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視覚知覚・認知計測技術と定量的疲労評価への応用

Quantitative measurement of human visual perception and its application to mental fatigue assessment

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Abstract: We have been developing techniques (1) to visualize spatiotemporal brain activities to investigate neural mechanisms underlying the human visual cognitive functions, especially the 3-D object perception from motion, and (2) to evaluate mental fatigue quantitatively by measuring perceptual performance of the visually presented flicker, namely, the flicker-perception threshold (FPT) on consumer devices. In this paper, we describe a method to solve the long-standing problem that the original flicker test inherently has, namely, arbitrariness and subjectivity in the subjects' response during determining FPT. We developed (a) a new method to control a subjective flickering sensation by changing the contrast of the visual stimuli instead of changing temporal frequency, and (b) a new paradigm, in which forced-choice task performance was used to determine FPT to eliminate arbitrariness of the subjects' response. The proposed techniques were implemented as application softwares, which enables us to measure mental fatigue quantitatively using consumer mobile devices such as smart phones and PCs.

Key Words: Visual cognitive function, Flicker perception threshold, Mental fatigue, Forced-choice task performance, MEG

1. Introduction

Critical flicker frequency (CFF), defined as a frequency at which intermittent light stimuli appear to be steady for the human observer, is known to become lower as mental fatigue accumulates [(1)]. Although CFF has decades of history as a reliable index of mental fatigue (flicker-test) [(2)], it requires a dedicated device to measure, which impeded the diffusion of the method to be used in general public.

The primary aim of this study is to develop a system to evaluate mental fatigue quantitatively and objectively by using measurements of the flicker-perception threshold (FPT) on consumer-devices such as cell-phones and PCs on which we do not have precise control of the temporal frequency of visual stimuli due to fixed display refresh rates (typically 30 or 60 frames per second (fps)). The main topics of this research were,

(i) to develop and validate visual stimuli which is capable of gradually change the degree of subjective flickering sensation on raster-scan display devices with fixed frame rates,
(ii) to design a psychophysical procedure to solve the long-standing problem that the original flicker test inherently has, namely, arbitrariness and subjectivity in the subjects' response during determining FPT, and
(iii) to construct a system that can store and retrieve measured data online.

2. Contrast-controlled flicker stimuli (CCFS)

Instead of changing a temporal frequency as in the original flicker test, we developed a method to control the degree of subjective flickering sensation by changing the contrast between on and off periods of the flickering visual stimuli (contract-controlled flicker stimuli: CCFS), which can be implemented even on the display devices with fixed frame rates.

To validate the compatibility of the proposed method (CCFS test) with the original flicker test, we conducted fatigue measurement tests in which 12 subjects were required to continue their office work, typically word processing on PCs, overnight until 8:30 am next morning. Temporal changes in mental fatigue on the subjects were evaluated every 2 hours from 2:30 pm on the first day by (a) the CCFS flicker test implemented on standard PC with simulated 30 fps fixed frame rate, (b) the CCFS flicker test implemented as a cell-phone application with 15 fps fixed frame rate, (c) the original flicker test (Shibata RDF-1), (d) subjective rating with visual analog scale (VAS) [(3)], and (e) Japanese version of standard questionnaire for subjective fatigue edited by Japan Society of Occupational Health [(4)].

Figure 1 shows the results of the fatigue measurements on a

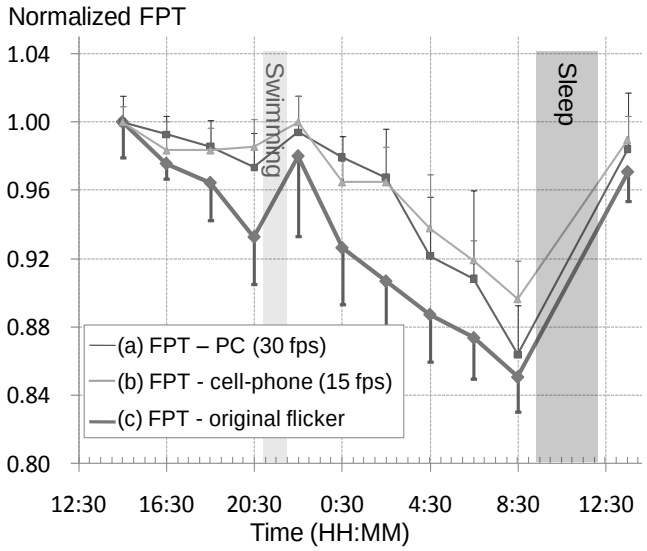

Fig. 1 Results of the FPT measurements during overnight office work setting using (a) the CCFS implemented as PC software, (b) the CCFS implemented on standard cell-phone application, and (c) the original flicker test.

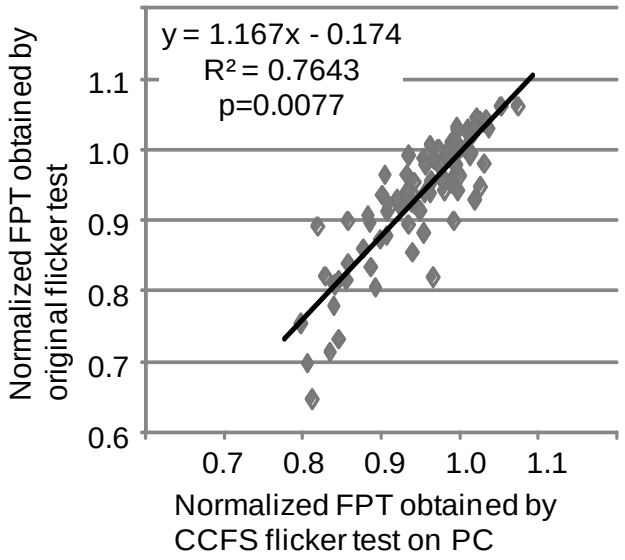

Fig. 2 Results of the correlation analysis between FPT values obtained by the CCFS flicker tests on PC and those by the original flicker tests, both normalized by the values at the first measurements at 2:30 pm on the first day.

typical subject, in which normalized FPT values measured in conditions (a), (b) and (c) were depicted. Results obtained by proposed CCFS tests ((a) and (b)) showed temporal characteristics similar to that obtained by the original flicker test (c).

The results of the correlation analysis (Fig. 2) showed that the FPT values obtained from CCFS tests on PC have significant correlation with those obtained from the original flicker tests ($r=0.874$, $p=0.0077$).

3. Forced-choice task for FPT detection (FC-FPT)

In the original flicker test, measurements of FPT rely on the voluntary response from the subjects on the subjective sensation of flicker. The arbitrariness on the subjects' response may introduce arbitrary biases on the fatigue measurements

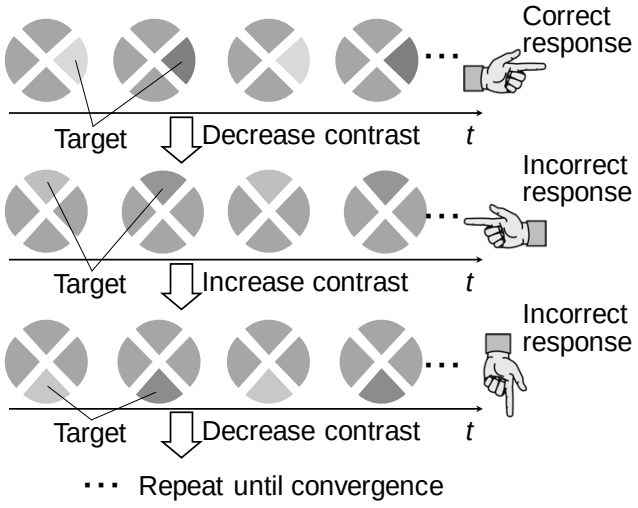

Fig. 3 FPT detection using forced-choice task (FC-FPT)

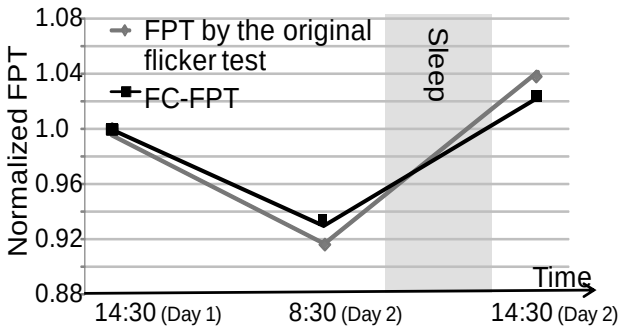

Fig. 4 Comparison between FPTs measured by the original flicker test (gray line) and the FC-FPT test (black line) in the typical subject during the overnight fatigue measurement session.

depending on subjects' intention to manipulate the results. This could pose major problem especially when the proposed technique was applied to the fatigue measurements in daily life where no one would be supervising the measurement sessions.

To solve this problem, we designed a forced-choice task for FPT detection (FC-FPT) in which subjects were required to choose a CCFS target among other alternative non-flickering stimuli (Fig. 3). The contrast of the CCFS targets were decreased if the subject responded correctly, and the contrasts were increased if the subject's response was incorrect. The FC-SPT task was repeated until the target contrast reached the convergence. Results of the FPT measurements using FC-FPT showed similar traces with the results obtained by original flicker test during the overnight fatigue measurement sessions (Fig. 4)

4. Implementation on consumer devices and online database system

The original idea of developing FC-FPT test by using CCFS stimuli was to make the quantitative mental fatigue measurement available in daily life. We have developed application programs to assess temporal changes in mental fatigue by measuring flicker perception threshold with CCFS and FC-FPT detection algorithms. The application programs

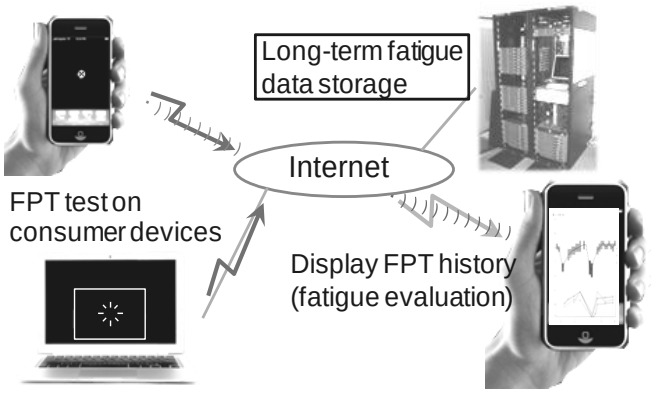

Fig. 5 Fatigue measurement database system based on the FPT test on consumer mobile devices and online data storage.

run on consumer mobile devices including smart phones that are gaining popularity in recent years.

To store and retrieve measured FPT data seamlessly without costing extra effort, we implemented an online fatigue measurement database system (Fig. 5). The database is accessible from the FC-FPT measurement application software installed on the mobile device and the stored data are retrieved on-demand in the form of line chart on which temporal changes of measured FPT values are displayed to show the personal history of mental fatigue.

5. Conclusion

We developed a new method to control subjective flickering sensation by changing the contrast of the flickering visual stimuli instead of changing temporal frequency, and a new paradigm, in which forced-choice task performance was used to determine the flicker-perception threshold to eliminate arbitrariness of the subjects' response. The proposed techniques were implemented as application softwares to measure mental fatigue quantitatively using consumer mobile devices such as smart phones and PCs.

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