Electroencephalographic Assessment of Mental Fatigue on Visual Tasks

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Background

- Mental fatigue induces deterioration in cognitive functions. Responses become slower, more variable, and more error prone after mental fatigue.

- It is also possible that cumulative mental fatigue leads to decreased productivity in the workplace and induces critical errors in the worst cases.

- The management of mental fatigue is important from the viewpoint of occupational risk management, productivity, and occupational health.
Motivation

- To gain more insight in the mechanisms that are central to mental fatigue and in arousal level and the cognitive functions that are most affected by mental fatigue.

- The assessment of mental fatigue should be conducted with more confidence from the viewpoints of both arousal level from EEG (Okogbaa et al., 1994) and cognitive information processing from ERP (Murata et al., 2005).
Purpose

- To explore the arousal level and cognitive function for mental fatigue in visual tasks by using electroencephalographic measures.
- To compare the behavior response (RT, ER) and physiological response (EEG, ERP) to mental fatigue in visual tasks.
- To examine the recovery state from mental fatigue after 180 min experimental tasks during the 60-min rest.
Electroencephalogram (EEG)

- Hans Berger (1873~1941), the discoverer of the human EEG, was a neuropsychiatrist. Electroencephalography is the neurophysiologic measurement of the electrical activity of the brain by recording from electrodes placed on the scalp or, in special cases, subdurally or in the cerebral cortex.

An early EEG recording done by Berger, 1924.
Electrode placement

- Electrode placement is accomplished by measuring the scalp. Electrode locations and names are specified by the International 10–20 system.

- This system ensures a system of placement that is reliable and reproducible.
The International 10–20 system
Basic EEG waveform

Delta

Theta

Beta

Alpha

1 s

50 µV

Eyes opened

0.5–4 Hz

4–8 Hz

13–20 Hz

8–13 Hz
The event-related potential (ERP) is a transient series of voltage oscillations in the brain recorded from scalp EEG following a discrete event.

An ERP is any stereotyped electrophysiological response to an internal or external stimulus.

It is any measured brain response that is directly the result of a thought or perception.
Averaged waveform of ERP
ERP Labeled

- To label ERP peaks and troughs as positive or negative “components,” as is the standard practice in the analysis of human scalp-recorded ERP (Picton, 1988; Niedermeyer et al., 1993), e.g., the P300 peaking between 200 and 500 ms after stimulus presentation.

- The P300 component is useful to identify the depth of cognitive information processing.
Method

Subject

- 23 male university students with a mean age of 22.0 ± 1.3 years participated as volunteer subjects.
- Normal hearing and normal or corrected-to-normal vision; no medical, psychiatric, or head injury, and not using any medications or drugs.
- An informed written consent form was obtained from all the participants.
- They were paid for their participation in the study.
Method

- **Subject**
  - 23 male university students with a mean age of 22.0 ± 1.3 years participated as volunteer subjects.
  - An informed written consent form was obtained from all the participants.
  - They were paid for their participation in the study.

- **Experimental Procedures**

  The Experiment Schedule for EEG measurement and experimental task

<table>
<thead>
<tr>
<th>8:30~9:00</th>
<th>9:00~9:30</th>
<th>9:30~10:00</th>
<th>10:00~11:00</th>
<th>11:00~12:00</th>
<th>12:00~12:30</th>
<th>12:30~13:00</th>
<th>13:00~13:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>20min EEG &amp; 5 min NASA-TLX (BT)</td>
<td>Mental Arithmetic</td>
<td>20min EEG &amp; 5 min NASA-TLX (AT)</td>
<td>Take rest</td>
<td>20min EEG &amp; 5 min NASA-TLX (60-min AT)</td>
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<td>Take rest</td>
<td>20min EEG &amp; 5 min NASA-TLX (60-min AT)</td>
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<tr>
<td>20min EEG &amp; 5 min NASA-TLX (BT)</td>
<td>Mental Arithmetic</td>
<td>Data Entry</td>
<td>Mental Arithmetic</td>
<td>20min EEG &amp; 5 min NASA-TLX (AT)</td>
<td>Take rest</td>
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</tbody>
</table>

Note: 20 min EEG measurements included 5 min EEG measurement at rest condition and 15 min Flanker task for ERP measurement.

BT denoted before task

AT denoted after task

60-min AT denoted 60-min after task.
The layout and the position of the test device
Behavior Response Tasks

- Participant wearing an EEG cap with scalp electrodes performed the modified flanker task.
- Participant was required to press a designated button on a control panel connected with the computer in response to the target stimulus.
- Designed buttons on the control panel were applied to orient the position between the start and control points of participant’s moving finger.
Behavior response

- Reaction time (RT) was measured as the time between the onset of the arrow array and the control button press.
- Error rate (ER) was calculated as the percentage of miss or erroneous responses.
The NASA-Task Load Index (TLX) rating scale

- The NASA-Task Load Index (NASA-TLX) consists of six component scales.
- An average of these six scales, weighted to reflect the contribution of each factor to the workload of a specific activity from the perspective of the rater, is proposed as an integrated measure of overall workload.
During the task performance, EEG was recorded by using an electrode cap (Quick-Cap, Compumedics NeuroScan, El Paso, Texas) with Ag/AgCl electrodes placed at F3, Fz, F4, Cz, Pz, O1, and O2 in the International 10–20 montage with an electronically linked mastoids reference.
- θ (4~8 Hz) can be seen during light sleep and the preconscious state just upon waking, and just before falling asleep.
- α (8~13 Hz) attenuates with extreme sleepiness or with open eyes and increased visual flow.
- β (13~20 Hz) is often associated with active, busy or anxious thinking and active concentration.
- One of the common findings on a drop in arousal level or mental fatigue is that the EEG shifts from fast and low amplitude waves to slow and high amplitude ones.
EEG measurement

- For measuring the background EEG pattern of participant, EEG spectral analysis was performed only for the 5-min rest condition.
- The recorded EEG during 5-min rest condition was subsequently transformed from time into frequency domains by fast Fourier transform (FFT) using a 5-s Hanning windowing function.
Basic index of EEG power

- The δ band was not included in our analysis, since it happens in a deep sleep state and usually overlaps with artifacts. The basic index means the relative power of the EEG θ, α and β bands.

- The relative power equation of the θ, α, and β bands are represented respectively as:

Relative power of θ =
(power of θ) / (power of θ + power of α + power of β). . . . . . . . . . . . . . . . . . . . . (1)

Relative power of α =
(power of α) / (power of θ + power of α + power of β). . . . . . . . . . . . . . . . . . . (2)

Relative power of β =
(power of β) / (power of θ + power of α + power of β). . . . . . . . . . . . . . . . . . . (3)
Since the basic indices have a tendency to “contradict each other”, the ratio indices were calculated to amplify the difference. The known ratio indices $\beta/\alpha$, $\theta/\alpha$, and $(\theta+\alpha)/\beta$ were analyzed in previous studies (Brookhuis and Waard, 1993; Ryu et al., 1997; Pyun and Kim, 2000).
ERP measurement

- For ERP measurement, the EEG data were segmented into stimulus-locked EEG epochs from 200 ms before and 800 ms after the onset of displaying the arrow array of flank test.

- The individual ERP waveform was averaged from 200 trials of flanker task.

- In this study, the ERP waveforms were induced from a modified flanker task.
Results (1)

- Performance Evaluation of Fatigue
  - A one-way (session: BT, AT, and 60-min AT) ANOVA carried out on the RT revealed no significant main effect of the session, whereas a one-way ANOVA conducted on the ER revealed a predominant difference between BT and AT, while no significant difference was found between BT and 60-min AT.
Results (2)

- Fatigue rating scale of NASA-TLX
  - The mean rating scale of mental fatigue tended to significantly increase immediately after the completion of the task. At 60 min after the completion of the experimental task, the rating scale decreased and was nearly equal to the value in the BT session.
Results (3)

- Basic indices of EEG Power
  - The basic indices $\theta$ and $\alpha$ at all recording sites tended to increase and decrease respectively, immediately after the completion of an experimental task. At 60 min after the experimental task was completed, the basic indices $\theta$ and $\alpha$ decreased and increased respectively, and recovered to the level in the BT session.
  - The basic index $\beta$ revealed no significantly difference among the three sessions.
Basic index $\theta$

<table>
<thead>
<tr>
<th>Session</th>
<th>Index value</th>
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<tbody>
<tr>
<td>BT</td>
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<td>AT</td>
<td></td>
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<tr>
<td>60-minAT</td>
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</tbody>
</table>

- F3
- Fz
- F4
- Cz
- Pz
- O1
- O2
Basic index $\beta$

<table>
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<tr>
<th>Index value</th>
<th>F3</th>
<th>Fz</th>
<th>F4</th>
<th>Cz</th>
<th>Pz</th>
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<th>O2</th>
</tr>
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<tr>
<td>60-minAT</td>
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</tbody>
</table>

Session

Index value

0.1

0.12

0.14

0.16

0.18

0.2

0.18

0.16

0.14

0.12

0.1

Session

BT

AT

60-minAT

F3

Fz

F4

Cz

Pz

O1

O2
Results (4)

- **Ratio index of EEG Power**
  - The ratio index $\theta/\alpha$ revealed significantly increased immediately after the completion of an experimental task than those before the task at all electrode sites, and recovered to closely original state at 60-min AT.
  - The ratio index $(\theta+\alpha)/\beta$ showed significant decrease after the completion of an experimental task at O1 and O2 electrode sites. Only the value at the occipital increased to the level in the BT session at 60 min after the experimental task was completed.
  - The ratio index $\beta/\alpha$ revealed no significantly difference among the three sessions.
Ratio index $\beta/\alpha$

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- F3
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<th>Ratio index $\theta/\alpha$</th>
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- F3
- Fz
- F4
- Cz
- Pz
- O1
- O2

The graph shows the ratio index $\theta/\alpha$ for different sessions and electrodes.
Ratio index $(\alpha+\theta)/\beta$

- Session: BT, AT, 60-minAT
- Index value: F3, Fz, F4, Cz, Pz, O1, O2

Graph showing trends in index values across different sessions.
Results (5)

- **P300 component of ERP**
  - The P300 latency at Pz tended to decrease immediately after the completion of an experimental task. It increased at 60 min after the experimental task was completed and recovered to the level in the BT session.
  - The P300 amplitude tended to decrease at the post-task measurement and to recover to the pre-task level at 60 min after the completion of the experimental task at recording sites of Pz, O1, and O2.
Discussion (1)

- Behavior response during mental fatigue
  - The decreased level of attention caused the increase in ER and RT.
  - At 60 min after the completion of the experimental task, the RT and ER decreased, which indicated that the state of fatigue had improved during the 60-min rest, but did not recover to the original state.
Discussion (2)

- **Basic indices of EEG power during mental fatigue**
  - The index $\theta$ increased and the index $\alpha$ decreased after 3 h of VDT task. The directions of their changes were consistent with those of previous studies (Åkerstedt et al., 1991; Lal and Craig, 2001).
  - The subjects revealed some extent of mental fatigue, but their alertness level was increased after the experimental task.
  - Mental arithmetic which was a secondary task is known to suppress EEG $\alpha$ activity (Klimesch, 1997).
Discussion (3)

- Ratio indices of EEG power during mental fatigue
  - Ratio index $\theta/\alpha$ of session BT discriminated session AT which no other indices could do and it recovered to closely original state at 60-min AT. It revealed index $\theta/\alpha$ was more available than the other two ratio indices for assessment of mental fatigue in VDT task.
  - After the completion of an experimental task, the ratio index $(\theta+\alpha)/\beta$ was decreased significantly at the occipital—visual dominating area. It revealed the main fatigue induced from VDT task was in the visual area.
  - The index value of $(\theta+\alpha)/\beta$ increased at 60-min AT manifested the fatigue had improved, but did not recover to original state except visual sensory after 60 min of rest.
Discussion (4)

- The P300 component of ERP during mental fatigue
  - The decreased activity of cognitive information processing (decrease of the P300 amplitude) were found to be effective measures of mental fatigue.
  - We did not find the delay of information processing due to the decrease of P300 latency after the experimental task. The possible reason was the mental arithmetic task improved the information processing capability.
Conclusion(1)

- In the EEG analysis for the VDT task, the $\alpha$ waves, $\theta$ waves, ratio indices $\theta/\alpha$ and $(\alpha+\theta)/\beta$ were found to be statistically significant. It revealed the main fatigue induced from VDT task was in the visual area. After 60 min of rest, the participants’ fatigue did not diminish to the original state except visual sensory.

- The P300 component of ERP indicated the possibility that one aspect of the mentally and physically fatigued state could be explained by the decreased activity of CNS. This phenomenon is related to a temporal prolongation of cognitive information processing and a decreased level of attention.
Conclusion(2)

- It revealed that index $\theta/\alpha$ was more available than the other two ratio indices and the amplitude of P300 had better discrimination than latency of P300 for assessment of mental fatigue.

- The method proposed in this study is potentially applicable to the evaluation of the fatigued state of workers and to the management of mental fatigue from the viewpoints of occupational risk management, productivity, and occupational health.
Thank you for your attention