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Supplementary Information

A Review of Brain-Computer Interface Games and an Opinion Survey from Researchers, Developers and Users. *Sensors* 2014, *14*, 14601-14633

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S1. Demonstration of Two Games

This appendix addresses the game demonstration at two conferences in South Korea in 2012: Human Computer Interaction (HCI) of Korea and Korea Computer Congress (KCC). In addition, the opinions collected before/after each participant played the games are presented.

S1.1. Methods

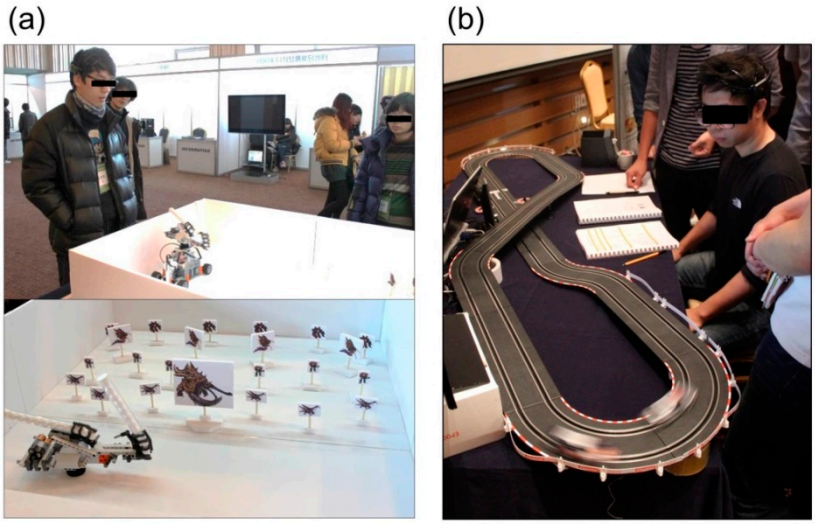
In the first game, a tank and cannon made of Lego blocks moves horizontally and fires a plastic ball straight ahead every 2 s. The cannon is mounted on the center of the Lego tank and rotates at left or right angles, but the participant can change the direction of the rotation. Originally, we planned to use motor imagery and conventional algorithms, such as common spatial patterns and Fisher linear discriminant analysis (FLDA) [1]. However, in most cases, we observed that motor imagery failed to provide the user with reasonable control and response time. Therefore, we modified the method of play in order to guarantee the user some degree of control. We asked the participant to clench his left or right teeth to change the direction of the moving cannon. The signals measured ("Emotiv EPOC": 14 channels with sampling rate 256 Hz) were delivered to the computer and the direction of the cannon's movement changed according to which channels on the left or right of the head showed higher power. The mission of the game is to hit as many monsters as possible with the cannonball until every ball has been fired. Although the control paradigm is EMG-based, we focused on the fact that it gives the user the experience of control without a conventional device, such as a keyboard, mouse, or joystick.

The second game was designed to use passive BCI. For this purpose, we adopted one of our previous games [2]. In this game, the participant simply attends to her/his car, while the system

processes the brain signals and quantifies the level of concentration. If the concentration level is high, the car's velocity increases and produces a louder driving sound. In the beginning of this game, the system calculates the distribution of the level of concentration and then controls the car's velocity according to where the current level lies in the distribution. The challenge of this game is to drive the track as many times as possible within a limited time (2 min.). These two games are demonstrated in Figure S1.

For participation, we invited visitors opportunistically to enjoy the games; sixteen played the first game and twenty played the second. Before and after they played the games, the participants were given questionnaires to rate their feelings and evaluations of the games on a 5 point Likert scale.

Figure S1. Game demonstration for visitors. Two games were designed to give participants the experience of active (**a**) and passive (**b**) paradigms.



S1.2. Evaluation Results

Table S1 shows results from the game participation. For the question about feelings (Q1), four states were listed: relaxation, interest and physical or mental conditions. The games seemed to be interesting to participants, as their responses to the questions were quite positive (points below 3 on the 5 point scale indicate more positive responses) with respect to interest, concentration level, game content and environment evaluation. Most of the participants answered "Yes" to the question asking whether they wanted to play another game.

We found some differences in our comparison of these two games. The first notable point refers to interest. In the passive paradigm, interest increased significantly (from 2.75 to 1.9) after playing the games. In the question that asked how easy it was to play the game, the responses were rather negative (3.25) for the active paradigm, and were slightly more positive (2.50) for the passive paradigm. However, the participants who played the active paradigm game seemed to focus on the game more (concentration: 1.88) than those who played the game with the passive paradigm (concentration: 2.35). Therefore, they might not be distracted by the environment, as we found that the mean value for "environment" was lower in the active (1.75) than in the passive paradigm (2.5). In the evaluation of the games' completeness, participants rated the active paradigm game a little lower (2.81) than the

passive game (2.30). We interviewed some participants after they played the games. Most said that the games were very interesting but that controlling the tank's cannon was difficult for them, and that while playing, they tried to find better ways to control it. On the other hand, users who played the game with the passive paradigm told us that they could feel the interaction through their mental concentration on the car.

Table S1. Questionnaire results. Question Q1 was asked before and after playing the game. Questions Q2 to Q8 were asked after participants played the game. The participants indicated their responses on a 5 point scale in questions 1 through 5; Q8 had only two options (Yes or No). The means and standard deviations are given for each question and paradigm.

Questions		**Active Paradigm**		**Passive Paradigm**	
Number of participants (M: Male, F: Female)		**16 (M: 10, F: 6)**		**20 (M: 16, F: 4)**	
		Before	**After**	**Before**	**After**
Q1) How do you feel?	Calm to Agitated: 1 to 5	2.25 ± 0.9	2.31 ± 0.98	2.70 ± 0.78	2.70 ± 1.05
	Interested to Bored: 1 to 5	1.88 ± 0.86	1.56 ± 0.61	2.75 ± 1.04	1.90 ± 0.89
	Body condition: (Good to Tired: 1 to 5)	2.56 ± 1.17	2.19 ± 1.07	3.25 ± 0.94	2.90 ± 0.62
	Mental condition: (Good to Tired: 1 to 5)	2.19 ± 0.95	2.19 ± 0.88	3.10 ± 1.04	2.95 ± 0.89
Q2) How much did you concentrate? (Strong to Poor: 1 to 5)		1.88 ± 0.78		2.35 ± 0.79	
Q3) How easy was the game to play? (Easy to Hard: 1 to 5)		3.25 ± 1.09		2.50 ± 1.07	
Q4) How do you say about game time? (Short to Long: 1 to 5)		2.81 ± 1.81		2.55 ± 0.92	
Q5) How good is the game content? (Good to Poor: 1 to 5)		1.94 ± 0.92		2.05 ± 0.86	
Q6) How good is the environment to play game? (Good to Poor: 1 to 5)		1.75 ± 0.83		2.50 ± 0.97	
Q7) Please grade the completeness of the game. (Perfect to Poor: 1 to 5)		2.81 ± 0.63		2.30 ± 0.71	
Q8) Do you want to play one more? (Yes or No)		Yes: 14, No: 2		Yes: 20, No: 0	

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