











## CONCLUSION

We conclude that it is possible to use this kind of template to play BCI P300 games without calibration. There is an obvious drop of performance compared to an individual calibration, but the use of this kind of template may prove sufficient in the context of training. We found no difference in classification accuracies between games but differences in game design yielded differences at the physiological level. This should be further investigated in the future in order to optimize the training, for instance by presenting the games in a specific order. These results could also allow to guide the design of new games to target specific components, toward a more individualized approach.

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## REFERENCES

- [1] U. Hoffmann, J.-M. Vesin, T. Ebrahimi, and K. Diserens, “An efficient P300-based brain-computer interface for disabled subjects,” *J. Neurosci. Methods*, vol. 167, no. 1, pp. 115–125, Jan. 2008.
- [2] J. Mattout, M. Perrin, O. Bertrand, and E. Maby, “Improving BCI performance through co-adaptation: Applications to the P300-speller,” *Ann. Phys. Rehabil. Med.*, vol. 58, no. 1, pp. 23–28, Feb. 2015.
- [3] E. Maby, M. Perrin, O. Bertrand, G. Sanchez, and J. Mattout, “BCI Could Make Old Two-Player Games Even More Fun: A Proof of Concept with ‘Connect Four,’” *Adv. Hum.-Comput. Interact.*, vol. 2012, p. 8, 2012.
- [4] E. Baykara *et al.*, “Effects of training and motivation on auditory P300 brain-computer interface performance,” *Clin. Neurophysiol.*, vol. 127, no. 1, pp. 379–387, Jan. 2016.
- [5] J. D. Jacoby, M. Tory, and J. Tanaka, “Evoked response potential training on a consumer EEG headset,” in *2015 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM)*, 2015, pp. 485–490.
- [6] M. Fouillen, E. Maby, L. Le Carrer, V. Herbillon, and J. Mattout, “ERP-based BCI training for children with ADHD: motivation and trial design,” *7th Graz Brain-Comput. Interface Conf. 2017*, 2017.
- [7] S. J. Johnstone, R. J. Barry, and A. R. Clarke, “Ten years on: A follow-up review of ERP research in attention-deficit/hyperactivity disorder,” *Clin. Neurophysiol.*, vol. 124, no. 4, pp. 644–657, Apr. 2013.
- [8] A. Barachant and M. Congedo, “A Plug&Play P300 BCI Using Information Geometry,” *ArXiv14090107 Cs Stat*, Aug. 2014.
- [9] F. Lotte and C. Guan, “Learning from other subjects helps reducing Brain-Computer Interface calibration time,” in *2010 IEEE International Conference on Acoustics, Speech and Signal Processing*, 2010, pp. 614–617.
- [10] U. Technologies, “Unity 3D,” *Unity*. [Online]. Available: <https://unity.com/frontpage>. [Accessed: 16-Apr-2019].
- [11] F. Akgul, *ZeroMQ*. Packt Publishing Ltd, 2013.
- [12] A. Gramfort *et al.*, “MNE software for processing MEG and EEG data,” *NeuroImage*, vol. 86, pp. 446–460, Feb. 2014.
- [13] D. Bates, M. Mächler, B. Bolker, and S. Walker, “Fitting Linear Mixed-Effects Models Using lme4,” *J. Stat. Softw.*, vol. 67, no. 1, pp. 1–48, Oct. 2015.
- [14] S. R. Searle, F. M. Speed, and G. A. Milliken, “Population Marginal Means in the Linear Model: An Alternative to Least Squares Means,” *Am. Stat.*, vol. 34, no. 4, pp. 216–221, Nov. 1980.
- [15] B. Z. Allison and J. A. Pineda, “Effects of SOA and flash pattern manipulations on ERPs, performance, and preference: implications for a BCI system,” *Int. J. Psychophysiol. Off. J. Int. Organ. Psychophysiol.*, vol. 59, no. 2, pp. 127–140, Feb. 2006.
- [16] M. S. Treder and B. Blankertz, “(C)overt attention and visual speller design in an ERP-based brain-computer interface,” *Behav. Brain Funct.*, vol. 6, no. 1, p. 28, May 2010.
- [17] P. Brunner, S. Joshi, S. Briskin, J. R. Wolpaw, H. Bischof, and G. Schalk, “Does the ‘P300’ speller depend on eye gaze?,” *J. Neural Eng.*, vol. 7, no. 5, p. 056013, Oct. 2010.
- [18] S. Fazli, F. Popescu, M. Danóczy, B. Blankertz, K.-R. Müller, and C. Grozea, “Subject-independent mental state classification in single trials,” *Neural Netw.*, vol. 22, no. 9, pp. 1305–1312, Nov. 2009.
- [19] B. Reuderink, J. Farquhar, M. Poel, and A. Nijholt, “A subject-independent brain-computer interface based on smoothed, second-order baselining,” *Conf. Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. IEEE Eng. Med. Biol. Soc. Annu. Conf.*, vol. 2011, pp. 4600–4604, 2011.
- [20] I. A. Basyul and A. Ya. Kaplan, “Changes in the N200 and P300 Components of Event-Related Potentials on Variations in the Conditions of Attention in a Brain-Computer Interface System,” *Neurosci. Behav. Physiol.*, vol. 45, no. 9, pp. 1038–1042, Nov. 2015.