Chapter 11
Case Studies on Biometric Application for Quality-of-Experience Evaluation in Communication

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11.1 Introduction

With the advent of the information age, new communication services of high diversity emerge continuously. The demand of people for communication services is growing higher. Traditionally, the service level has been determined based on QoS (Quality of Service). QoS is the ability to provide different priority to different applications, users, or data flows. In other words, it is expected to guarantee a certain level of performance to a data flow, for instance, a required bit rate, delay, delay variation, packet loss, or bit error rates may be guaranteed. QoS sometimes refers to the level of service quality [1]. With the spread of smartphones, QoS is crucial for real-time streaming multimedia applications in a user mobile environment, for example, multiplayer online games and video streaming. These applications often require fixed bit rate and are prone to be affected by delay. QoS is especially important in a situation where the network resource capacities are limited.

Recently, QoE (Quality of Experience) is focused as a subjective metric to reflect user experience for the real-time streaming multimedia applications [2–4]. Since QoS is a quality measure evaluated from the service provider's point of view, it cannot directly describe users' satisfaction with services from the user's point of view. Nowadays, the service providers realize that they make much account of QoE to keep the users for their services. Therefore, QoE has become one of the important topics as a mobile communication ultimate metrics in the academic field as well as in the business field. The future development trend of telecommunication industry will become the key for the survival and profitability of communication operators,

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that is, to develop full telecommunication service, enhance customer perceptibility, retain users, expand the size of users, and constantly improve market share.

Historically, QoS has preceded QoE. Before advent of QoE, communication services were objectively evaluated by QoS parameters such as packet loss rates, delay, delay variation, or average throughput, which has little relationship with customer evaluation. QoS is related to the network or communication system and the media that delivers contents. Then, in 2007, QoE has been defined as a subjective measure from the user's perspective of the communication service quality [5]. Laghari and Connelly [6] also referred that QoE needs to capture people's aesthetic and hedonic needs.

QUALINET (European Network on Quality of Experience in Multimedia Systems and Services) actively studied QoE under the COST Action IC 1003. As their working definition in 2014, QoE was defined as the degree of delight or annoyance for a service from the user's viewpoint [7]. This working definition was successfully included in recommendation of the International Telecommunication Union (ITU) as ITU-T P.10 [8] in 2016. Meaning of the user's viewpoint can be considered as human expectations, feelings, perceptions, cognition, and satisfaction for the service provided [9]. In other words, QoE is a blueprint of all human subjective quality needs and experiences for his/her particular contextual usage of service [6]. Although QoE is a subjective measure, communication operators desire to measure it to improve their service from the viewpoint of their customer.

One big issue is how to capture subjective evaluation for the service from user's viewpoint. As described in [3], one of the generic methods for QoE evaluation is MOS (mean opinion score), which is the average of values determined by subjects as their individual opinion by use of the predefined scale [10]. Usually the subject assigns his/her opinion after a set of experimental trial, so that MOS cannot record time-varying evaluation of the subject during the experiment. Therefore, in recent years, researches and developments of QoE pay attention to estimating QoE from human biological signals such as skin conductance activity [11] or EEG (electroencephalogram) [12, 13], where EEG was used for evaluation of the video streaming services.

In this chapter, we focus on Internet service quality evaluation by biometrics. In particular, QoE for mobile game services is evaluated by use of EEG biometric signals. The mobile game is targeted because data traffic of smartphone is rapidly increasing [14] as well as revenues from mobile gaming market are very promising in future [15]. In addition, Japan had is the third largest gaming market in the world in 2018 next to the first United States and the second China. The Japanese gaming market had grown to $19.2 billion. Since then, as the mobile gaming companies are expanding in Japan, its gaming market is expected to swell more. Therefore, QoE evaluation is also needed for the mobile gaming market and its related companies.

The purpose of this study is to analyze the relationship between the quality of the communication service and the biometric signal when the communication state changes in the mobile environment. As the QoS parameter that effects the quality of the communication service, delay is selected. In such a varying environment, we measure EEG of game players and collect their QoE evaluation. Simultaneous measurement of the biological signal and QoE under a time-varying communication condition is a new challenge in this area. We also verify the relationship between the biological signal and QoE.

11.2 Experimental Setting

11.2.1 Game for Experiment

Since existing real mobile games are affected by unstable factors such as the number of the online players, the distance to the online game server, and induced delay, it is very difficult to set stable network conditions. Therefore, an original RPG (role-playing game) was developed under a pseudo-QoS-controllable communication environment in order to obtain the relationship between EEG and QoE accurately.

The game process shown in Fig. 11.1 is divided into four modes: the introduction mode, the practice mode, the experiment preparation mode, and the experiment mode. Each mode is shown in Figs. 11.2, 11.3, 11.4, and 11.5, respectively.

The experimental procedure is as follows. When a subject executes this application, the game introduction mode automatically starts. In the introduction mode, explanation of the operation method is shown on the display, and the subject can read the explanation until the subject understands how to operate the game. Upon understanding the operation method, the subject pushes the play button to transit to the practice mode. During the 3 min practice mode, the subject operates a character from the starting point to the end point to attack monsters along the way of the mode task map shown in Fig. 11.6. After completion of the practice mode, it automatically transits to the experiment preparation mode. In the experiment preparation mode, seven buttons with the number from 1 to 7, respectively, are prepared. Seven groups with different QoS parameters values are set corresponding to the seven buttons. By pushing one from the seven buttons, the subject transits to the experimental mode with the designated QoS parameters. Details of the different QoS parameter values will be introduced in the following section. During the 2 min experiment mode, the subject operates a character from the starting point to the end point to attack the monsters along the way of the task map shown in Fig. 11.7. After completion of the experiment mode, it automatically returns to the experiment preparation mode, and then the subject selects the next button. This cycle lasts until all seven tasks complete.

11.2.2 Experiment Preparation

The subject is asked to play the original game with the wireless EEG measurement apparatus Polymate Mini AP108 (hereinafter, referred to as the EEG apparatus). The subject uses a tablet PC, which has no influence on the EEG apparatus, to operate the game task.

Fig. 11.1 Game process

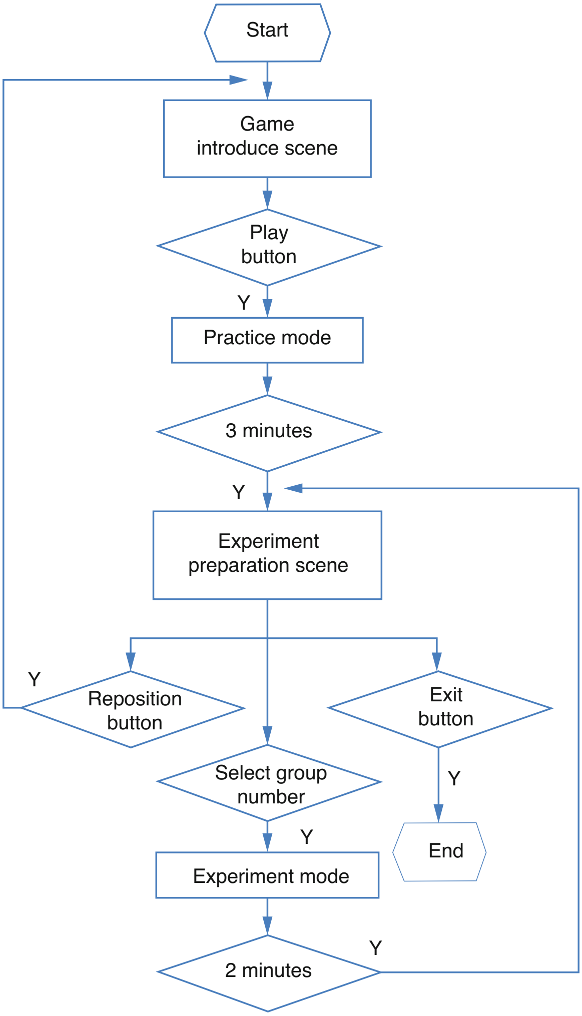


Fig. 11.2 Introduction mode

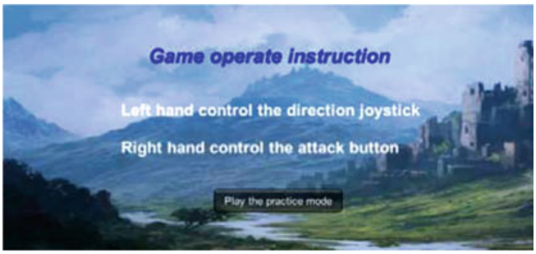
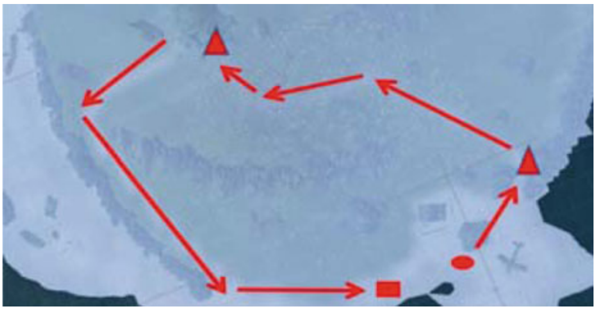


Fig. 11.3 Practice mode

Fig. 11.4 Preparation mode

Fig. 11.5 Experiment mode

Fig. 11.6 Practice task map



In the experiment setting shown in Fig. 11.8, PC(1) is used to control QoS parameters, PC(2) is used to record the EEG data, tablet PC is used to operate the game task, and the EEG apparatus is used to measure EEG. The experiment device information is shown in Table 11.1. An experimental scene is shown in Fig. 11.9.

Fig. 11.7 Experiment task map

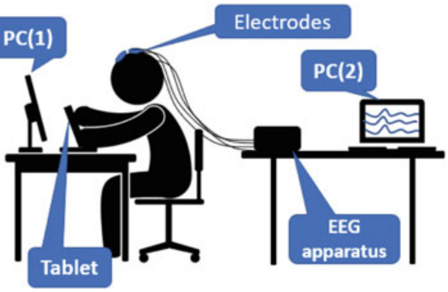


Fig. 11.8 Experiment setting

Table 11.1 Experiment device

Device	Model	OS
Note PC (1)	ASUS	Windows 7
Note PC (2)	Panasonic	Windows 10
Tablet PC	ASUS	Android 7.0
EEG apparatus	Polymate Mini AP108	

Fig. 11.9 Experiment scenes

The numbers of subjects that have RPG experiences but are not experts are the following: 9 subjects of Chinese and 7 subjects of Japanese, totally 16 subjects. Each subject carries out seven game tasks.

11.2.3 Subjective Evaluation Experiment Procedure

Subjective experiment was conducted by SS (single stimulus) evaluation method [16], whose experimental process is shown in Fig. 11.10, where squares denote tasks, circles denote value sets of QoS parameters, and triangles denote subjective evaluation after completion of each task. The subject is asked to operate one task for 2 min, followed by a QoE evaluation period presented. Seven tasks are randomly presented to each subject.

Game task QoS parameter values are shown in Table 11.2. Task 1 is regarded as a benchmark without any deterioration. Task 2, Task 3, and Task 4 have a deterioration with delay; Task 5, Task 6, and Task 7 have a deterioration with character moving speed.

11.3 EEG Measurement

11.3.1 EEG Measurement Apparatus and Measurement Points

The wireless EEG measurement apparatus is shown in Fig. 11.11, where 10 small-scale ACT electrodes are available as the AP108 accessories. Six areas of the brain, Fp1, Fp2, F3, F4, FZ, and CZ, are selected as the measurement points of the EEG apparatus according to the international 10–20 electrode system shown in Fig. 11.12.

11.3.2 EEG Frequency Bands and Significance

EEG is a test that records the electrical activity of the brain. Normally, it is a noninvasive method placing the electrodes along the scalp. These electrodes pick up voltage fluctuations resulting from ionic current inside the brain [17].

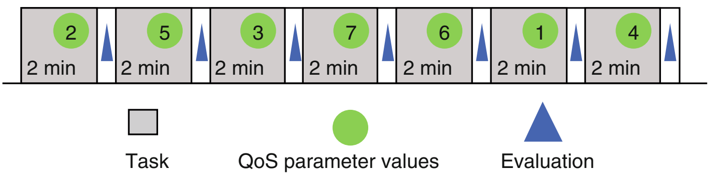


Fig. 11.10 Experiment scenes

Table 11.2 Task and QoS parameter values

	Task1	Task2	Task3	Task4	Task5	Task6	Task7
Delay (s)	0.0	0.6	0.9	1.5	0.0	0.0	0.0
Character moving speed (%)	100	100	100	100	80	60	40

Fig. 11.11 EEG apparatus

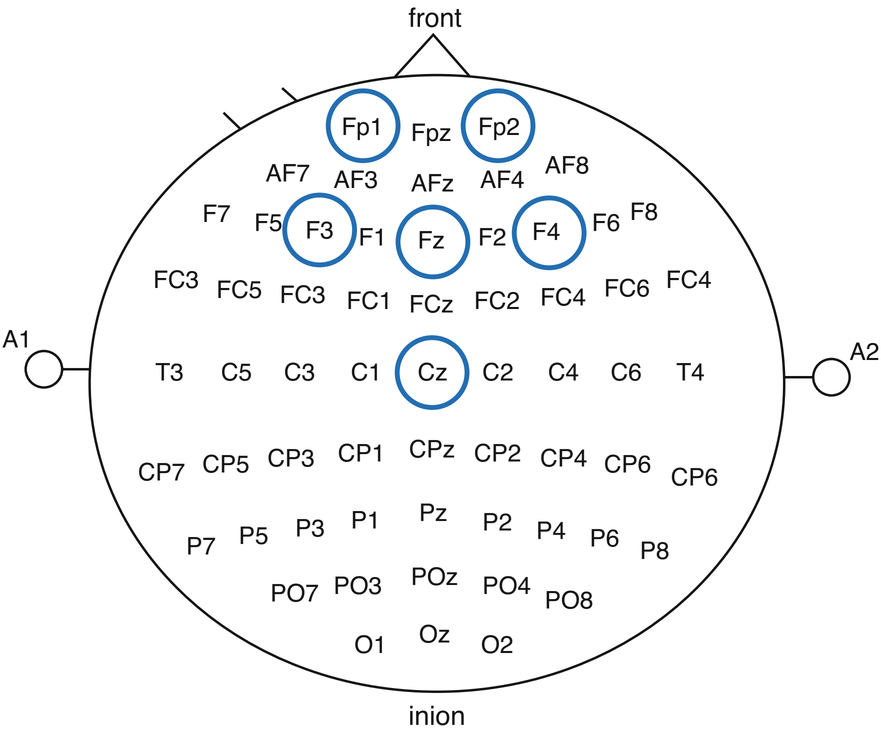


Fig. 11.12 Measurement points

The fluctuations are typically observed as waveforms of varying frequency and amplitude measured in voltage that is EEG.

EEG waveforms are generally divided into bands by frequency. Spectral methods are usually used to extract frequency bands, which are usually classified into bandwidths known as Delta (δ), Theta (θ), Alpha (α), and Beta (β) [18]. The EEG frequency bands are shown in Table 11.3.

Table 11.3 EEG frequency bands

Band	Frequency (Hz)
δ wave	<4
θ wave	$4\leq$ and <8
α wave	$8\leq$ and <14
β wave	$14\leq$

Fig. 11.13 Delta wave

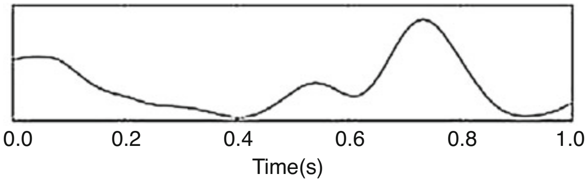


Fig. 11.14 Theta wave

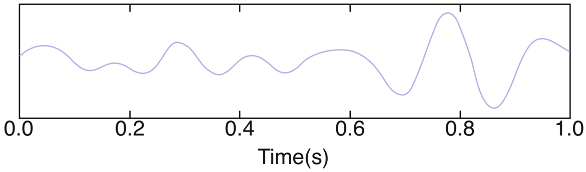


Fig. 11.15 Alpha wave

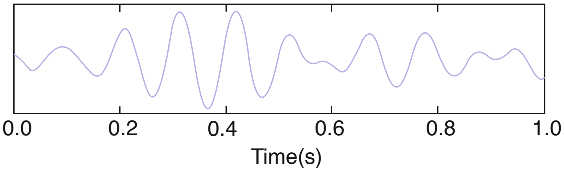
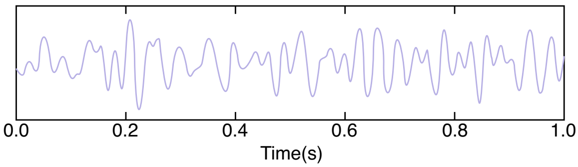


Fig. 11.16 Beta wave



The frequency range of δ wave is up to 4 Hz, shown in Fig. 11.13. It is the slowest wave, that is, its frequency is low, as well as its amplitude is the highest. Normally it is observed in deep sleep and meditation.

The frequency range of θ wave is from four to seven Hz, shown in Fig. 11.14. θ wave is observed during light sleep and meditation [19]. It is also observed in high concentration.

The frequency range of α is from 8 to 13 Hz, shown in Fig. 11.15. α wave is observed during meditation, relaxation, or contemplation.

The frequency range of β is from 14 Hz to about 30 Hz, shown in Fig. 11.16. β wave is observed during normal waking state of consciousness and is generally attenuated during active movements [20]. It can be divided into three sub-bands.

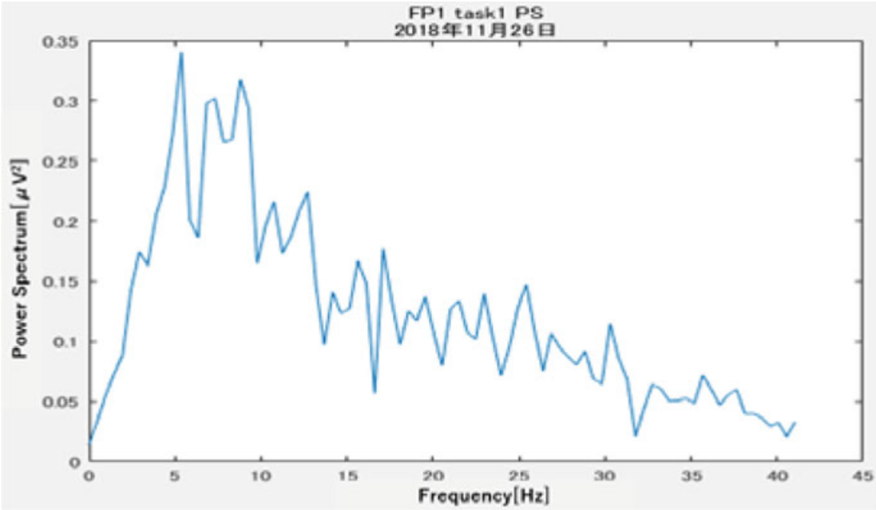


Fig. 11.17 FP1 position's EEG power spectrum for Task 1

11.3.3 EEG Power Spectrum

Through the experiments, we have obtained EEG time series data of 16 subjects. After artifacts such as blinking are selected to cut out, a Butterworth filter of 4–30 Hz is applied to five sections of the measured EEG waveform data. Consequently, each section has 1024 points. Then fast Fourier transform is applied to the waveform, and respective power spectrum is calculated. Finally, the power spectrum of the five sections is averaged to calculate the final power spectrum results. For example, one of the subject in every task FP1 position's EEG power spectrum is shown in the following figures (Figs. 11.17, 11.18, 11.19, 11.20, 11.21, 11.22, and 11.23).

11.4 Experimental Results

11.4.1 EEG Power Spectrum Comparison

The second subject's FP1 position power spectrum for Task 1 and Task 3 are shown in Fig. 11.24 as an example of the EEG analysis. In Fig. 11.24, the solid line presents Task 1, and the dotted line does Task 3. Regarding Task 1, the measured main waves are α and θ waves at FP1 position for all of 16 subjects. While α wave is the main brain waveform in the state of awakening and relaxation, θ wave is the main brain waveform in the state of high concentration. Both waveforms coexist in the situation where the subject operates the game under normal network conditions. However, when a QoS parameter value deteriorates, θ wave increases at FP1 position through all experiments with a varying degree. We consider the reason for this phenomenon

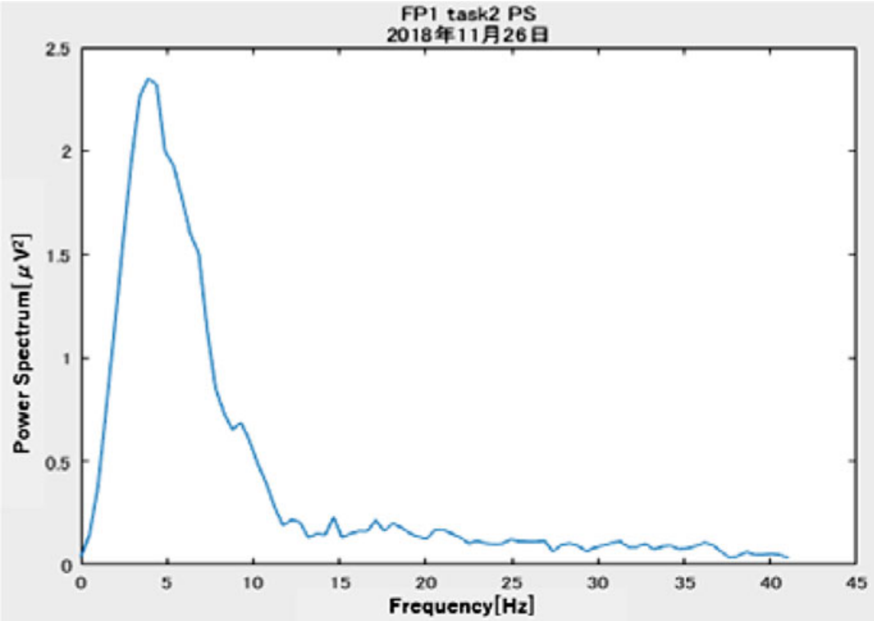


Fig. 11.18 FP1 position's EEG power spectrum for Task 2

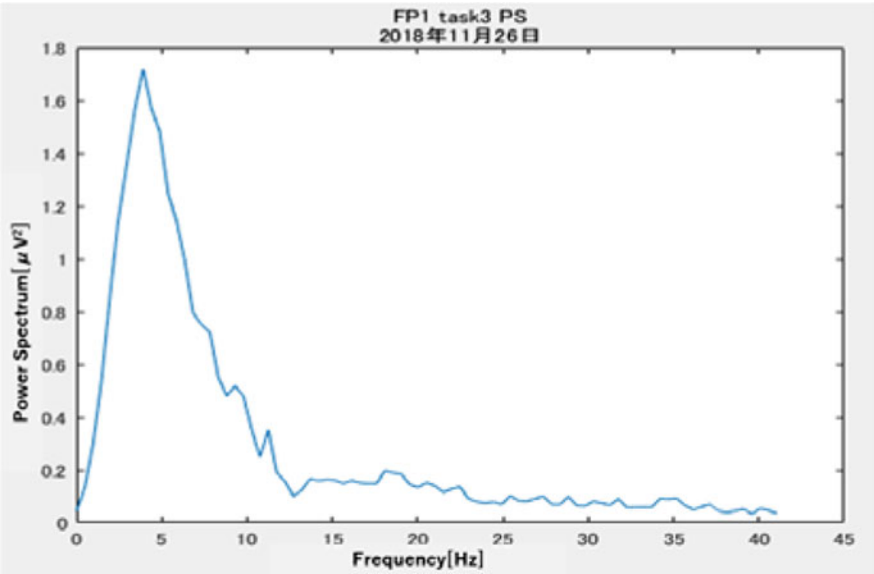


Fig. 11.19 FP1 position's EEG power spectrum for Task 3

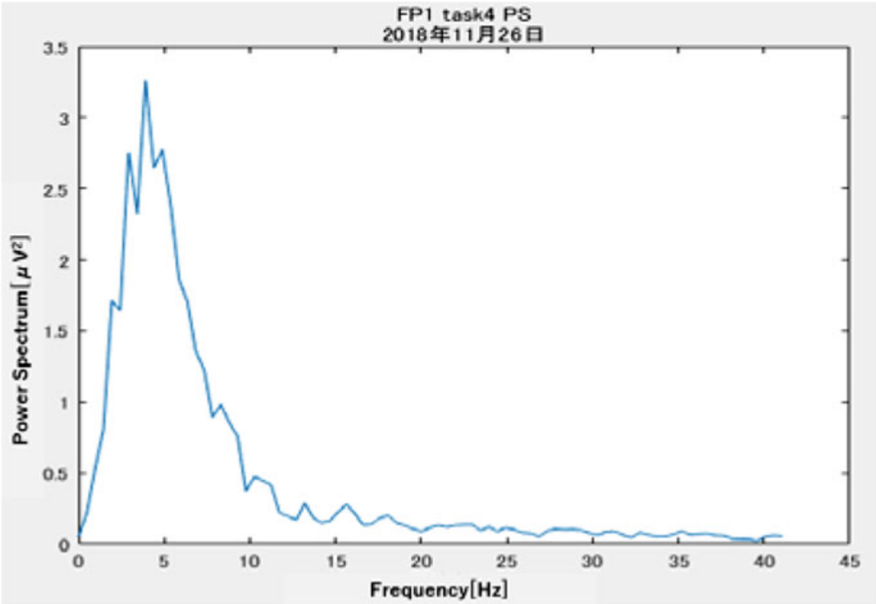


Fig. 11.20 FP1 position's EEG power spectrum for Task 4

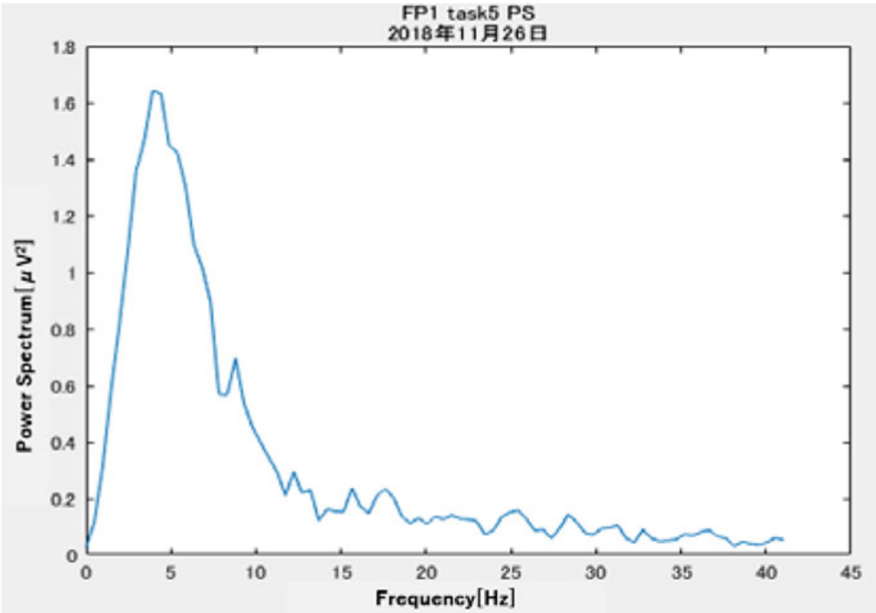


Fig. 11.21 FP1 position's EEG power spectrum for Task 5

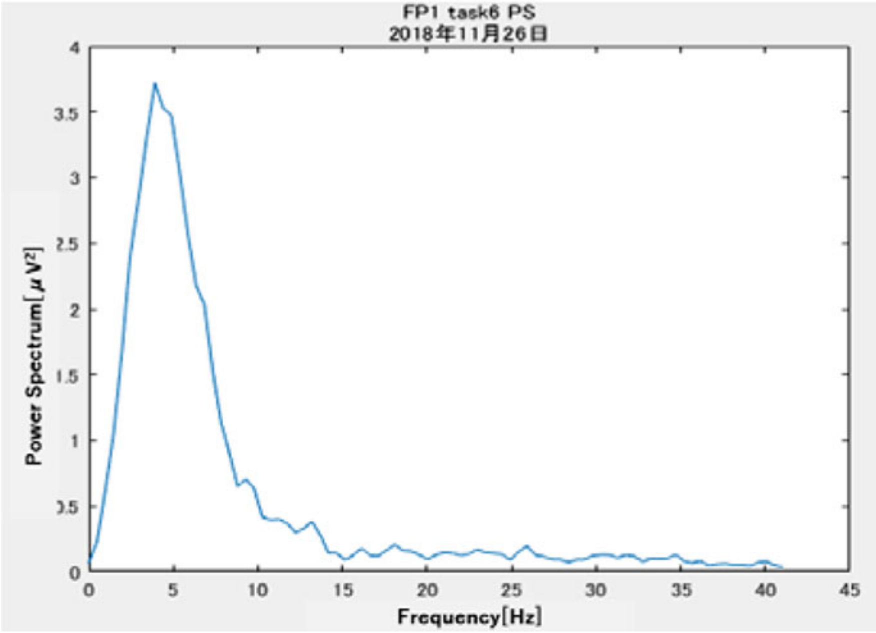


Fig. 11.22 FP1 position's EEG power spectrum for Task 6

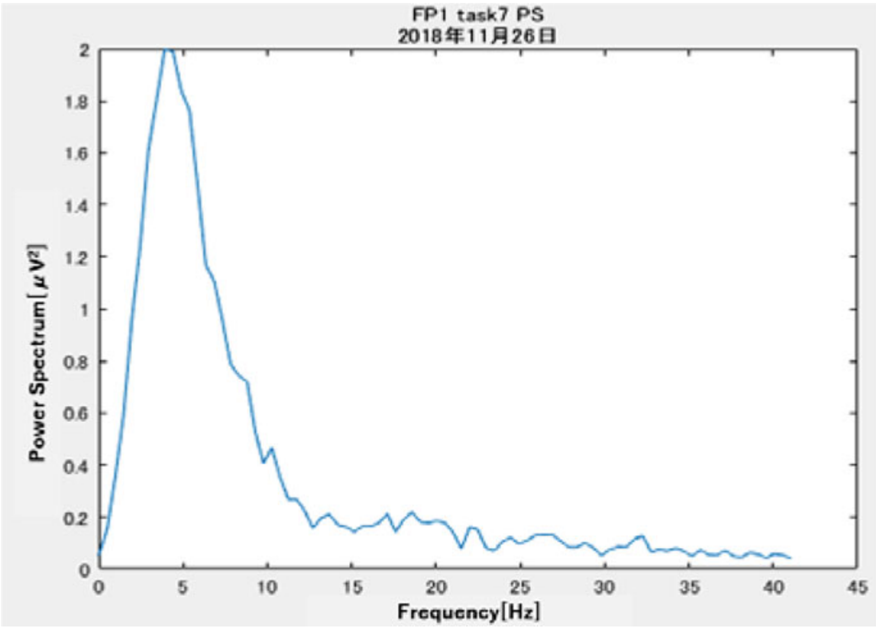


Fig. 11.23 FP1 position's EEG power spectrum for Task 7

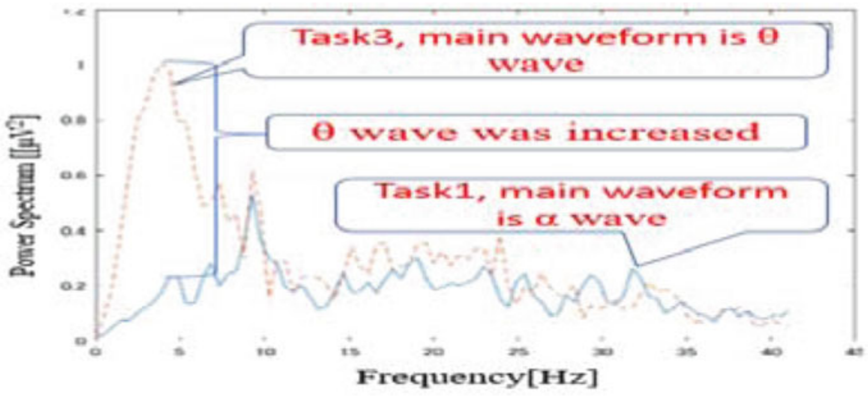


Fig. 11.24 Example of FP1 Task 1 and Task 3 power spectrum

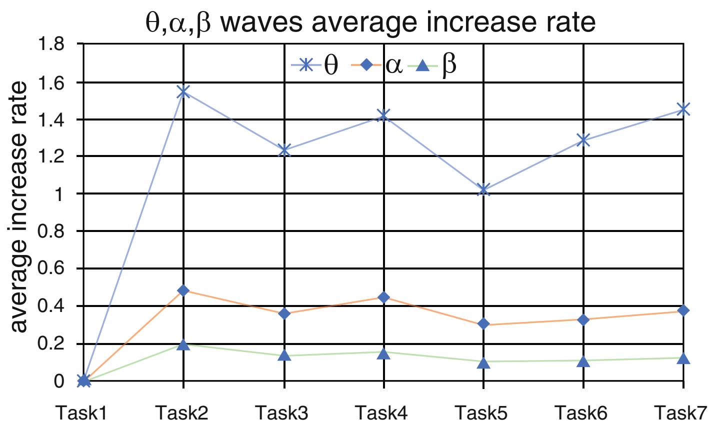


Fig. 11.25 Average increase rate

is that the subject must concentrate to accomplish the game task when he/she feels difficulty to play the game because of the QoS deterioration.

11.4.2 Average Increase Rate of Each Waveform

Regarding Task 1 as a benchmark, we calculated the 16 subjects average power spectrum value increase rate ([(the power spectrum value of each task in a specific band – the power spectrum value of specific Task 1 in a specific band)/the power spectrum value of Task 1 in a specific band]) of each task with three waveforms θ, α, and β, which are shown in Fig. 11.25. It is found that the θ wave has a great impact on the value of the QoS parameter which deteriorates than the other waves.

Compared with Task 1, the power spectrum value on the θ wave increases more than double. On the other hand, the average power spectrum values of α and β waveforms just a little increase. It can be observed that, in the process of mobile game operation, θ wave can be used as an important reference index to judge whether the QoS parameter values have deteriorated or not. It can also provide an important basis for predicting gaming QoE from EEG.

11.4.3 Average Increase Rate of Each Electrode Positions

We calculate the average power spectrum value increase rate of θ wave relative to Task 1 for each task at each electrode positions of 16 subjects, which is shown in Fig. 11.26. Obviously, when the value of the QoS parameter deteriorates, the θ waves at FP1 and FP2 positions have a very significant impact; both have increased more than twice in comparison with the average power spectrum value at other electrodes. Therefore, FP1 and FP2 can be regarded as the important positions of brain wave signal detection to help the prediction of gaming QoE. In the next section, we focus on the analysis of FP1 position and θ wave.

11.4.4 Comprehensive Comparison

In the experiments, two kinds of QoE were evaluated: a comprehensive QoE and an immersion QoE. In addition, the game score was recorded for each game task. These data are averaged for 16 subjects as comprehensive comparison. The

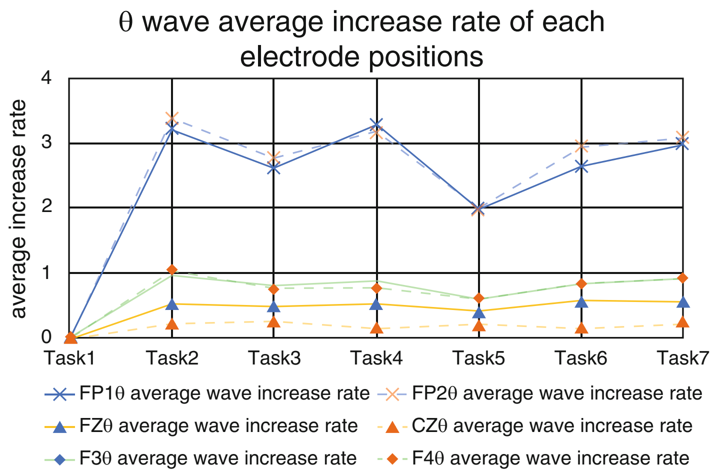


Fig. 11.26 Average increase rate of each electrode positions

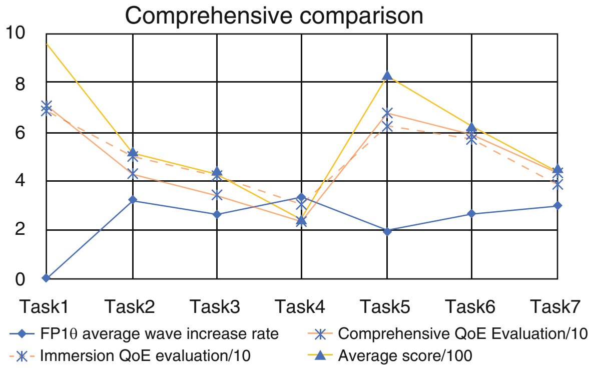


Fig. 11.27 Comprehensive comparison

averaged results are shown with the increasing rates of θ wave at the position FP1 in Fig. 11.27.

It can be found that the QoS parameter values and the QoE values have proportional relationship. Namely, when a QoS parameter value decreases, the QoE values and scores also decrease. On the other hand, besides Task 3, the average power spectrum value of θ wave is inversely proportional to the value of the QoS parameter, when the QoS parameter value decreases, the average power spectrum value of θ wave increases. In other words, when a QoS parameter deteriorates, the subjects' attention becomes more focused. In next section, we will explain the reason why Task 3 is different with other tasks in the following analysis.

11.4.5 Player Level Comparison

Sixteen subjects are grouped as high-level players (HP) and low-level players (LP) by the averaged game score based on a threshold.

Regarding the delay, shown in Fig. 11.28, we can find that the comprehensive QoE evaluation values obviously differ between HP and LP in Task 3. HP seems to think that Task 3 and Task 2 are similar, because they can perform these tasks smoothly compared to LP and they spend similar attention to operate Task 2 and Task 3, so the θ wave increase rates of HP have similar tendency in Tasks 2 and Task3. On the other hand, LP thinks that Task 3 is much more difficult than Task 2. They cannot finish the task smoothly, so they begin to lose some interest in the game. So, their attention drops when they feel it is difficult to finish the task, and θ wave also appears to drop dramatically. Therefore, Task 3 is different from the other tasks in comprehensive comparison.

In addition, from Fig. 11.29, it is found that QoE evaluation trend regarding the character moving speed changing is similar between HP and LP for Tasks 5, 6, and 7. On the other hand, θ wave changing, however, obviously differs in Tasks 6 and 7 between HP and LP. Slower character moving speed may have a greater impact on

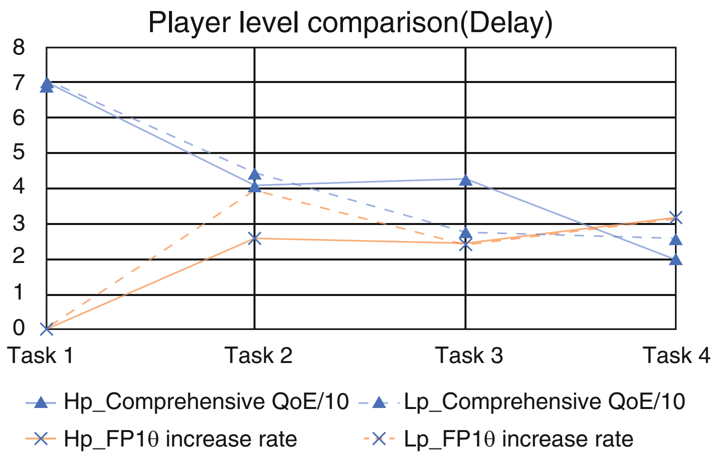


Fig. 11.28 Player level comparison of delay

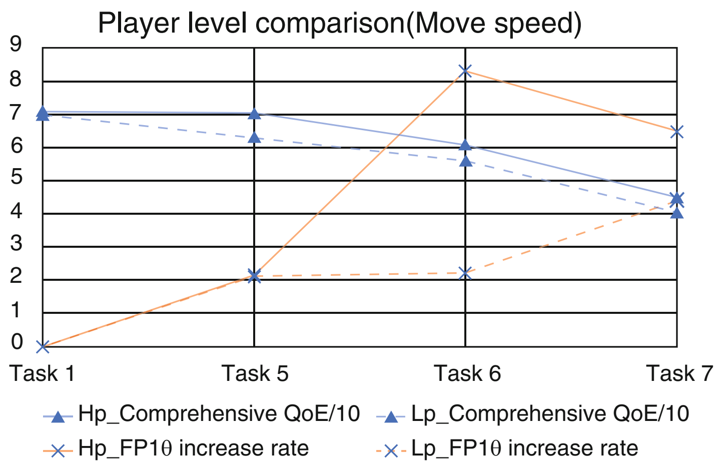


Fig. 11.29 Player level comparison of moving speed

HP. Although HP and LP have similar subjective perception for slow change of the character moving, HP will pay more attention to accomplishing the tasks even for the slow character moving.

Immersion QoE comparison between HP and LP is shown in Fig. 11.30. It is found that LP has tendency to show higher immersion than HP when the QoS parameter values deteriorate.

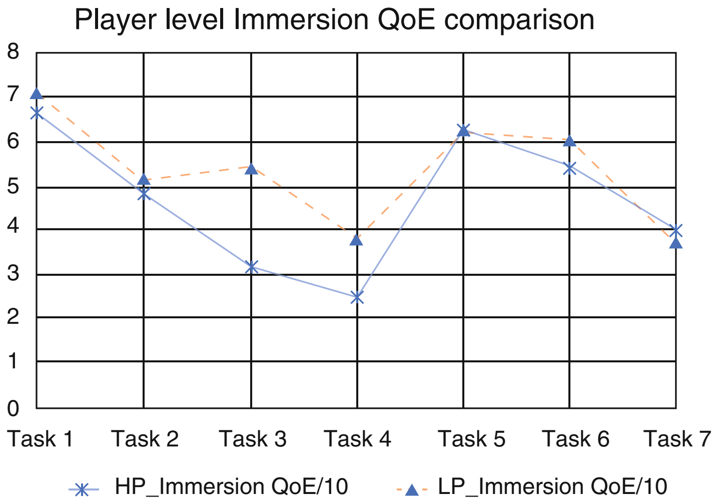


Fig. 11.30 Player level comparison for immersion QoE

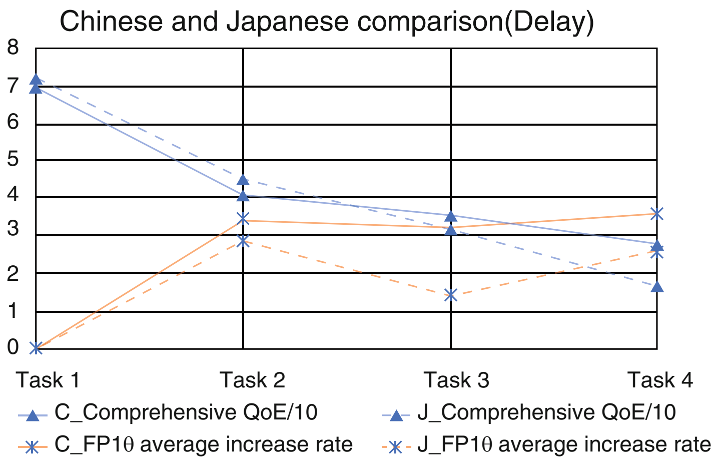


Fig. 11.31 Chinese and Japanese comparison of delay

11.4.6 Chinese and Japanese Comparison

Of the 16 subjects, 9 are Chinese, and 7 are Japanese. In this section we will analyze the differences between them.

Figure 11.31 shows that Japanese change in comprehensive QoE amplitude is more obvious with delay deterioration. This indicates that the Japanese are more sensitive to delay change when they operate an RPG. On other hand, Chinese power spectrum value increasing rate of θ wave is obviously higher than Japanese.

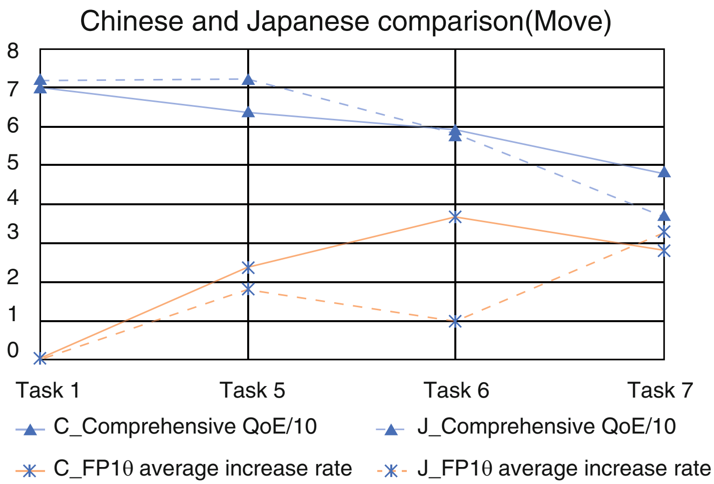


Fig. 11.32 Chinese and Japanese comparison of moving speed

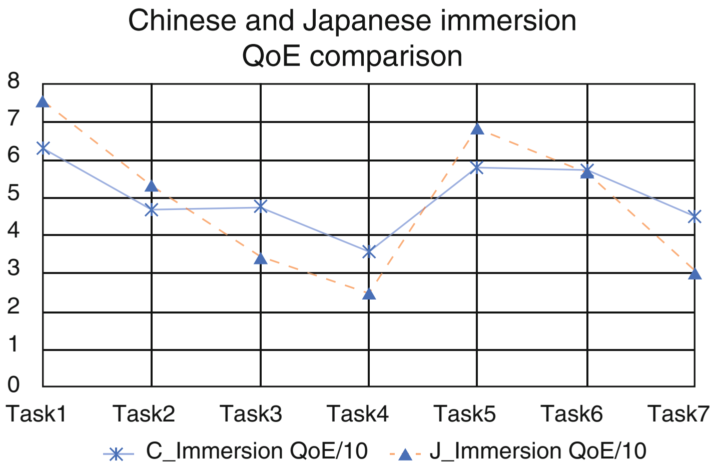


Fig. 11.33 Chinese and Japanese comparison of immersion QoE

In addition, regarding the character moving speed, shown in Fig. 11.32, the values of comprehensive QoE are almost the same as in the delay scenarios. The increasing rate of θ wave for the Chinese power spectrum value is also higher than Japanese obviously. And the immersion QoE comparison between Chinese and Japanese is shown in Fig. 11.33. Japanese change in immersion QoE amplitude is more obvious, so Japanese immersion QoE is more susceptible to the deterioration of QoS parameter values.

Because the number of participants in the experiment is not so large for each nationality, the results of the experiment cannot prove that there is a significant difference between the two nationalities. The significance is that individual differences in nationality, gender, and player level should be considered as a reference for QoE prediction from EEG.

11.5 Conclusions

Case studies of user-centric evaluation for a mobile game application have been conducted. EEG was used as a direct metric to capture user situation, and QoE evaluation was obtained from the user for different QoS situations. Through these experiments, we have verified that there is a certain relationship between EEG and QoE. It can be concluded that this relationship might be useful to predict user satisfaction through EEG. Of course, this prediction is based on only considering the impact of network traffic condition on user QoE while gaming but is excluding audio, game content, and other factors.

In a real situation, more rough classification of QoE can be useful as user satisfaction evaluation. For example, five scales of QoE (excellent, good, fair, poor, bad) might be enough to determine the user satisfaction level. On the other hand, individual differences must also have an impact on gaming QoE, so we should also consider the issue of individual differences in the prediction model.

This study has validated the relationship between QoE and EEG. Also, it can be found out what differences exist in the relationship between QoE and EEG when there are differences in the level of game players. The future ultimate purpose of this study is to predict the QoE of users through the relationship between QoE and EEG and apply it to the communication industry and the game industry.

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