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An experiment on attention ability based on Electroencephalogram (EEG) in different PMV Conditions

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Abstract

Occupants' attention ability in seven PMV conditions is measured by means of electroencephalogram (EEG) and verbal voting. This can show us occupants' attention state change by time and environmental condition. To achieve the objective of this study, seven healthy male students' EEG was measured in seven PMV conditions each. Their EEG was measured in each condition for 65 minutes. EEG was measured on Fp1 and Fp2, and sorted out according to the frequency using power spectral analysis. The following results were achieved. First, in scope of moderate temperature environment, a higher level of attention was shown in relatively lower temperatures than in higher temperatures. Second, higher level of attention was shown in higher temperature in extreme condition compared to extremely cold temperature. Third, the occupants' attention ability, measured by EEG varied with time and was found to be different than the occupants' perceived attention from a verbal vote.

Keywords: Attention, EEG, PMV

1 INTRODUCTION

This study was conducted in the fall of 2013 as a follow-up of a previous research on stress that was carried out in the spring of 2013 (Choi, 2014; -Windsor Conference) in order to explore the attention ability of occupants based on EEG measurements, using the Predicted Mean Vote model.

Attention can be defined as the cognitive process of concentrating on something in order to complete a certain task within a specific time span (Silverman, 1964). While most studies have measured productivity as a result of performance, they have ignored the process of attention as a basic element of performance. Such methodology has missed the opportunity to explain the complicated process of how indoor environments affect the occupants' productivity both physiologically and psychologically.

Actually, many studies that have explored the effect of the indoor thermal environment on occupants' attention and productivity (Choi and Chun, 2009; Kim et al., 2007; Mazon, 2013; Tham and Willem, 2010) have used psychological paper tests to measure the attention ability, neglecting the process of how indoor environments can affect human productivity. Recently, many studies that have explored attention ability by using electroencephalogram (EEG) measurements have been published in different subject areas including education, physical education, ergonomics and human sensibility ergonomics (Derbali et al., 2011; Kim and Sul, 2003; Park et al., 2010; Shim and Seung, 2009). However, it would be useful to measure the effectiveness of brain activity related to temporal variations in attention using

approaches that rely on something other than paper tests. Electroencephalogram (EEG) is the recording of the electrical potential between various points on the surface of the scalp. The EEG signal can be analysed by reference to the time or the frequency domain of the signal. Frequency-domain analyses are based on measurements of the frequency of the signal, as in power spectral analysis (Hugdahl, 1995). In this way, the EEG is divided into the following frequency bands: delta (0-4Hz), theta (4-8Hz), alpha (8-13Hz), beta (13-30Hz) and gamma (30-50Hz).

In this study, Sensory Motor Rhythm (SMR) waves are used to investigate concentration. SMR waves are defined in the frequency range of 12-15 Hz and they encompass both alpha waves and beta waves. This frequency range is an attention-related range (Sterman, 1977). The middle beta (16-20Hz) waves are often aroused when a person is engaged in high mental activity, such as learning, memorising or computing. Previous studies that have examined attention using EEG analysis applied the ratio of the theta wave activity, which is associated with the state of sleepiness, to the sum of the SMR wave activity and the middle beta activity. In this study, a specific power ratio, (SMR+Middle Beta/Theta) was used to analyse attention level (Lee et al., 2009).

In one of our previous research studies, which explored the effect of indoor air temperature on the occupants' attention ability based on electroencephalogram analysis, the EEG frequency showed that, for the selective attention aspect, the occupants' attention increased to a greater degree at a lower temperature (20.5℃) than it did at a neutral temperature (24.0℃). In addition, in the process of maintaining concentration, the occupants' attention was shown to occur more immediately at a lower temperature in comparison to a neutral temperature, and the occupants also achieved awakening status faster, enabling them to retain their attention (Lee et al., 2012). However, this study had some limitation in that the experiment was only conducted using two temperatures (20.5℃ and 24.0℃).

In this context, the purpose of this study is to analyse the impact of the indoor air temperature (in the range from PMV-3 to PMV+3) on the occupants' attention ability based on electroencephalogram (EEG) measurements. The findings of this study can contribute to the findings from other research studies that have been carried out on the relationship between thermal environments and performance. Moreover, this study aims to identify the temporal variations of attention in different air temperatures.

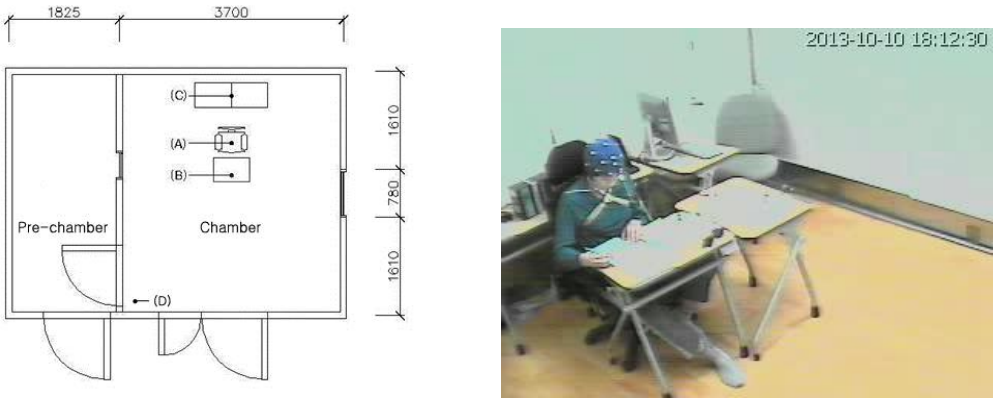
2 METHODS

2.1 Experimental Conditions

The experimental period was from September to December in 2013. 7 male students (ages 22-28) participated in the study and received monetary compensation. Their participation was approved by the Institutional Review Board (IRB) at Yonsei University. The subjects reported that they were in good health and were not diagnosed with brain diseases. Experiments were conducted in a climate chamber in the Yonsei University. The experiments consisted of seven conditions, which were calculated by using the equation of Predicted Mean Vote by Fanger (1970). The air temperature was changed, as shown in Table 1. The other environmental conditions were: 50% relative humidity, 0.1m/s air velocity, 0.7clo clothing value and 1.0met metabolism. The subjects were placed in a pre-chamber, set at a neutral temperature (PMV0), in order to insure that they were thermally equal prior to the experiment. Figure 1 shows the feature of the climate chamber.

Table 1. Climate chamber conditions and related by PMV values

PMV	Air temperature (℃)	
	set	actual
-3	14.60	14.79 ± 0.06
-2	17.80	17.92 ± 0.06
-1	21.10	21.12 ± 0.03
0	24.40	24.40 ± 0.01
+1	27.60	27.47 ± 0.06
+2	30.80	30.81 ± 0.00
+3	33.80	33.80 ± 0.03



a) b)

Figure 1. The feature of climate chamber. a) Plan of the chamber b) Participant wired with and EEG electrode

2.2 Measuring Tools: EEG recording System

The electroencephalogram (EEG) was recorded with Ag/AgCl electrodes from 8 scalp locations by 10-20system(Jasper, 1958) using an electrode cap. The right earlobe served as reference. The recording locations included 4 lateral sites to the left of the midline (Fp1, F3, T3, P3), and their homologous sites to the right of the midline as shown in Figure 2. Electrooculogram (EOG) was recorded for artifacts including blinks and eye movements using disposable surface electrodes (Tyco Healthcare Group LP, Norwalk, CT, USA). All signals were recorded with bio-signal instrumentation system MP150 (Biopac system Inc., Santa Barbara, CA, USA). A 0.1-35Hz band-pass filter was used for all online recordings. EEG and EOG were sampled at 1000Hz. A Power Spectral Density using the 'BrainMap-3D' S/W (Laxtha, Daejeon, Korea) was computed to divided the EEG raw signal into the three following frequencies: Theta (4-8Hz), SMR (12-15Hz) and Middle Beta (16-20Hz) in order to compute the attention level ((SMR+M-Beta)/Theta) as described above.

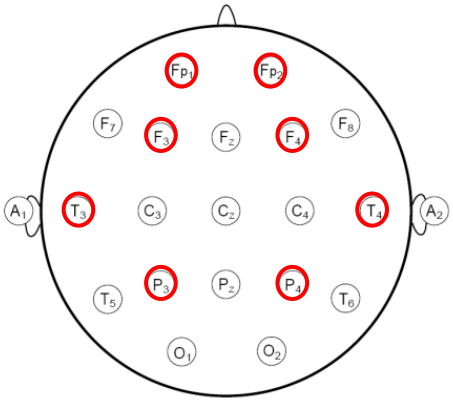


Figure 2. International 10-20 system of electrode placement (Jasper, 1958)

2.3 Experimental Procedures

Each subject was exposed to seven different PMV conditions, i.e. one condition per day. EEG electrodes were attached after the subjects put on sweatshirts and pants. The subjects then sat in the pre-chamber for 15 minutes in order to adapt to the neutral environment. They then moved to the climate chamber and the electrodes were connected to a computer. During the experiment, the subjects were asked to study or read a book for 65 minutes. After measuring EEG for 65minutes, the subjects were asked to answer how well they were able to concentrate, selecting from a response range that varied from 'Couldn't concentrate at all' to 'Concentrated very well'. To control the order effect, the experimental condition order of each of the subjects was different, as shown in Table 2. In total 49 experiments were conducted.

Table 2. Order of the experiment for each subject

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Subject A	PMV-3	PMV-2	PMV-1	PMV0	PMV+1	PMV+2	PMV+3
Subject B	PMV-2	PMV-1	PMV0	PMV+1	PMV+2	PMV+3	PMV-3
Subject C	PMV-1	PMV0	PMV+1	PMV+2	PMV+3	PMV-3	PMV-2
Subject D	PMV0	PMV+1	PMV+2	PMV+3	PMV-3	PMV-2	PMV-1
Subject E	PMV+1	PMV+2	PMV+3	PMV-3	PMV-2	PMV-1	PMV0
Subject F	PMV+2	PMV+3	PMV-3	PMV-2	PMV-1	PMV0	PMV+1
Subject G	PMV+3	PMV-3	PMV-2	PMV-1	PMV0	PMV+1	PMV+2

3 RESULTS

In this study, Fp1 and Fp2 EEG channels were analysed since previous studies on attention ability using the frequency of SMR+Middle Beta/Theta also analysed those two channels (Jang and Lee, 2008; Lee et al., 2012; Lee et al., 2009).

3.1 Attention Ability in Mild Temperatures

In this part of the experiment, the level of attention in PMV+1, 0 and -1 conditions was compared because a space that is hotter than PMV+1 or colder than PMV-1 is unsuitable for an actual indoor environment.

Figure 3 shows the brain mapping of the attention response variation with time for PMV=-1, PMV=0 and PMV=+1. The 65 minutes of exposure time was divided into

13 sections by five-minute intervals. The values of relative power are expressed by colour in high-to-low order: red, orange, yellow, green, blue, and violet.

At all times, the pre-frontal lobe brain activity of the occupants was higher in the PMV0 and PMV-1 conditions than it was in the PMV+1 condition. The brain activity was higher in the PMV-1 condition than it was in the PMV0 condition during the first half of the exposure (1-30 min.), but it was higher in the PMV0 condition than it was in the PMV-1 condition in the latter half of the exposure (30-65 min.).

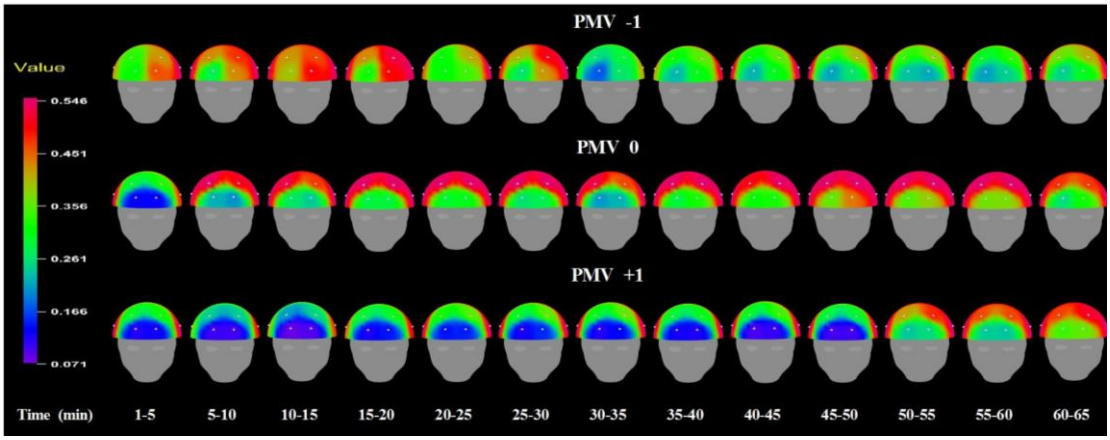
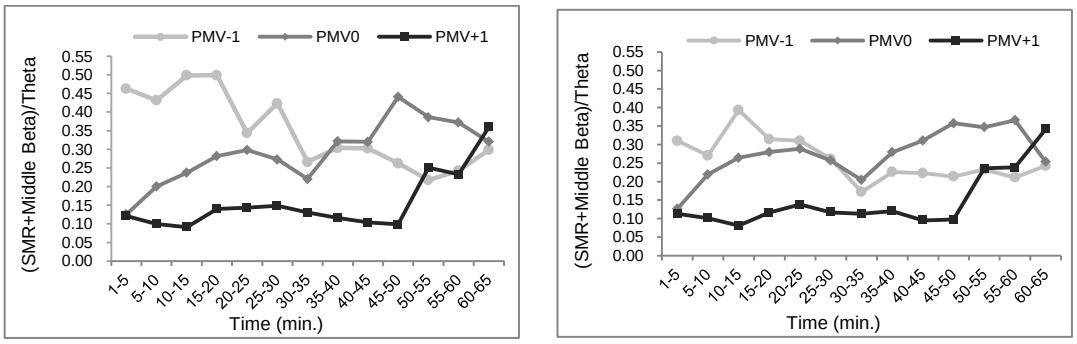


Figure 3. Mapping for the attention with time in PMV-1, PMV0 and PMV+1

Figure 4 shows the result of mapping as a graph. There seems to be a reverse phenomenon starting from 30 minutes between the PMV0 condition and the PMV-1 condition, as mentioned above.

Lee et al (2012) mentioned that a PMV-1 condition is more favourable for selective function of attention than a PMV0 condition, and this finding is also supported by the results of this current research. However, this current study also found that a reverse phenomenon occurred between the PMV0 and PMV-1 conditions after 30 minutes.

The EEG of attention was relatively low in the PMV+1 condition as compared to the PMV0 or PMV-1 conditions in all the experimental times except for last 10 minutes. In order to examine the continuous aspect of this progress, it is necessary to expand the length of the experimental time.

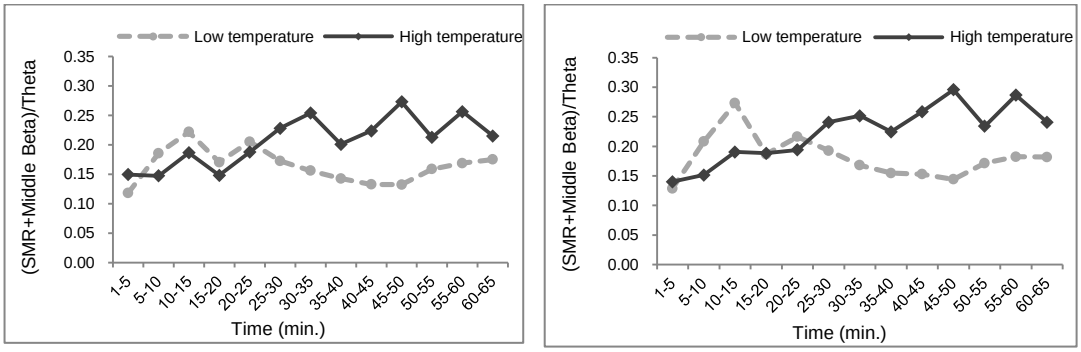


a) b)

Figure 4. Temporal variation of attention in the pre-frontal lobe. a) Fp1, b) Fp2

3.2 Attention Ability in Extreme Temperatures

Figure 5 shows the course of attention (SMR+Middle Beta/Theta) in the pre-frontal lobe with time in low (PMV-3&-2) and high (PMV+3&+2) temperatures. The brain activity in a low temperature environment means the mean value of the brain activity in PMV-3 and -2 conditions; in a high temperature environment, the mean value of the brain activity in PMV+3 and +2 conditions. At the beginning of experiment, the low temperature environment was slightly better for concentration as compared to the high temperature environment. However, after 25 minutes, a significant change in the ability to concentrate occurred between the low temperature environment and the high temperature environment. The brain was activated to a greater degree in the high temperature environment than it was in the low temperature environment. It seems that, after 25 minutes, the occupants were able to maintain continuous attention better in an environment with an extremely higher temperature than in an environment with an extremely lower temperature.



a) b)

Figure 5 Temporal variation of attention in the pre-frontal lobe in high and low temperature. a) Fp1, b) Fp2

3.3 Comparison with Perceived Attention

Figure 6 shows the attention (SMR+Middle Beta/Theta) in the pre-frontal lobe with PMV after 60 minutes, and Figure 7 shows the verbal vote of perceived attention at the same time (0 = couldn't concentrate at all; 6 = concentrated very well). Broadly speaking, the aspect of brain activity seems similar to the verbal vote of perceived attention in the left and right pre-frontal lobe. Based on the EEG analysis, the highest attention level occurred in the PMV+1 condition, but in the verbal vote it occurred in both the PMV0 condition and the PMV+1 condition. For the verbal vote, the lowest attention level occurred in the higher temperature environment (PMV+2, PMV+3), while the lowest brain activity occurred in the low temperature environments (PMV-2, PMV -3).

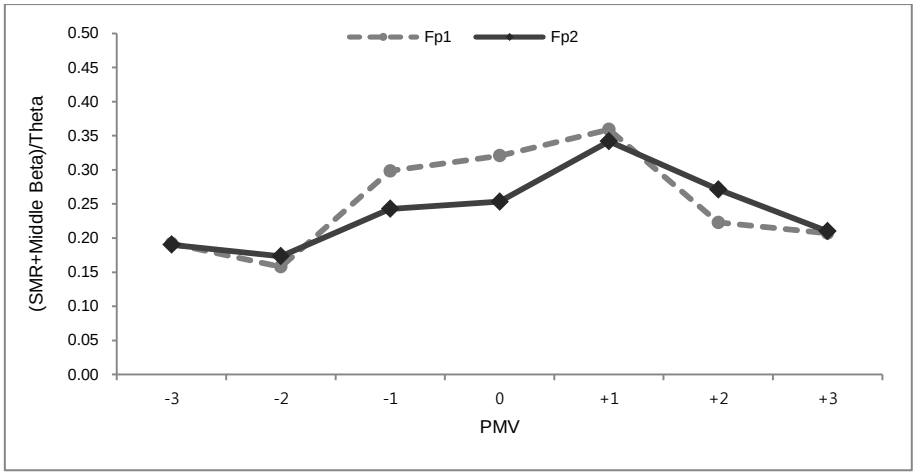


Figure 6 Attention in the pre-frontal lobe with PMV after 60min

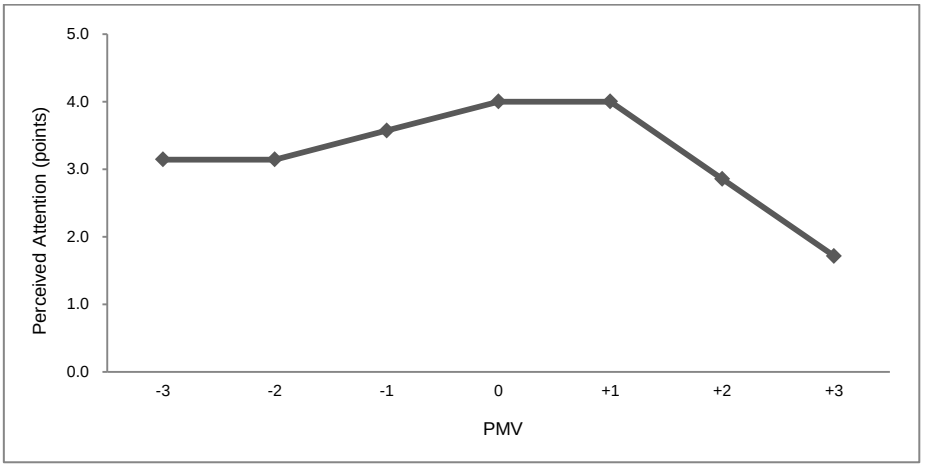


Figure 7 Perceived attention with PMV

Figure 8 shows the brain activity of attention in the pre-frontal lobe with PMV from the beginning of the experiment, at five minutes, and after 60 minutes. The brain was most activated in the PMV-1 condition right after the beginning of the experiment, while it was most activated in the PMV+1 condition at the end of the experiment. It seems that the occupants' attention ability, as measured by EEG, varies over time. When starting the experiment, the brain activity in the PMV-1 condition was found to be significantly higher than it was in the other conditions. However, the difference between the conditions decreased after 60 minutes and the highest brain activity was found to occur in the PMV0 and PMV+1 conditions. This suggests that indoor air temperature increasing affects the occupants' attention early in the process of concentrating, but it seems that the effect of temperature decreases as the occupants adapt to the environment as time goes by.

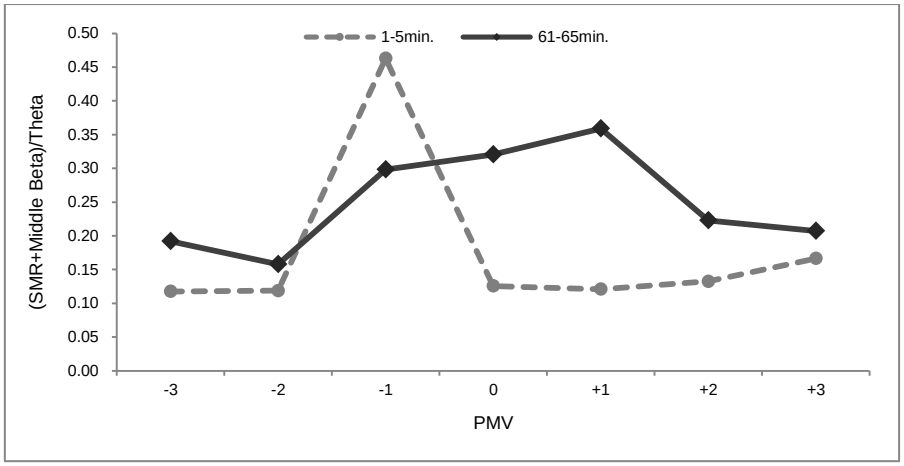


Figure 8 Comparison of attention by time passed

4. CONCLUSIONS

This study was conducted in various indoor air temperature environments using a PMV model based on EEG measurement in order to investigate the effect of indoor air temperature on the occupants' attention ability. The following are some of the insights gained from the experiment.

Relatively lower temperature had the advantage of increasing the occupants' attention at the beginning of the experiment. However, higher temperature had the advantage of maintaining the occupants' attention after 25 minutes (in extreme conditions) and after 30 minutes (in moderate conditions).

The increase in attention was the best at the beginning of the PMV-1 condition. This effect from temperature was decreased over time. After one hour, not much difference in the ability to maintain attention was found between the PMV-1 condition and the PMV +1 condition, and the PMV+1was the best condition.

The results for perceived attention by verbal vote were different than the results for brain activity. The subjects noted that the PMV0 condition and the PMV+1 condition were both best for attention, but brain activity was better in the PMV+1 condition.

In conclusion, indoor thermal environments that support attention should be changed over time. This dynamic control of air temperature is required technology in places where occupants need to focus their attention, such as offices, classrooms, laboratories, etc.

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References

Choi, Y. & Chun, C., 2009. The Effect of Indoor Temperature on Occupants' Attention Abilities. *Journal of the Architectural Institute of Korea,* 25(12)**,** pp 411-418.

Derbali, L., Chalfoun, P. & Frasson, C., 2011. Assessment of Learners' Attention While Overcoming Errors and Obstacles: An Empirical Study. *Artificial Intelligence in Education,* 6738, pp 39-46.

Fanger, P.O., 1970. *Thermal comfort,* Copenhagen : Danish Technical Press.

Hugdahl, K., 1995. *Psychophysiology: The mind-body perspective,* Cambridge : Harvard University Press.

Jang, S. & Lee, H., 2008. The Effect of Musical Genre on Mental Focusing. *Korean Journal of Psychology,* 2008**,** pp 262-263.

Jasper, H. H., 1958. The ten twenty electrode system of the international federation. *Electroencephalography and clinical neurophysiology,* 10**,** pp 371-375.

Kim, D., Kim, S., Park, S., Jeon, M., Kim, G., Kim, C., Chung, J., Baek, S. & Sakong, J., 2007. The Effects of Indoor Air Quality on the Neurobehavioral Performance of Elementary School Children. *Annals of Occupational and Environmental Medicine,* 19(1)**,** pp 65-72.

Kim, J. & Sul, J., 2003. The Effects of the Concentration and Imagery Through the Regulation of the Brain Wave on the Performance Learning of Golf Putting. *Journal of Korean Society of Sport Psychology,* 14(3), pp 355-364.

Lee, C., Kwon, J., Kim, G., Hong, J., Shin, D. & Lee, D., 2009. A Study on EEG based Concentration Transmission and Brain Computer Interface Application. *Journal of the institute of electronics engineers of Korea,* 46(2)**,** pp 41-46.

Lee, H., Choi, Y. & Chun, C., 2012. Effect of Indoor Air Temperature on the Occupants' Attention Ability based on the Electroencephalogram Analysis. *Journal of the Architectural Institute of Korea,* 28(3)**,** pp 217-225.

Mazon, J., 2013. The influence of thermal discomfort on the attention index of teenagers: an experimental evaluation. *International journal of biometeorology***,** pp 1-8.

Park, S., Hu, H. & Lee, W., 2010. A Study on Physiological Signal Changes Due to Distraction in Simulated Driving. *Journal of the Ergonomics Society of Korea,* 29(1)**,** pp 55-59.

Shim, J. & Seung, I., 2009. Influences of Brain Education Program on Concentration and Prefrontal EEG Activation of Children`s. *Journal of the Korean Society for Child Education,* 18(3)**,** pp 19-36.

Silverman, J., 1964. The problem of attention in research and theory in schizophrenia. *Psychological Review,* 71(5), pp 352.

Sterman, M., 1977. Sensorimotor EEG operant conditioning: Experimental and clinical effects. *The Pavlovian Journal of Biological Science: Official Journal of the Pavlovian,* 12(2)**,** pp 63-92.

Tham, K. W. & Willem, H. C., 2010. Room air temperature affects occupants' physiology, perceptions and mental alertness. *Building and Environment,* 45(1)**,** pp 40-44.