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Louis Korczowski, Alexandre Barachant, Anton Andreev, Christian Jutten,  
Marco Congedo

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Louis Korczowski, Alexandre Barachant, Anton Andreev, Christian Jutten, Marco Congedo. ”Brain Invaders 2”: an open source Plug

Play multi-user BCI videogame. 6th International Brain-Computer Interface Meeting (BCI Meeting 2016), May 2016, Pacific Grove, CA, United States. Proceedings of the 6th International Brain-Computer Interface Meeting, pp.10.3217/978-3-85125-467-9, <10.3217/978-3-85125-467-9-224>. <hal-01318726>

**HAL Id: hal-01318726**

**<https://hal.archives-ouvertes.fr/hal-01318726>**

Submitted on 19 May 2016

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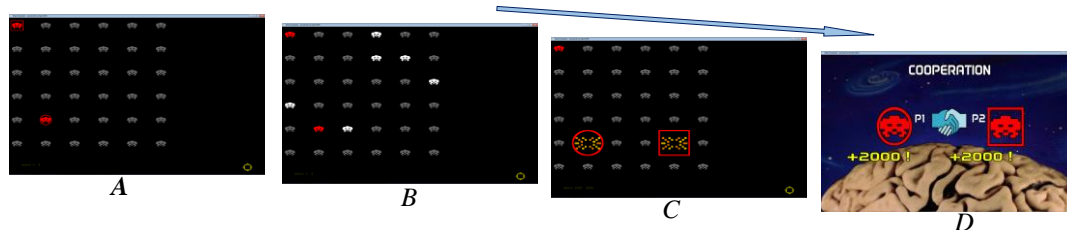
# “Brain Invaders 2”: an open source Plug & Play multi-user BCI videogame

L. Korczowski<sup>\*1</sup>, A. Barachant<sup>2</sup>, A. Andreev<sup>1</sup>, C. Jutten<sup>1</sup>, M. Congedo<sup>1</sup>

<sup>1</sup>GIPSA-Lab, Univ. Grenoble Alpes, CNRS, Grenoble, France. <sup>2</sup>Burke Medical Research Institute, White plains, NY, USA.

\*P.O. Box: 11 rue des Mathématiques, 38400 Saint-Martin-d’Hères. E-mail: louis.korczowski@gipsa-lab.fr

*Introduction:* In 2011 we proposed « Brain Invaders » [1], a BCI videogame inspired from the vintage game Space Invaders. The software was released open source and was compatible with OpenVIBE [2]. The system is based on ERP classification using the oddball paradigm with a grid of 36 possible targets. This second version extends the game to the multi-user scenario. It includes four game modes namely *Solo*, *Collaboration*, *Cooperation*, *Competition* which are suitable for hyperscanning studies. Thanks to a classification algorithm based on Riemannian geometry, the system shows very good accuracy and is fully “Plug & Play”, no calibration phase is needed.



**Figure 1.** Brain Invaders v2: (A) Level initialization. (B) After a short delay, the game flashes randomly all the aliens. (C) The game destroys the most likely alien(s) according to the classification. (D) If the player(s) succeed(s) at destroying the target(s), s/he (they) is awarded by a fixed amount of points or by a factor proportional to the number of repetitions required.

*Material, Methods and Results:* “Brain Invaders 2” includes several characteristics that make it suitable for recreational, educational and research purposes: ■ Random alien target and alien distractor localization on a 6x6 grid (see Fig. 1A). Unpredictable flashing pattern (see Fig. 1B) with pseudo-random generated inter-stimulus interval (ISI) according to an exponential distribution. ■ Supervised adaptive classification method using the minimum distance to mean (MDM) of covariance matrices according to the Fisher information metric [3] and extended in the multi-user case according to [4]. This classification method has shown state-of-the-art performances, yet is simple, and can run on modest computers. ■ The system has been tested extensively on more than 250 subjects in controlled conditions (see Table 1) and also on hundreds of subjects during numerous public demonstrations and competitions (not presented here). It has been described by the participants as engaging and entertaining.

**Table 1** List of the experiments using the Brain Invaders software with the minimum, average and maximum online classification performance of the participants. Chance level is 1/36.

Database	Mode(s)	# subjects	# sessions	Electrodes	Min (%)	Av (%)	Max (%)	Ref.
bi2012a	solo	26	1	17-wet	28.19	47.79	68.94	
bi2013a	solo	24	Up to 8	16-wet	42.86	62.88	92.31	[5]
bi2014a	solo	71	3	16-dry	16.67	35.55	72.97	
bi2014b	solo-collaboration	38	4	2x32-wet	36.73	68.30	94.74	[4]
bi2015a	solo	50	3	32 wet	33.33	68.04	100	
bi2015b	cooperation-competition	44	4	2x32 wet	27.5	74.0	98.75	

*Discussion:* The authors propose a complete state-of-the-art ERP-BCI chain for single-/multi-user. The use of open source code and OpenVIBE allows quick experimental protocol design and classification methods prototyping. This is part of an ongoing research and development effort concerning the Brain Invaders.

*Acknowledgements:* The software is freely available on the GPL license into the package “openvibe-gipsa-extensions”. This research is partially funded by the European Research Council project CHES 2012-ERC-AdG-320684. The authors would like to thank Ekaterina Ostaschenko and Martine Cederhout for the experimental support.

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