行政院國家科學委員會專題研究計畫　成果報告

子計畫一：以 VR 動感平台為基礎之人機介面操控者心理工作負荷偵測(I)

計畫類別：整合型計畫
計畫編號：NSC93-2218-E-009-023-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：國立交通大學電機與控制工程學系(所)

計畫主持人：林進燈

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行政院國家科學委員會補助專題研究計畫 ■ 成 果 報 告 □期中進度報告

以生理訊號為基礎之人機介面設計與應用–人類操控機器的新模式–子計畫

一：以 VR 動感平台為基礎之人機介面操控者心理工作負荷偵測(Ｉ)

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計畫主持人：林進燈 教授
共同主持人：
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中　華　民　國　94 年　10　月 11　日

行政院國家科學委員會專題研究計畫成果報告

以生理訊號為基礎之人機介面設計與應用−人類操控機器的新模式−子計畫一：以 VR 動感平台為基礎之人機介面操控者心理工作負荷偵測(Ⅰ)

計畫編號：NSC 93－2218－E－009－023－

執行期限：93 年 08 月 01 日至 94 年 07 月 31 日

主持人：林進燈

Abstract

The electroencephalographic (EEG) relates of driver's mental workload changes is studied in this research. Accidents usually caused by lack of alertness and awareness have a high fatality rate especially in night driving environments. It becomes extremely dangerous in some situations such as the appearance of an unexpected obstacle in the middle of the road. Combining the technology of virtual reality (VR), a realistic driving environment is developed to provide stimuli to subjects in our research. The VR scene designed in our experiment is driving a car on the freeway at nighttime. Independent Component Analysis (ICA) is used to decompose the sources in the EEG data. ICA combined with power spectrum analysis and correlation analysis is employed to investigate the EEG activity related to driver's mental workload. According to our experimental results, the appearance of N400 Event-Related Potential (ERP) at CPz is highly correlated to the surprising mental status. Furthermore, the level of surprising status can be evaluated with the amplitude of the N400 ERP.

Key Word: metal workload, independent component analysis (ICA), Electroencephalogram (EEG), virtual reality (VR), Event-Related Potential (ERP).

1. Introduction

The incidence of road collisions and the resulting deaths, injuries and property damage have been regarded as a significant social problem. In many instances, the traffic accidents often occur from late at night to early morning, and especially when the driver is distracted. Driving at night is one of the most hazardous situations commonly faced by the driver. It is now well known that the rate of fatal traffic accidents is 3 to 4 times higher at night than at daytime. It is also understood that under nighttime conditions, many humanvisual abilities such as spatial resolution, contrast discrimination, stereoscopic depth perception, accommodation, response and reaction time are degraded [1]. So that nighttime driving is a serious issue for more investigations, especially for the appearance of unexpected obstacles. This critical issue motivates us to discover what reactions happened in the human brain when a driver encountered the unexpected obstacle. Driver reactions to the sudden incidental appearance of an object such as a child rushing out may differ depending on the driver's attention to the peripheral scene. A more complete understanding of the attentive mechanisms of the brain will improve driver responses and increase driving safety. K. Eba and his group [2] introduced a real driving experiment to observe the brain activities related to driving situation. In a car driving task with and without an unexpected dummy doll rushing out, they recorded the homodynamic activities of the frontal lobe by near infrared spectroscopy (NIRS). As a result, they concluded that the right rostromedial prefrontal cortex can play important roles in spatial attentive recognition of driving scene. By the progressed improvement of virtual-reality technology, we can do more realistic driving experiments for driver's mental workload study in VR environment to save the time and costs.

The use of driving simulation for vehicle design and driver perception studies is progressing rapidly. This is because how applicable driving simulation is to the real world is unclear. Keneny and Panerai [3] suggested that, in driving simulators with a large field of view, longitudinal speed can be estimated correctly from visual information. On the other hand, recent psychophysical studies have revealed an unexpectedly important contribution of vestibular cues in distance perception and steering, prompting a re-evaluation of the role of visuo–vestibular interaction in driving simulation studies.

For the event-related-based EEG studies, some specific features of EEG are expected to occur in the brain activities respecting to different situations. Moreover, the Event-Related Potential [4-6] analysis has widely used for the EEG data processing. The interested target is called a single event within the experiments, thus the brain activities related to the event were extracted for further analysis. The key problem to perform such a work is the inability to dynamically quantify cognitive changes in the human capacity. In this project, we has tried to determine the relationship between different stimuli and human cognitive responses accompanying correct, incorrect and absent motor responses through the use of event-related brain potential (ERP) signals. Moreover, we concern about the unexpected obstacle dodging task related to the ERP response.

Some studies have been proposed incongruent cognitive state. In these studies, they proposed an incongruent situation to induce the N400 by visual or auditory stimulus [6]. The N400 is a broad negative wave that peaks in the surface EEG around 400 ms after a semantically incongruous word in a meaningful sentence [7-8]. There are also many studies proposed that the N400 can be elicited in response to semantic processing of non-verbal stories [9].

In this project, we want to investigate the EEG dynamics related to the unexpected obstacle dodging subjects' task. With combining the technology of virtual reality (VR), a realistic stimuli environment is provided to subjects in our research. An unexpected task is provided to the subjects with a broken-down car appears in the middle of the road. The subjects are requested to dodge the broken-off car as soon as possible without collision in the experiments. One of the main purpose of our research is to investigate EEG changes relate to mental workload by analyzing the subjects' EEG features corresponding to the With-Cue task and the Without-Cue task.

This report is organized as follow. The experimental setup is given in Section II. In Section III, we explore the signal analysis procedure by applying ICA, power spectrum analysis, and correlation coefficient. The experimental results are described in Section IV. Detailed discussions of our experimental results are given in Section V. Finally, the conclusions are summarized in Section VI.

2. Experimental Setup

The main purpose of our research is to investigate EEG changes relate to mental workload by analyzing the subjects' EEG features corresponding to the With-Cue task and the Without-Cue task. As we have mentioned in Section 1, the previous studies of incongruent context were focused on semantics [2-6, 10-12]. With combining the technology of virtual reality (VR), a realistic stimuli environment is provided to subjects in our research. The experimental setup is shown in Figure 1

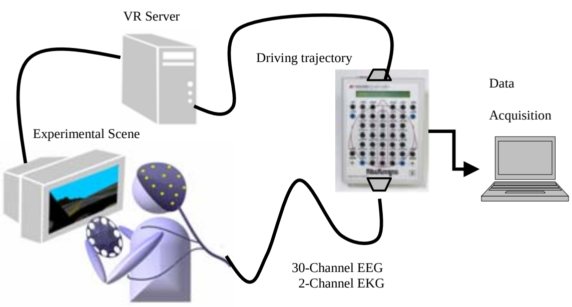


Figure 1. Block diagram of the virtual-reality (VR)-based driving simulation environment and physiological signal acquisition.

In our experiments, subjects are asked to sit in front of a monitor with their hands on the steering wheel to control the car in the VR environment. A 30-channel EEG electrode cap was mounted on the subject's head and a 2-channel electrode was put at the middle of the chest to record the physiological EEG, EOG and EKG signals. The physiological signals and the event data from the scene are then send through the Neuroscan biomedical signal amplifier to the data acquisition laptop.

The VR Scene Driving Environment

The fatality rate of nighttime driving accidents is much higher than that in daytime because the driver's abilities of vision, vehicle control are obviously declined in nighttime. The response time of the drivers will also be slow due to the range of visibility is diminished in nighttime. It becomes extremely dangerous in some situations, such as the appearance of an unexpected obstacle in the middle of the road. We designed a nighttime driving experiment in this study. The VR scene was displayed on a color XVGA 42" Plasma Display Panel (PDP) to simulate a night driving scene on freeway. The subjects are asked to sit in front of the PDP with the distance 60cm between subject and displayer. The freeway VR scene we used in this research includes four lanes from left to right of the road, as shown in Figure 2. The distance from the left side to the right side of the road is equally divided into 256 points (digitized into values 0-255), where the width of each lane and the car are 60 units and 32 units, respectively. The frame rate of the scene changes as the driver is driving at a fixed velocity of 120 km/hr on freeway. The subjects are asked to keep the car in the VR scene in the middle of the third lane (left-counting).

Protocol of the Experiment

The subject is asked to control the simulated car in the VR scene with the steering wheel and keep the car in the middle of the third lane. A surprising task is provided to the subjects with a broken-down car appears in the middle of the road. The subjects are requested to dodge the broken-off car as soon as possible without collision in the experiments. Two different tasks are designed for the further EEG investigation: they are the Without-Cue task and With-Cue task. In the Without-Cue task, the unexpected broken-off cars will appear randomly in front of the simulated car appeared without any cue. By contrast, an exclamation mark will appear before the broken-off car in the With-Cue task, to reduce the surprising level to subjects. One of the main purpose of our research is to investigate EEG changes relate to mental workload by analyzing the subjects' EEG features corresponding to the With-Cue task and the Without-Cue task. The Inter-trial intervals (ITIs) are set from 10 to 30 seconds, and differ from trial to trial randomly to aviod the anticipating effect of subjects. The experimental setting is given in Figure 3.

Figure 2. The experimental VR scene of nighttime driving with a broken car.

Each subject participated in three nighttime driving experiments in three different days. The experiments start from a 1~5 minutes training session and follows by two 30-min sessions including a 5 min break between these two experiments. The EEG signals as well as the steering angle trajectory are recorded synchronously during the experiments. The exclamation mark is designed to provide a simple hint to subjects before the broken-off car appears in the With-Cure task.

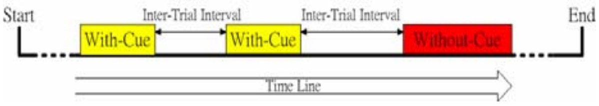


Figure 3. The experimental scheme.

Subjects and Signal Collection

Ten healthy volunteers (including seven males and three females) with no history of gastrointestinal, cardiovascular, or vestibular disorders participated in the experiments. They were requested not to smoke, drink caffeine, use drugs, or drink alcohol, all of which could influence the central and autonomic nervous system for a week prior to the main experiment. Screening confirmed that subjects were free of past or current psychiatric and neurological disorders. Three subjects' EEG data were excluded for further analysis because of the unexpected artifacts (ex: severe head shaking) within the data. A total of seven subjects (one female and six males, ages from 21 to 26, all right-handed) with normal or corrected normal vision participated in the VR-based unexpected-incident driving experiment are their EEG signals and the steering angle trajectory were simultaneously recorded. An electrode cap is mounted on the subject's head for signal acquisition on the scalp. The EEG electrodes were placed based on the 10-20 International System.

3. Analysis Procedure

In this project, we proposed an EEG analysis procedure to investigate the EEG changes related to different surprising status through analysis the ERP difference between the with-cue and without-cue tasks as shown in Figure 4. The sampling rate of the 30-ch EEG signals is 250Hz. The EEG signals were filtered with a 1~50Hz band-pass filter for line noise and artifacts removal. The ERP extraction process in this study is -100 ms to 1000 ms respected to the onset of obstacle appearance. The extracted ERP are processed by the independent component analysis (ICA) for the blind source (or component) decomposition.

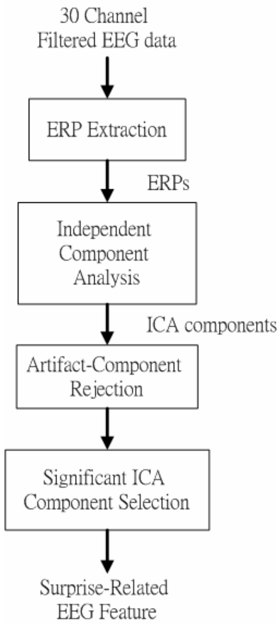


Figure 4. Flowchart of the EEG signal analysis procedure.

Independent Component Analysis

The first applications of ICA to biomedical time series analysis were presented by Makeig et al. [13]. This report showed segregation of eye movements from brain EEG phenomena, and separation of EEG data into constituent components defined by spatial stability and temporal independence. Subsequent technical reports by Ghahremani, Makeig, and Jung et al. [14-17] demonstrated that ICA could also be used to remove artifacts from continuous or event-related (single-trial) EEG data prior to averaging. In our experiment, we assume that the multi-channel EEG recordings are mixtures of underlying brain sources and artificial signals. We suppose that the number of sources is the same as the number of sensors by assuming that the source numbers contributing to the scalp EEG are statistically independent; that is, if there are N sensors, the ICA algorithm can separate N source components. The conduction of the EEG sensors is assumed to be instantaneous and linear such that the measured mixing signals are linear and the propagation delays are negligible. We also assume that the signal source of muscle activity, eye, and cardiac signals are not time locked to the sources of EEG activity which is regarded as reflecting synaptic activity of cortical neurons. Therefore, the time courses of the sources are assumed to be independent. The important fact of using ICA to distinguish a source, s_i, from mixtures, x_i, is that the activity of each source is statistically independent of the other sources [17]; i.e., the mutual information between any two sources, s_i and s_j, is zero. The task of ICA algorithm is to recover a version of the original sources S by finding a square matrix W that inverts the mixing process linearly and saves the identical scale and permutation. For EEG analysis, the rows of the input matrix X are the EEG signals recorded at different electrodes, the rows of the output data matrix U = WX are time courses of activation of the ICA components The columns of the inverse matrix W^{-1} give the projection strengths of the respective components onto the scalp sensors. The scalp topographies of the components provide information about the location of the sources (e.g., eye activity should project mainly to frontal sites and the visual event-related potential is on the center to posterior area, etc.). "Corrected" EEG signals can then be derived as $X = W^{-1}U$.

Event-Related Potential (ERP) Analysis procedure

The unexpected obstacle can be regarded as a single event within the experiments. Thus, the single-trial Event-related potential (ERPs) in with-cue tasks and without-cue tasks are extracted and collected for the following analysis, as shown in Figure 5.

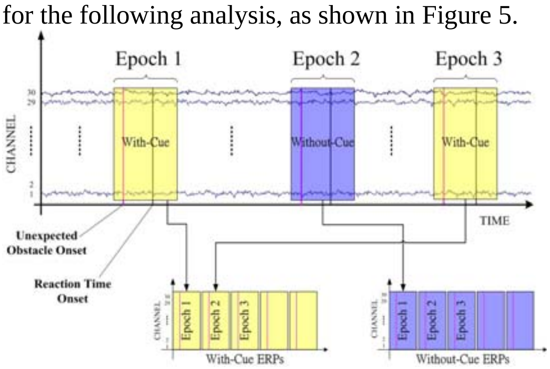


Figure 5. ERP Extraction from EEG Raw Data.

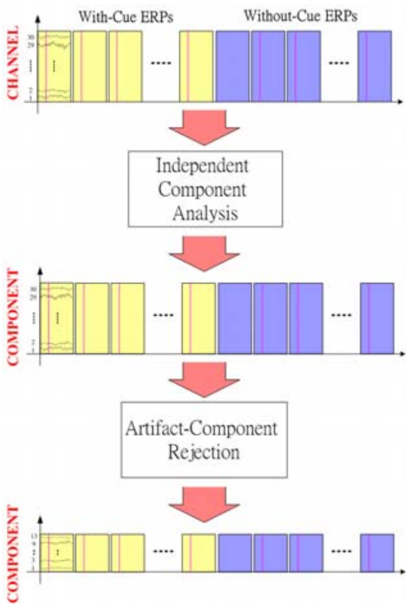


Figure 6. Independent component analysis and artifact-component rejection.

The extracted ERP are further send to the independent component analysis (ICA) for the source (or component) decomposition. The decomposed ICA components are used for artifact-component rejection, as shown in Figure 6. The averaged With-Cue ERP and the averaged Without-Cue ERP are then calculated, respectively, as shown in Figure 6. A subtraction operation is applied to evaluate the difference between the averaged With-Cue ERP and the averaged Without-Cue ERP. The surprise-related components can be evaluated according to the averaged ERP difference, as shown in Figure7.

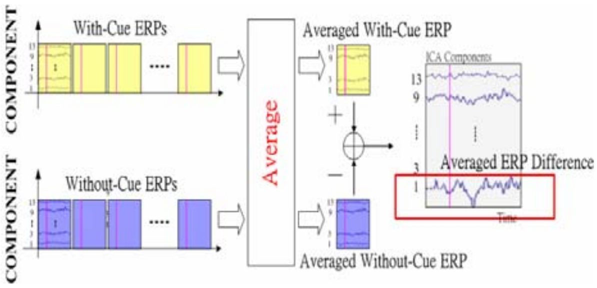


Figure 7. Surprise-Related Components Selection.

4. Experimental Results

From the time course analysis of the ICA components in without-cue tasks, we may find common component of different subjects and the component areas are closely located in the CPz. The contributions of the common ICA sources were then projected back to CPz EEG channel. Figure 8 shows the projection result of subjects. The projection amplitude of CPz has negative peak at about 300 ms for without-cue tasks and the projection amplitude of CPz has a negative peak at about 360 ms for the without-cue tasks.

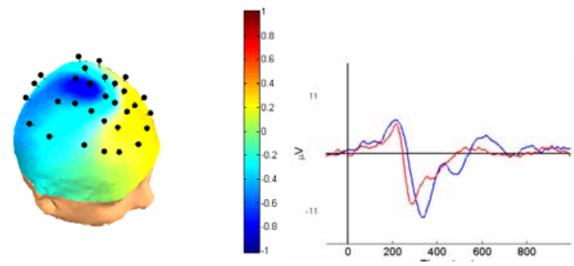
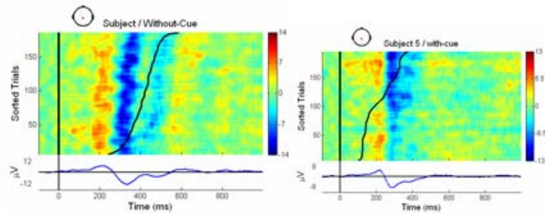


Figure 8. Results of the common ICA component on CPz channel.

Figure 9 plots the ERP image of subject 5 where common ICA component was projected to CPz channel. The ERP image is a rectangular colored image in which every horizontal line represents activity occurring in a single experimental trial (or a vertical moving average of adjacent single trials). Instead of plotting activity in single trials such as left to right traces, we encode their values with color codes. The color value indicates the potential value at each time point in the trial. By stacking above each other the color-sequence lines for all trials in a dataset, the ERP image is produced. The trace below the ERP image shows the average of the single trial activity, i.e. the ERP average of the imaged data epochs. The black line of this figure is reaction time of the subject. We define the reaction time as the moment when subject starts to steer the wheel to dodge the unexpected obstacle.



(a) (b)

Figure 9. The ERP images of subject 5 in without- and with-cue tasks at CPz channel.

Figure 9 shows the projection amplitude of CPz corresponding to with- and without-cue tasks and we may find the major differences occurred at around 350 to 400 ms. From the ERP image, the EEG activity of each trial locked on the stimulus onset with negative potential. We called this negative potential as N400. It is noted that the source location is evoked at CPz channel not at occipital region. These ERPs are not evoked by visual stimulus. In addition, according to Fig. 9(a), the magnitude of N400 at around 350 to 400 ms is proportional to the reaction time. It can be inferred that when the surprising level is higher (the reaction time is longer), the magnitude of N400 at around 350 to 400 ms will larger.

Figure 10 shows the EEG power spectrum activities of subject 5 at CPz channel. The above left scalp map shows the channel location on the cortex. The above right sub figure shows the overlapping ERP averages of subject 5. The blue line in it is the ERP average of without-cue tasks and red line for with-cue tasks.

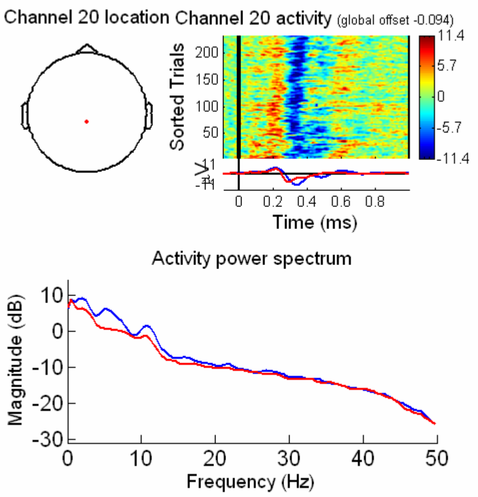


Figure 10. The EEG power spectrum of subject 5 at CPz channel corresponding to without-cue tasks and with-cue tasks.

5. Discussion

In the present study, we measure brain potentials while subjects drive a car on the freeway with an unexpected incoming incident as an obstacle. It was expected that the subjects were being surprised. In our investigation, we observed that the surprising status is similar to the incongruently cognitive processing in the human brain. In many other studies, an N400 was evoked by the semantic incongruent experiment [10-12]. Several studies have shown that incongruent words elicit a negative ERP component peaking around 400 ms after stimulus presentation. Normally, N400s to words are reduced in amplitude upon repetition thus indicating the generating cerebral structures participate in memory processes. ERPs have been examined to pictures in sentence contexts using the anomalous sentence task in which the N400 was originally observed. In addition to this, there are also many studies shown that anomalous final pictures and anomalous final words generated a larger N400 than congruous final pictures and words. Also, the time courses of the effects were similar for both pictures and words. The effects for pictures displayed a different scalp distribution than the effects for words. Specifically, the N400 congruity effects at occipital and parietal sites were larger for words than for pictures. Conversely, the N400 congruity effects at frontal sites were larger for pictures than for words. These results suggest that the N400 reflects a semantic processing mechanism that is functionally similar for pictures and words. However, the brain regions responsible for the storage and processing of semantic representations for pictures and words may be partially non-overlapping, resulting in slightly different scalp distributions.

In our study, the N400 was evoked by an unexpected obstacle dodging task. The simulation that a subject drives on the freeway with unexpected obstacle's appearance is similar to a subject listen to a sentence with incongruous final word. Therefore it is reasonable that the N400 potentials occur in our experiments. This also leads us to consider the relationship between N400 potential and the mental workload caused by surprising tasks.

6. Conclusion

Driving safety is concerned as an important issue in nowadays. Driving at night is one of the most hazardous situations commonly faced by the driver. It was observed that under nighttime conditions, many visual abilities such as spatial resolution, contrast discrimination, stereoscopic depth perception, accommodation, response and reaction time are degraded. It becomes extremely dangerous in some situations, such as the appearance of an unexpected obstacle in the middle of the road. The surprise-related feature of ERP signals have been successfully discovered according to our experimental results. The N400 component has been observed in without-cue tasks and with-cue tasks. Furthermore, the level of surprising status can be evaluated with the amplitude of the averaged surprise-related ERP. The length of the reaction time was also proofed that it is highly related to the level of mental workload.

7. References

[1] S. Plainis, K. Chauhan, I.J. Murray, W.N. Charman, "Retinal adaptation under night-time driving conditions," Department of Optometry and Vision Sciences.

[2] K.Eba, A.Kozato, "Spatial Attention in Car Driving Activates the Right Tostromendial Prefrontal Cortex," *Technical Report of TOYOTA CENTRAL R&D LAB.*

[3] Andras Kemeny, Francesco Panerai, "Evaluating perception in deiving simaulation experiments," *Trends in Cognitive Sciences*, Vol. 7, pp. 31-37, 2003.

[4] Knight RT. "Decreased response to novel stimulus after prefrontal lesions in man," *Electroencephalogr Clin Neurophysiol* Vol. 59, pp. 9-20, 1984.

[5] Naatanen R. "Attention and brain function," *Hillsdale*, NJ Erlbaum, 1992.

[6] Schroger E. "A neural mechanism for involuntary attention shifts to changes in audiotory stimulation". *J Cogn Neurosci* Vol. 8, pp. 527-539, 1996.

[7] W.B. McPherson, P.J. Holcomb, "An electrophysiological investigation of semantic priming with pictures of real objects," *Psycho-physiology*, Vol. 36, pp. 53–65. 1999.

[8] K.D. Federmeier, M. Kutas, "Meaning and modality: influences of context, semantic memory organization, and perceptual predictability on picture processing," *J. Exp. Psychol. Learn. Mem. Cogn.* Vol. 27, pp. 202–224, 2001.

[9] G. Ganis, M. Kutas, M.I. Sereno, "The search for 'common sense': an electrophysiological study of the comprehension of words and pictures in reading," *J. Cogn. Neurosci*, Vol. 8, pp. 89–106, 1996.

[10] Jeff P. Hamm, Blake W. Johnson, Ian J. Kirk, "Comparison of the N300 and N400 ERPs to picture stimuli in congruent and incongruent contexts," *Clinical Neurophysiology*, vol. 113, pp. 1339-1350, 2002.

[11] Erich Schroger, M.-H. Giard, Ch. Wolff, "Auditory distraction: event-related potential and behavioral indices," *Clinical Neurophysiology*, vol. 111, pp. 1450-1460, 2000.

[12] Mika Koivisto, Antti Revonsuo, "Cognitive representations underlying the N400 priming effect," *Cognitive Brain Research*, vol. 12, pp. 487-490, 2001.

[13] S. Makeig and M. Inlow, "Lapses in Alertness: Coherence of Fluctuations in Performance and EEG Spectrum," *Electroencephalogy. Clin. Neurophysiol.*, Vol. 86, pp. 23-35, 1993.

[14] T. P. Jung, S. Makeig, C. Humphries, T. W. Lee, M. J. McKeown, V. Iragui, T. J. Sejnowski, "Removing electroencephalographic artifacts by blind source separation," *Psychophysiology*, Vol. 37, pp. 163-78, 2000.

[15] T. P. Jung, S. Makeig, W. Westerfield, J. Townsend, E. Courchesne, and T. J. Sejnowski, "Analysis and visulization of single-trial event-related potentials," *Human Brain Mapping*, 14(3), pp. 166-85, 2001.

[16] M. Girolami, "An alternative perspective on adaptive independent component analysis," *Neural Computation*, vol. 10, pp. 2103–2114, 1998.

[17] T. W. Lee, M. Girolami, and T. J. Sejnowski, "Independent component analysis using an extended infomax algorithm for mixed sub -Gaussian and super-Gaussian sources," *Neural Computation*, vol. 11, pp. 606–633, 1999.