Brain-Machine Interfaces: Progress in Large Clinical Validation

José del R. Millán, Tom Carlson, Luca Tonin, Serafeim Perdikis, Andrea Biasiucci and Robert Leeb

Abstract— **Brain-machine interfaces (BMI) have largely been demonstrated in laboratory conditions involving, mainly, healthy users. We have recently carried out a series of studies with a substantial number of motor-disabled end-users operating different brain-controlled devices in ecological conditions and without the assistance of BMI experts.**

I. INTRODUCTION

In the European integrated project TOBI (Tools for Brain-Computer Interaction), we have started to combine brain-machine interfaces (BMI) and assistive technologies [1] in order to develop a variety of practical devices for motor-disabled people. These brain-controlled prototypes range from text entry systems [2], to telepresence robots [3] and to rehabilitation devices [4]. In total, these prototypes have been tested by nineteen end-users and patients suffering from mild to severe levels of motor impairment. Importantly, tests have been mostly carried out by non-BMI experts outside our lab. In particular, experiments took place at the patients' clinic (in the case of rehabilitation) and end-users' home or an assistive technology support center [5].

II. METHODS

All three BMI devices are based on the voluntary modulation of electrical rhythmic brain activity measured with electroencephalogram (EEG). The BMI differentiates between two motor imagery tasks, plus intentional non-control. This is achieved through the use of a probabilistic classifier with evidence accumulation [6, 7]. Our BMI approach incorporates some additional principles —in particular, shared control— so as to increase reliability, reduce workload, and facilitate split attention.

For the text entry and telepresence robot, end-users need first to undertake a period of training in order to learn to modulate some control features of their EEG (frequencies at certain locations). Participants had to achieve a stable and high level of BMI performance ($\geq 70\%$) after no more than 5–7 two-hour sessions, which were carried out once or twice per week. Only then, were they allowed to progress to the evaluation of the brain-controlled prototype devices. The subjects selected to take part in these studies were affected by different levels of myopathy, spinal cord injury, tetraglegia, spino-cerebellar ataxia, or multiple sclerosis.

In the case of the rehabilitation system, stroke patients did not need to train to achieve a specific level of BCI performance before progressing to the therapy. Instead we directly exploited any discriminant EEG feature functionally related to execution (or the attempted execution) of the target motor task to rehabilitate —extension of the affected hand in our case. Four chronic stroke patients performed a total of 10 rehabilitation sessions, two sessions per week.

III. RESULTS AND CONCLUSIONS

Despite the short and non-intense training period, around 50% of the end-users mastered their BMI well enough to progress to the brain-controlled device tests (telepresence robot and text entry system). All succeeded in operating the devices, and many tried both. In total, 6 end-users tested the text-entry system and 9 end-users tested the telepresence robot. This is not a trivial achievement, as good BMI control does not necessarily transfer into proper operation of the device, which requires split-attention between the BMI task and the application itself. In the case of the chronic stroke patients, all four carried out their rehabilitation protocol satisfactorily and achieved significant improvements in their clinical scores (Fugl-Meyer).

Altogether, these results indicate that BMIs are mature enough to start leaving the laboratory and entering daily environments of end-users (homes and assistive technology support centers) and patients (clinics). Our future work will focus on extending the clinical evaluation with more subjects and on improving the underlying principles of our BMI.

REFERENCES

[1] J. d. R. Millán, R. Rupp, G. Müller-Putz, et al., "Combining brain-computer interfaces and assistive technologies: State-of-the-art and challenges," *Front. Neurosci.*, vol. 4, 161, 2010.

[2] S. Perdikis, A. Ramsey, R. Leeb, J. Williamson, A. Al-Khodairy, R. Murray-Smith, and J. d. R. Millán, "Clinical evaluation of a hybrid-BCI text-entry system," in *Proc. TOBI Workshop III*, 2012.

[3] L. Tonin, T. Carlson, R. Leeb, and J. d. R. Millán, "Brain-controlled telepresence robot by motor-disabled people," in *Proc. Annual Intl. Conf. IEEE Eng. Med. Biol. Soc.*, 2011.

[4] A. Biasiucci, R. Leeb, A. Al-Khodairy, V. Buhlmann, and J. d. R. Millán, "Brain controlled functional electrical stimulation for motor recovery after stroke," in *Proc. TOBI Workshop IV*, 2013.

[5] R. Leeb, S. Perdikis, L. Tonin, A. Biasiucci, M. Tavella, A. Molina, A. Al-Khodairy, T. Carlson, and J. d. R. Millán, "Transferring brain-computer interface skills: From simple BCI training to successful application control," *Artif. Intell. Med.*, in revision, 2013.

[6] J. d. R. Millán, P. W. Ferrez, F. Galán, E. Lew, and R. Chavarriaga, "Non-invasive brain-machine interaction," *Int. J. Pattern Recognition Art. Intell.*, vol. 22, pp. 959–972, 2008.

[7] S. Perdikis, H. Bayati, R. Leeb, and J. d. R. Millán, "Evidence accumulation in asynchronous BCI," *Int. J. Bioelectromagnetism*, vol. 13, pp. 131–132, 2011.