test of Sphericity[a]

Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
stim	dprime	1.000	.000	0	.	1.000	1.000	1.000
	beta	1.000	.000	0	.	1.000	1.000	1.000
	rtime	1.000	.000	0	.	1.000	1.000	1.000
	tw60	1.000	.000	0	.	1.000	1.000	1.000
	tw90	1.000	.000	0	.	1.000	1.000	1.000
	tw120	1.000	.000	0	.	1.000	1.000	1.000
block	dprime	.259	11.373	9	.260	.595	.792	.250
	beta	.276	10.825	9	.297	.611	.823	.250
	rtime	.552	4.997	9	.838	.794	1.000	.250
	tw60	.236	12.138	9	.214	.653	.904	.250
	tw90	.170	14.930	9	.099	.643	.885	.250
	tw120	.238	12.090	9	.216	.555	.721	.250
stim * block	dprime	.537	5.240	9	.817	.840	1.000	.250
	beta	.124	17.578	9	.044	.584	.773	.250
	rtime	.331	9.317	9	.417	.691	.982	.250
	tw60	.264	11.196	9	.271	.650	.899	.250
	tw90	.519	5.513	9	.792	.765	1.000	.250
	tw120	.216	12.903	9	.175	.594	.791	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: stim + block + stim * block

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table B3. Mauchly's Test of Sphericity of all ANOVA measure

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
stim	dprime	Sphericity Assumed	.000	1	.000	.004	.951	.000
		Greenhouse-Geisser	.000	1.000	.000	.004	.951	.000
		Huynh-Feldt	.000	1.000	.000	.004	.951	.000
		Lower-bound	.000	1.000	.000	.004	.951	.000
	beta	Sphericity Assumed	102.164	1	102.164	.961	.350	.088
		Greenhouse-Geisser	102.164	1.000	102.164	.961	.350	.088
		Huynh-Feldt	102.164	1.000	102.164	.961	.350	.088
		Lower-bound	102.164	1.000	102.164	.961	.350	.088
	rtime	Sphericity Assumed	98.681	1	98.681	.792	.394	.073
		Greenhouse-Geisser	98.681	1.000	98.681	.792	.394	.073
		Huynh-Feldt	98.681	1.000	98.681	.792	.394	.073
		Lower-bound	98.681	1.000	98.681	.792	.394	.073
	tw60	Sphericity Assumed	.001	1	.001	.007	.937	.001
		Greenhouse-Geisser	.001	1.000	.001	.007	.937	.001
		Huynh-Feldt	.001	1.000	.001	.007	.937	.001
		Lower-bound	.001	1.000	.001	.007	.937	.001
	tw90	Sphericity Assumed	5.459	1	5.459	5.388	.043	.350
		Greenhouse-Geisser	5.459	1.000	5.459	5.388	.043	.350
		Huynh-Feldt	5.459	1.000	5.459	5.388	.043	.350
		Lower-bound	5.459	1.000	5.459	5.388	.043	.350
	tw120	Sphericity Assumed	12.240	1	12.240	3.807	.080	.276
		Greenhouse-Geisser	12.240	1.000	12.240	3.807	.080	.276
		Huynh-Feldt	12.240	1.000	12.240	3.807	.080	.276
		Lower-bound	12.240	1.000	12.240	3.807	.080	.276
Error(stim)	dprime	Sphericity Assumed	1.001	10	.100			
		Greenhouse-Geisser	1.001	10.000	.100			
		Huynh-Feldt	1.001	10.000	.100			
		Lower-bound	1.001	10.000	.100			
	beta	Sphericity Assumed	1063.521	10	106.352			
		Greenhouse-Geisser	1063.521	10.000	106.352			
		Huynh-Feldt	1063.521	10.000	106.352			

		Lower-bound	1063.521	10.000	106.352			
	rtime	Sphericity Assumed	1245.846	10	124.585			
		Greenhouse-Geisser	1245.846	10.000	124.585			
		Huynh-Feldt	1245.846	10.000	124.585			
		Lower-bound	1245.846	10.000	124.585			
	tw60	Sphericity Assumed	1.361	10	.136			
		Greenhouse-Geisser	1.361	10.000	.136			
		Huynh-Feldt	1.361	10.000	.136			
		Lower-bound	1.361	10.000	.136			
	tw90	Sphericity Assumed	10.131	10	1.013			
		Greenhouse-Geisser	10.131	10.000	1.013			
		Huynh-Feldt	10.131	10.000	1.013			
		Lower-bound	10.131	10.000	1.013			
	tw120	Sphericity Assumed	32.152	10	3.215			
		Greenhouse-Geisser	32.152	10.000	3.215			
		Huynh-Feldt	32.152	10.000	3.215			
		Lower-bound	32.152	10.000	3.215			
block	dprime	Sphericity Assumed	4.371	4	1.093	3.273	.021	.247
		Greenhouse-Geisser	4.371	2.378	1.838	3.273	.048	.247
		Huynh-Feldt	4.371	3.170	1.379	3.273	.032	.247
		Lower-bound	4.371	1.000	4.371	3.273	.101	.247
	beta	Sphericity Assumed	1365.988	4	341.497	3.070	.027	.235
		Greenhouse-Geisser	1365.988	2.443	559.243	3.070	.056	.235
		Huynh-Feldt	1365.988	3.291	415.122	3.070	.037	.235
		Lower-bound	1365.988	1.000	1365.988	3.070	.110	.235
	rtime	Sphericity Assumed	4382.377	4	1095.594	4.899	.003	.329
		Greenhouse-Geisser	4382.377	3.175	1380.440	4.899	.006	.329
		Huynh-Feldt	4382.377	4.000	1095.594	4.899	.003	.329
		Lower-bound	4382.377	1.000	4382.377	4.899	.051	.329
	tw60	Sphericity Assumed	.951	4	.238	.892	.478	.082
		Greenhouse-Geisser	.951	2.611	.364	.892	.446	.082
		Huynh-Feldt	.951	3.617	.263	.892	.470	.082
		Lower-bound	.951	1.000	.951	.892	.367	.082
	tw90	Sphericity Assumed	1.554	4	.389	.867	.492	.080
		Greenhouse-Geisser	1.554	2.572	.604	.867	.456	.080

		Huynh-Feldt	1.554	3.539	.439	.867	.482	.080
		Lower-bound	1.554	1.000	1.554	.867	.374	.080
	tw120	Sphericity Assumed	2.369	4	.592	1.217	.319	.109
		Greenhouse-Geisser	2.369	2.221	1.066	1.217	.319	.109
		Huynh-Feldt	2.369	2.884	.821	1.217	.320	.109
		Lower-bound	2.369	1.000	2.369	1.217	.296	.109
Error(block)	dprime	Sphericity Assumed	13.352	40	.334			
		Greenhouse-Geisser	13.352	23.781	.561			
		Huynh-Feldt	13.352	31.697	.421			
		Lower-bound	13.352	10.000	1.335			
	beta	Sphericity Assumed	4449.246	40	111.231			
		Greenhouse-Geisser	4449.246	24.426	182.154			
		Huynh-Feldt	4449.246	32.906	135.212			
		Lower-bound	4449.246	10.000	444.925			
	rtime	Sphericity Assumed	8944.743	40	223.619			
		Greenhouse-Geisser	8944.743	31.746	281.758			
		Huynh-Feldt	8944.743	40.000	223.619			
		Lower-bound	8944.743	10.000	894.474			
	tw60	Sphericity Assumed	10.658	40	.266			
		Greenhouse-Geisser	10.658	26.111	.408			
		Huynh-Feldt	10.658	36.165	.295			
		Lower-bound	10.658	10.000	1.066			
	tw90	Sphericity Assumed	17.932	40	.448			
		Greenhouse-Geisser	17.932	25.719	.697			
		Huynh-Feldt	17.932	35.394	.507			
		Lower-bound	17.932	10.000	1.793			
	tw120	Sphericity Assumed	19.461	40	.487			
		Greenhouse-Geisser	19.461	22.211	.876			
		Huynh-Feldt	19.461	28.836	.675			
		Lower-bound	19.461	10.000	1.946			
stim * block	dprime	Sphericity Assumed	.518	4	.130	1.482	.226	.129
		Greenhouse-Geisser	.518	3.359	.154	1.482	.234	.129
		Huynh-Feldt	.518	4.000	.130	1.482	.226	.129
		Lower-bound	.518	1.000	.518	1.482	.251	.129
	beta	Sphericity Assumed	125.512	4	31.378	.331	.855	.032

		Greenhouse-Geisser	125.512	2.335	53.746	.331	.754	.032
		Huynh-Feldt	125.512	3.091	40.612	.331	.808	.032
		Lower-bound	125.512	1.000	125.512	.331	.578	.032
	rtime	Sphericity Assumed	67.243	4	16.811	.280	.889	.027
		Greenhouse-Geisser	67.243	2.765	24.320	.280	.824	.027
		Huynh-Feldt	67.243	3.927	17.122	.280	.886	.027
		Lower-bound	67.243	1.000	67.243	.280	.608	.027
	tw60	Sphericity Assumed	.561	4	.140	.249	.908	.024
		Greenhouse-Geisser	.561	2.600	.216	.249	.835	.024
		Huynh-Feldt	.561	3.595	.156	.249	.892	.024
		Lower-bound	.561	1.000	.561	.249	.628	.024
	tw90	Sphericity Assumed	2.060	4	.515	1.173	.337	.105
		Greenhouse-Geisser	2.060	3.059	.674	1.173	.337	.105
		Huynh-Feldt	2.060	4.000	.515	1.173	.337	.105
		Lower-bound	2.060	1.000	2.060	1.173	.304	.105
	tw120	Sphericity Assumed	4.251	4	1.063	2.262	.079	.184
		Greenhouse-Geisser	4.251	2.375	1.790	2.262	.119	.184
		Huynh-Feldt	4.251	3.164	1.343	2.262	.097	.184
		Lower-bound	4.251	1.000	4.251	2.262	.163	.184
Error(stim*block)	dprime	Sphericity Assumed	3.497	40	.087			
		Greenhouse-Geisser	3.497	33.594	.104			
		Huynh-Feldt	3.497	40.000	.087			
		Lower-bound	3.497	10.000	.350			
	beta	Sphericity Assumed	3789.499	40	94.737			
		Greenhouse-Geisser	3789.499	23.353	162.273			
		Huynh-Feldt	3789.499	30.905	122.617			
		Lower-bound	3789.499	10.000	378.950			
	rtime	Sphericity Assumed	2404.869	40	60.122			
		Greenhouse-Geisser	2404.869	27.649	86.979			
		Huynh-Feldt	2404.869	39.272	61.237			
		Lower-bound	2404.869	10.000	240.487			
	tw60	Sphericity Assumed	22.532	40	.563			
		Greenhouse-Geisser	22.532	26.000	.867			
		Huynh-Feldt	22.532	35.945	.627			
		Lower-bound	22.532	10.000	2.253			

tw90	Sphericity Assumed	17.565	40	.439
	Greenhouse-Geisser	17.565	30.589	.574
	Huynh-Feldt	17.565	40.000	.439
	Lower-bound	17.565	10.000	1.757
tw120	Sphericity Assumed	18.790	40	.470
	Greenhouse-Geisser	18.790	23.753	.791
	Huynh-Feldt	18.790	31.645	.594
	Lower-bound	18.790	10.000	1.879

Table B4. Univariate Result of Two-way ANOVA of all Measure

*3. block * stim*						
Measure	block	stim	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
dprime	1	1	4.302	.125	4.024	4.580
		2	4.309	.175	3.918	4.700
	2	1	4.190	.240	3.656	4.724
		2	3.949	.245	3.403	4.496
	3	1	3.942	.244	3.398	4.487
		2	4.023	.203	3.572	4.474
	4	1	3.704	.199	3.260	4.148
		2	3.877	.190	3.454	4.299
	5	1	3.760	.271	3.156	4.364
		2	3.759	.272	3.152	4.366
beta	1	1	11.173	3.614	3.121	19.226
		2	12.643	3.542	4.751	20.535
	2	1	15.345	4.039	6.345	24.346
		2	15.192	4.947	4.169	26.215
	3	1	16.178	3.028	9.432	22.925
		2	21.224	4.938	10.221	32.227
	4	1	20.595	4.375	10.847	30.343
		2	24.280	4.983	13.177	35.383
	5	1	18.240	4.286	8.689	27.791
		2	17.829	4.110	8.671	26.987
rtime	1	1	393.501	9.455	372.434	414.568
		2	397.535	9.714	375.891	419.180
	2	1	401.337	10.219	378.568	424.105
		2	403.858	10.214	381.099	426.617
	3	1	402.499	7.601	385.563	419.435
		2	404.822	9.197	384.330	425.315
	4	1	411.787	7.924	394.131	429.443
		2	411.093	7.729	393.872	428.314
	5	1	412.132	8.988	392.105	432.158
		2	413.418	9.413	392.445	434.391
tw60	1	1	.390	.194	-.043	.824
		2	.383	.154	.040	.725
	2	1	.343	.180	-.057	.743

		2	.198	.184	-.211	.607
	3	1	.519	.227	.013	1.024
		2	.596	.173	.211	.982
	4	1	.451	.199	.007	.895
		2	.315	.222	-.180	.811
	5	1	.243	.109	-.001	.486
		2	.481	.300	-.188	1.151
tw90	1	1	.186	.217	-.297	.669
		2	.867	.232	.349	1.385
	2	1	.418	.238	-.112	.948
		2	.664	.225	.163	1.164
	3	1	.707	.205	.251	1.163
		2	.908	.250	.352	1.465
	4	1	.378	.279	-.244	1.000
		2	.613	.158	.260	.966
	5	1	.061	.255	-.506	.628
		2	.925	.351	.142	1.708
tw120	1	1	-.703	.268	-1.299	-.106
		2	-.008	.377	-.847	.831
	2	1	-.352	.288	-.994	.289
		2	.028	.365	-.784	.841
	3	1	-.265	.270	-.866	.337
		2	.399	.390	-.471	1.268
	4	1	-.128	.322	-.846	.589
		2	.098	.308	-.588	.783
	5	1	-.725	.305	-1.405	-.045
		2	.646	.345	-.123	1.415

Table B5. Mean of all measures for upper and lower position stimuli in five experiment blocks