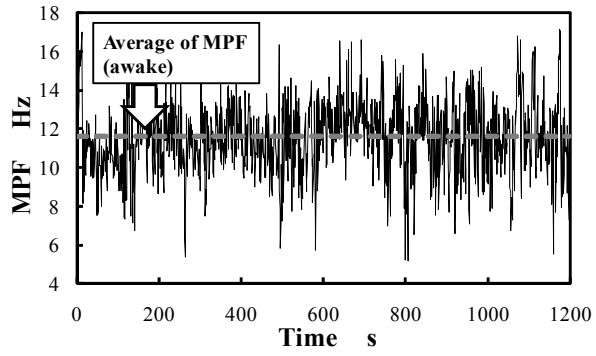

Fig.5 Times series of MPF during high arousal state (participant A).

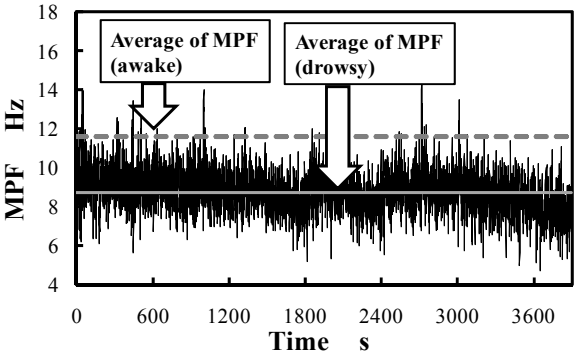

Fig.6 Times series of MPF during very low arousal state (participant A).

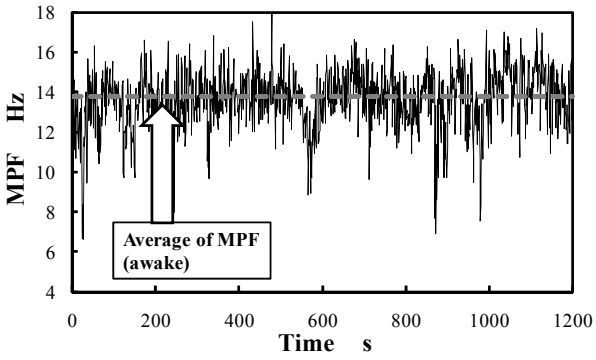

Fig.7 Times series of MPF during high arousal state (participant B).

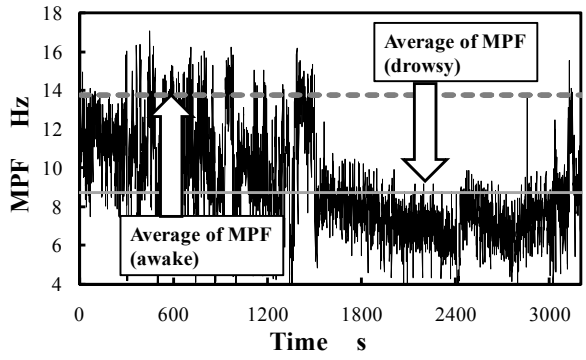

Fig.8 Times series of MPF during very low arousal state (participant B).

carried out.

The beep sound with various frequencies and human's voice were used. The cycle of beep sounds was 0.1 s. The speaker was installed 700mm vertically and 300mm horizontally away from the participant. The duration of the warning sound was fixed to 5 s. The warning sounds used in the experiment are summarized as follows. Beep sound of 1 kHz is most intimate and frequently used as a feedback to some operation. Beep sound of 4 kHz is regarded as most sensitive to humans. Beep sound of 10 kHz is regarded as difficult to hear especially for older adults whose perceptual ability declined.

(1) beep sound of 1 kHz

(2) beep sound of 4 kHz

(3) beep sound of 10 kHz

(4) Human's warning voice

The order of presentation of four types of warning sound was randomized across the participant.

The data analysis was carried out as follows (See Fig.3). The effect of warning sound on the enhancement of arousal level was evaluated using MPF before and after presentation of warning sound. The mean values of MPF before and after the presentation of warning sound were calculated as shown in Fig.3. The abnormal data were removed as shown in Fig.4. The data beyond the mean value + 3 x standard deviation or below the mean value - 3 x standard deviation were removed from the analysis.

3. Results

The X-bar control chart of mean power frequency (MPF) obtained from FFT analysis of EEG. The time series of MPF corresponds to data under high arousal and under very low arousal state is depicted in Fig.5 and

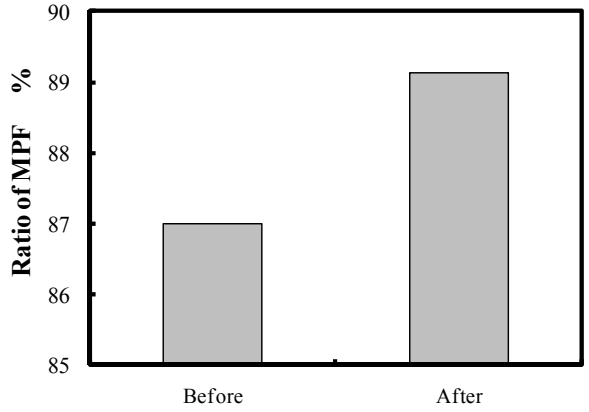

Fig.9 Ratio of MPF to mean MPF during high arousal state before and after warning sound.

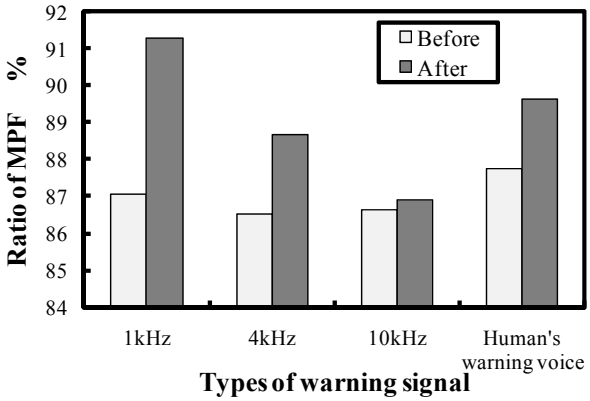

Fig.10 Ratio of MPF to mean MPF during high arousal state before and after warning sound (for each of four types of warning sounds).

Fig.6, respectively. Similar data for other participant is shown in Fig.7 and Fig.8.

According to Fig.3, effect of warning sound on the enhancement of arousal level was evaluated was evaluated. The results are summarized in Fig.9-Fig.10, and Fig.11. As for Fig.9, a t-test was carried out on the ratio of MPF to mean MPF during high arousal state. As a result, a significant (p<0.05) difference of the ratio before and after the warning sound was detected. A similar t-test was carried out for each type of sound shown in Fig.10. No significant difference of the ratio before and after the warning sound was detected before and after the presentation of each warning sound. A one-way (type of warning sound) ANOVA was carried

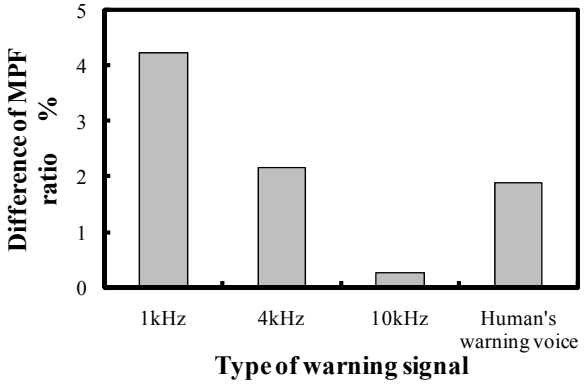

Fig.11 Difference of ratio of MPF to mean MPF during high arousal state before and after warning sound (for each of four types of warning sounds).

out on the difference of ratio of MPF to mean MPF during high arousal state (Fig.11) revealed no significant main effect.

4. Discussion

As shown in Fig.5-Fig.8, we can evaluate the arousal state of participant using Time series of MPF. This is in agreement with the results of Murata and Nishijima [14]. It has been confirmed further that the mean power frequency of EEG decrease under drowsy states.

As shown in Fig.9, it seems that the warning sound helps to change the state from low arousal level to somewhat high arousal level. However, the difference of alarm effect among four types of warning sound was not confirmed statistically, although the data shown in Fig.10 and Fig.11 in appearance seems to demonstrate the advantage of the beep sound of 1 kHz over other warning sounds.

Landstrom et al.[13] discussed the effectiveness of sound exposure as a means against driver drowsiness. The effectiveness of the waking sound system was verified through subjective ratings by lorry drivers. This system is used by a driver when he or she feels that their arousal level is becoming lower, and there is a risk of falling asleep. The disadvantage of Landstrom [13] is that

one must intentionally and spontaneously use the waking alarm system by monitoring their drowsiness by oneself. Objectively measuring and monitoring arousal level and providing warning sound with drivers is more necessary and have more social contribution than the warning or alarm system by Landstrom et al.[13]. Therefore, in this study, monitoring the arousal level not subjectively but objectively using MPF, the effectiveness of alarm sound was explored. In this respect, this study must be more advantageous than Landstrom et al. [13]

The most important issue is to predict reliably the time when the driver becomes drowsy and potentially cause disastrous traffic accidents. However, at present, it is still not possible to predict the arousal level on the basis of the EEG values. Although the warning sound was found to increase arousal level, the different alarm effect among four types of warning sounds was not confirmed in the range of this experiment. More systematical experimental paradigm might be necessary to confirm the alarm effect among four types of warning sounds. For example, regarding type of sounds not as within-subject factor, but as between-subject factor might be an effective way for the verification, although such a method requires many time and participants.

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