A Mental Fatigue Measurement System Based on Face Images

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ABSTRACT

In this study, we focused on eye movements during gaze and lip movements during speech, and examined a measurement method of mental fatigue. Face images can be taken easily with a camera, and eye and lip movements are used as an indicator of objective emotions and physical condition.

1 INTRODUCTION

Many sensing technologies and its systems such as wearable terminals, automatic driving systems, and other applications have been reported lately. As an example, sensing technology is used in drowsiness detection systems applied to measure the heart rate and brain waves during driving [1] and in a fatigue state detection system using facial expression recognition [2]. However, further development of sensing technology is needed to new invention, e.g, autonomous cars, health measuring system that is easy to use at home. By the way, the fatigue feeling is understood as an awareness symptom of the cerebral cortex restraint. It appears overall in facial expressions, attitudes, postures, and behaviors. It is said that other people can guess the occurrence of fatigue accurately by just looking objectively [3]. Therefore, we considered using face image as a simple measurement method. It is known that the condition can be estimated objectively with information of face image such as eye movement or lip movement. We examined whether these changes can be a parameter of simple fatigue measurement method. In previous studies of lip movement, we have been working on utterance training by lip-movement and utterance recognition without using voice data [4-5]. It has been experienced that the amplitude of opening lips depended on their physical or mental condition and their fatigue influenced the smoothly speaking. In previous research of eye movement, Mizushina et al. reported that the amplitude of micro saccades generated during task execution may be used as a parameter for psychological stress [6]. Also Wakui et al. indicated that the arousal state of humans was sensitively reflected on the pupil size and various eye movements (Saccade, VOR (Vestibulo-Ocular Reflex), Vergence eye movement, etc.) and these parameters were able to be applied for various filed to measure the arousal state of humans [7]. Therefore, we believe that mental fatigue can be measured by objectively evaluating changes in eye and lip movements in face image information.

2 EXPERIMENT

As the fatigue task, the subject performed a simple calculation task for 90 min, and the eye movements during the task were measured using a wearable eye movement measurement device. In addition, we measured CFF and lip movement measurement, which is commonly used as a fatigue indication, before and after the experiment. The experiment flow chart is shown in Fig. 1. 10 students (7 males and 3 females) participated in this experiment their age range was 20-24. In addition, the experiment was conducted in an electromagnetic shield room at our university. This experiment was conducted in accordance with the Tokai University ethical code on human experiments.

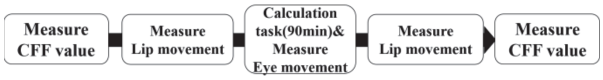


Figure 1: Flow of the experiment

2.1 CFF Measurement method

CFF (critical fusion frequency) is a higher-order visual characteristic that involves the cerebrum, is effective for measuring mental fatigue, and is widely used conventionally. CFF decreases with increasing fatigue.
A reduction in flicker value not only indicates peripheral fatigue but also is considered useful as a judgment index of central fatigue [8]. Therefore, CFF was used to measure fatigue brought on by the calculation tasks. To measure CFF value, we used a flicker-measuring instrument (Takei Scientific Instruments Co., Ltd.). We used the rising and descending method to analyze the data. When light is blinked slowly, we can distinguish the flickering of light, but if it gradually flashes at a high speed, the flicker eventually disappears. This is the rising method. On the other hand, when light is blinked speedy, we cannot distinguish the flickering of light, but if it gradually flashes at a slow speed, the flicker eventually appears. This is the descending method. We collected the each maximum flicker frequency which can be discriminated.

2.2 Calculation task

We selected a 90-minute calculation task as the fatigue task. An example of the task is shown in Fig. 2. The calculation task was carried out by touch operation on a laptop display (Sony Corporation) and consisted of adding random single-digit numbers arranged vertically in Excel. The subjects added two numbers and typed the sum into the cell across from the second number. The second number was then used as the first number for the next calculation. The subjects were instructed to perform the calculation as accurately and quickly as possible. The subjects took a 3-minute break after completing half of the 90-minute task.

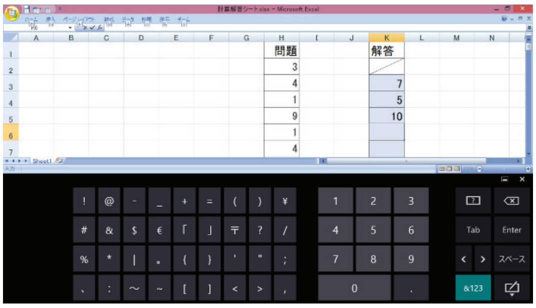


Figure 2: Example of the calculation task

2.3 Eye movement measurement method

Eye movements during the calculation task were measured with particular attention to gaze point. Eye movements during gaze include fixation eye movement, which has been reported to change according to psychological state [6]. The device used to measure eye movement was the EMR-8b (Nac Image Technology, Inc., Tokyo), which uses the pupil/corneal reflection method for eye movement detection and has a detection rate of 60 Hz. As a definition of gaze point, if the sampling interval is longer than the refractory period of the saccade (150 to 160 ms), there is a possibility that the eye will return to the previous gazing component again. Therefore, we used the definition reported by Fukuda et al. [9]. In this definition, a gaze point was defined as occurring when the eye movement speed was less than 10 deg/sec and the gazing time was longer than 150 ms. In this experiment, a subject wore the eye movement measuring equipment of a cap type and did a calculation task. Their head was not fixed during the task. Therefore, the small movement to compensate for head movement is included in eye movement in a gaze point.

2.4 Lip movement measurement method

Lip movement was measured before and after the calculation task, using a system based on Intel® RealSense ™ SDK. A RealSense SR300 Camera was used to capture each subject's face image, and 30-fps image processing was carried out to acquire the feature points of the face. A total of 78 feature points were extracted from the face, of which 20 were extracted around the lips. Data on these feature points were saved in the .csv format, a movie of the lip movement analyzer screen was saved in the .avi format, and the recorded voice was saved in the .wav format. Figure 3 shows the feature points around the mouth. The subject's face was not fixed so that natural speaking would be maintained. The subjects spoke to the camera while seated, and began speaking when the experimenter gave a start sign. The utterance sentences were 5 sentences including 5 Japanese vowels from utterance training books [10]. The sentences used were “Attara aisouyoku aisatsu shinasai” (“You should greet him/her in a friendly way when you meet them”), “Ikigai wo motemete ikou” (“Let’s seek fulfillment in your life”), “Ukatu ni umai uso” (“I sing away my troubles”), “Eiyoyo eikouyo eiennni” (“Honor and glory forever”), and “Oukami no oukina touboe” (“The howling of the wolf”). These five sentences were uttered five times each in the order above (vowel order "a", "i", "u", "e", "o").

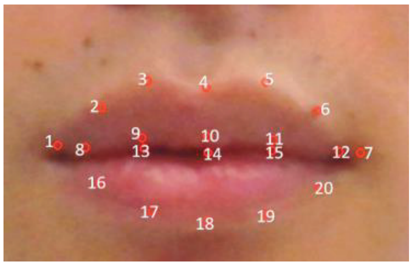


Figure 3: Feature points around the mouth

3 RESULTS

3.1 CFF result

Table 1 shows the average of CFF before and after the task and result of paired t-test. CFF significantly decreased in 6 of 10 subjects in bold type ($p < 0.01$). As a result, CFF of all subjects were reduced due to performing the calculation task for 90 min. Therefore, we concluded that the calculation task showed a tendency to cause mental fatigue.

3.2 Calculation task result

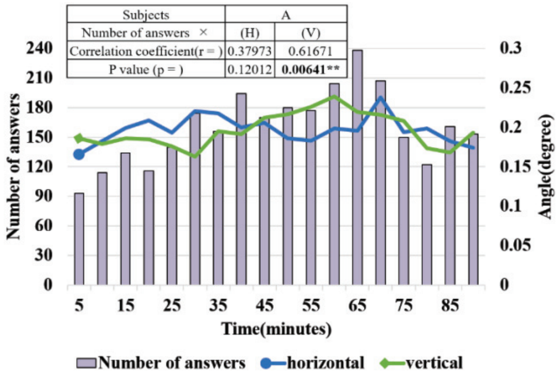
The numbers of answers and the number of incorrect answers differed among subjects. However, they answered about 3000 questions on average. In addition, the number of incorrect answers was about 30 questions, except for subject A, including operation mistakes on the touch panel. The reason the number of incorrect answers was large in A is the decrease in CFF is the largest from the results in Table 1, which presumed to be due to this subject feeling a fatigue strongly. Also, although the rate of incorrect answers is not larger than A, similar trend was seen in B whose CFF decreased 2.4Hz. From the above, it is presumed that fatigue has influenced the number of answers and the rate of incorrect answers.

Table 1: CFF of all subjects before and after the task and result of paired t-test between before and after. (Hz)

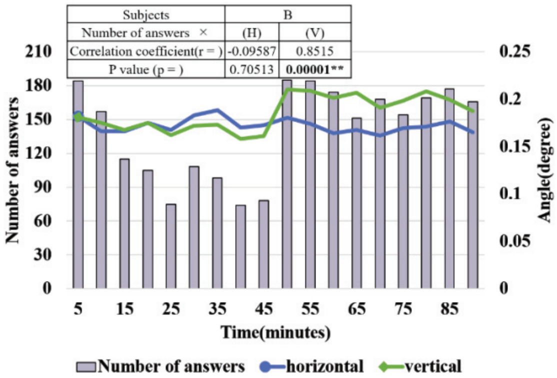
	Before	After	Change Value	p=
Subject A	**36.7**	**33.6**	**-3.1**	**0.0006**
Subject B	**35.3**	**32.9**	**-2.4**	**0.0002**
Subject C	**32.7**	**30.4**	**-2.3**	**0.0032**
Subject D	**40.2**	**38.1**	**-2.1**	**0.0003**
Subject E	**36.4**	**34.8**	**-1.6**	**0.0045**
Subject F	**33.4**	**32.1**	**-1.3**	**0.0018**
Subject G	32.6	31.7	-0.9	0.0947
Subject H	33.2	32.5	-0.7	0.2977
Subject I	34.7	34.1	-0.6	0.1679
Subject J	30.6	30.1	-0.5	0.2443

3.3 Eye movement result

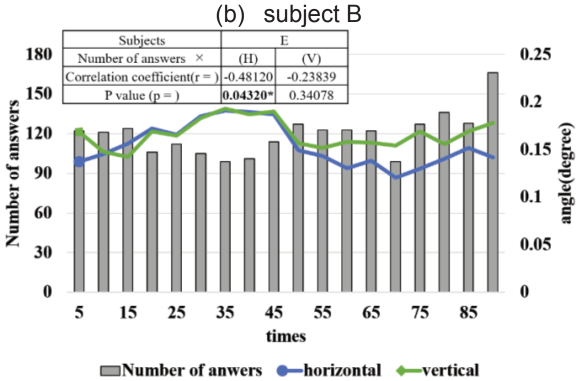
In subject H, eye movements data for 10 to 25 minute were not measured well. It was difficult to analyze the video data of subject C during the experiment because it was damaged. Therefore, 2 of the 10 subjects were excluded from the analysis of eye movement. The standard deviation of eye movements at gaze points was calculated by the movements within each gaze. Thus, the change of the eye movement at each gaze during calculation task could be obtained in real time. We examined the correlation between the number of answers and the standard deviation of eye movements during gaze points. As the result, 4 of the 8 subjects (A, B, E, G) showed a significant correlation between 'the horizontal or vertical eye components of movements and the number of answers. In subjects A and B in Fig. 4(a) and (b), there was a significant positive correlation between the number of answers and the vertical component of eye movement during gaze($p<0.01$). The horizontal and vertical components of subject B showed the same tendency in the first half of the task as shown in Fig. 4 (b), however the number of answers and the vertical components of eye movements increased after 45 minutes. This result is estimated to be due to a 3 minute break in 45 minutes. In subject E in Fig. 4 (c), there was a significant negative correlation between the number of answers and the horizontal components of eye movements during gaze($p<0.05$). Subject E's horizontal and vertical components of eye movement showed the same tendency as subject B in the first half of task, after that the horizontal and vertical components of eye movements decreased. In subject G in Fig. 4 (d), there was a significant positive correlation between the number of answers and the horizontal components of eye movements during gaze($p<0.05$). Results of other subjects did not show a significant correlation between the number of answers and the horizontal or vertical components of eye movements during gaze. Constant tendency was not obtained, since there were the subjects who showed the increase of the vertical components of eye movement and the subjects



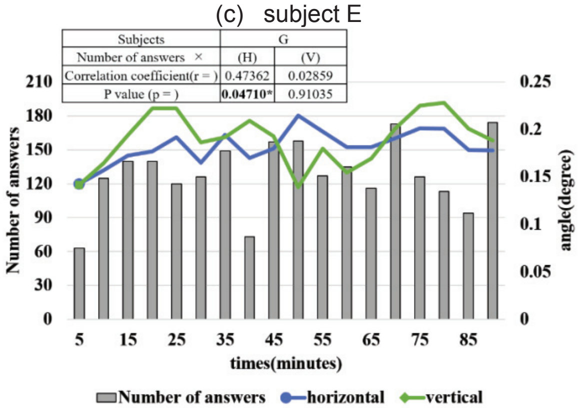
(a) subject A



(b) subject B



(c) subject E



(d) subjects G

Figure 4: The standard deviation of small involuntary eye movements every 5 minutes during calculation task(*:p<0.05)

who showed the increase or decrease of the horizontal components of eye movement. In addition, CFF decreased three subjects of those. However, it suggests that these results have some kind of relation to the standard deviation of eye movement during gaze and the number of answers and suggest the possibility that we can check the internal state of the person by analyzing the eye movement at the gaze during work.

3.4 Lip movement result

Because previous research suggests that lip movement changes due to time elapsed [4], we analyzed the opening area of the lips during utterance. The opening area was calculated based on feature points 1, 4, 7, and 18 (Fig. 3) because only very small differences were found when the area was calculated using all the feature points of the lips. Although subjects uttered each sentence five times, only the data from the third, fourth and fifth utterances were analyzed because those from the first and second showed unstable lip movement. Figure 5 shows the stacked graph of average opening area during 3 utterances of the “a” ~"o" . The lip opening areas of 4 subjects (A, D, H, I) were larger during the utterance of all sentences after the task. Only subject F showed smaller opening areas after the task. The lip opening areas of the other subjects (B, C, E, G, J) did not change significantly. There was not much change in the lip opening area before and after the task regardless of the utterance sentences, though some subjects tended to show a larger opening area after the task, suggesting that there might be a certain correlation between fatigue and lip opening area. However, there were also subjects who did not show much difference between their opening area before and after the task, and the possibility therefore remains that individual speaking habits may play a role. We will continue to investigate whether these changes are due to fatigue.

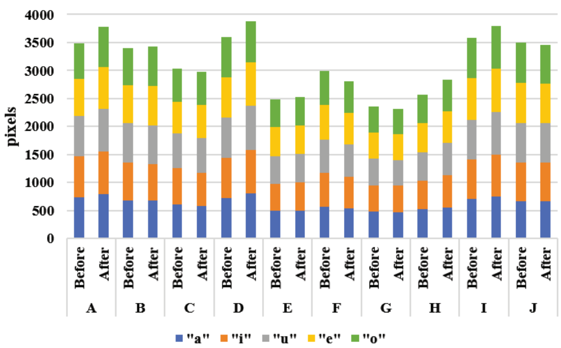


Figure 5: The stacked graph of average opening area during the “a” ~"o" utterance of all subjects

4 CONCLUSIONS

To confirm that changes in the standard deviation of eye movement at the gaze points during a task and the opening area of the lips before and after the task are effective for measuring fatigue, we had subjects perform simple calculation problems for 90 min. CFF values were taken to indicate the degree of fatigue and the number of answers was taken to indicate a change in the internal state of the subject, such as his or her degree of concentration and degree of fatigue. The present results demonstrate that eye movement during gaze correlates with CFF and the number of answers. Furthermore, 4 subjects out of 10 showed an increase in the opening area of the lips when uttering the tested sentences after the task, suggesting that lip movement may also change with fatigue.

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