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A Business Proof-of-Concept of a Brain-Computer Interface for Cognitive Enhancement

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***Abstract*— This study reports on the implementation of a business proof-of-concept of a brain-computer interface product for cognitive enhancement, focusing on the technical advances that enabled its development.**

I. INTRODUCTION

Brain-Computer Interfaces (BCIs) translate brain signals into meaningful commands for applications such as communication, motor substitution, neurorehabilitation, and entertainment, to name a few. Most existing BCIs have proof-of-concepts carried out in research laboratories [1]. Although there have been technological efforts dedicated to this new discipline, very few companies have demonstrated clear business cases. This is mainly because market solutions must go further than **technology proof-of-concept** and be competitive, solve a clear need with reliability, have an affordable cost for the client, be easy to operate by non-technical professionals, assure a good experience for the final customer (user of the BCI tech), and guarantee post-sale service, among others.

A **business proof-of-concept** is reported herein, for a BCI product developed by Bitbrain [2]. Five Centers in Spain acquired the technology/service at full price and integrated this new technology in their offer portfolio, to build a valid business proof-of-concept. These Centers have been using the technology for a little more than one year, on around 100 users during approximately 1000 hours, fully autonomously (without any intervention from Bitbrain). The Centers actively offered this service to their clients, who paid full price to access the technology. Personnel had no previous experience with EEG or similar technologies, and were fully autonomous after a short training session of less than 8 hours.

II. THE BCI PRODUCT: ELEVVO

Elevvo implements a **BCI for cognitive enhancement** adapted for three types of use: clinical (cognitive rehabilitation), wellness (cognitive training), and high performance (peak cognitive performance). The **rationale** behind this BCI is to produce cognitive improvement as a result of neuroplastic changes in the upper alpha (UA) of posterior brain areas [3], [4]. This is supported by the relationship between increased parieto-occipital alpha activity and cognitive function, which relies on inhibitory mechanisms of task-irrelevant brain regions [5].

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Fig. 1. BCI session with an elderly user.

A. Main components of the BCI product

EEG hardware is one of the main limitations for the effective adoption of BCIs. This is the reason why two new EEG devices were developed. For the clinical sector, there is the Versatile EEG, which is a mobile and semi-dry 16 channel EEG system designed with great portability, cleanliness and easy placement (under 3 minutes). For the wellness and high performance sectors, there is the Minimal EEG (see Figure 1), which is a wearable and light 12 channel dry-EEG system with great portability, ergonomics, cleanliness and easy placement (under 2 minutes). Both devices cover the FP1, FP2, F3, F4, P3, P4, PO7, PO8, O1 and O2, key sensors for online signal processing.

The main objective of the **software** is to avoid any technical and manual processes. This is why all interventions present pre-fixed parameters only (pre/post tests, number of training sessions and phases, execution time, etc), and all processes are automated (artifact filtering and decoding). The only process executed by the professional is the EEG setup, which has a very simplified interface based on the scheme of a head displayed on the screen, with color-coded sensor impedances (green, yellow, and red). The software also automates the neurocognitive and EEG tests (pre/post assessment), and the training sessions.

Signal processing (artifact filtering and EEG decoding) is fully automated in the calibration phase, based on EEG data collection during 2 minutes in resting state and 2 minutes in a task-related activity. The Independent Component Analysis

(ICA) matrix is then computed for the online filtering of the blinking component, using IAF as the frequency bin with the maximum power value in the extended alpha range 7-13 Hz, and the training baseline (lower and upper limits) using the mean (and the 5th-95th percentiles) of the UA power distribution. EEG processing is automated (three steps): filtering of the blinking component by FastICA, epoch rejection by a time-domain threshold ($> 200\mu V$) at any sensor, and then by a frequency-domain threshold. Finally, power values are computed for each epoch in the (1-3 Hz) and (20-30 Hz) bands affected by ocular and muscular artifacts. The log-transf power values are then converted to z-scores and outliers are removed (> 2.5) at any sensor. See [3] for details.

B. BCI product functionality

The professional selects the type of intervention, which usually lasts seven or 12 sessions. The first and last sessions are the participant pre/post assessments, lasting 40 minutes on average (pre/post neurocognitive tests such as the Pasat, N-back, etc; and pre/post EEG in basal and task related states). All tests are computerized and automated. The intermediate training sessions last 30 minutes each (with a calibration phase of four minutes, and six phases of four minutes for BCI training). All training sessions are automated. At the end of the intervention, a cloud service produces the **final report** with the participant's pre/post neurocognitive results and EEG changes, plus the results of the changes in UA power activity within sessions. This report is essential for the professional to understand the results and indicates the next steps taken with the client.

III. RESULTS

Fifty-nine participants participated in pre/post tests and five training sessions (seven-day intervention program adapted to the clinical, wellness and high performance sectors). The following tests were carried out: (i) *Paced Auditory Serial Addition Task (PASAT)*, which evaluates the rate of information processing and working memory. (ii) *Digits backward*, which evaluates immediate memory and working memory. (iii) *Mental rotation*, which evaluates visuospatial mental rotation abilities. (iv) *Sternberg task*, which evaluates visuospatial working memory and processing speed. The main EEG metric is the UA power change between the initial and final EEG screenings in the task-related activity.

Table I shows the results of the cognitive tests. Bonferroni correction was applied. In terms of **cognitive results**, the PASAT scores (correct answers and time elapsed) were significantly improved. The number of correct answers for the mental rotation and Sternberg tasks was significantly improved, along with the score of the Digits test. Regarding the **EEG results**, analysis of the UA power pre-post enhancement revealed a considerable increase ($t_{58} = -4.8, p < .005$; medium effect size, $d = .45$), with an average increase of 40.2%. Trend analysis demonstrated a significant UA power increase across NF sessions ($t_{58} = 3.3, p = 0.002$). Regarding within-session enhancements, no significant power increase was found between pre- and post- NF screenings.

TABLE I
COGNITIVE RESULTS

Test	Scores	Pre mean (SEM)	Post mean (SEM)	df	t-stat t-value	p-value
PASAT	score	52.97(8.61)	55.60(5.20)	57	−3.25	.016
	time (s)	226.54(80.25)	207.19(68.86)	57	4.23	.001
Digits backwards	score	10.68(3.14)	11.67(2.66)	56	−3.02	.030
	span	6.74(1.38)	7.16(1.15)	56	−2.59	.096
Mental rotation	score	33.65(6.16)	36.88(6.11)	56	−4.92	< .001
	reaction time (s)	4.01(0.51)	3.93(0.47)	56	1.44	1.24
Sternberg	score	28.33(6.84)	30.28(7.60)	57	−4.23	.001
	reaction time (s)	2.18(0.35)	2.13(0.38)	57	1.95	.45

Trend analysis revealed a significant power increase across NF trials ($t_{58} = 4.6, p < 0.005$).

IV. CONCLUSIONS

A business proof-of-concept was reported herein, for a brain-computer interface product developed by Bitbrain Technologies. The product addresses cognitive enhancement, and has been adapted to three markets: clinical, wellness and peak-performance.

From a strictly technical point of view, there are several issues that have been positively addressed: (i) **Ease of use**: two new EEG technologies have been developed, which are easy to use and setup by non-technical personnel; plus, all interventions are fixed and automated, in such a way that the technological burden is very low and encapsulated in the software (especially all signal processing). As a result, non-technical users can operate it autonomously in less than eight hours of the training time. (ii) **Convenience**: the EEG can be setup in 2-4 minutes and is very clean (dry-EEG or steel-water semidry-EEG based). The interventions have been adapted to a duration of 45 minutes, for simple integration into the professionals' practice. The product is portable so interventions can be carried out almost everywhere. Finally, the equipment performs not only the intervention but also carries out pre/post tests, which are integrated into a final report, so the professional can perform the interventions and measure the effect in a single tool. (iii) **Comfortable and ergonomic use**: the EEG can be setup quickly, does not produce pain or discomfort, and there is no need to clean hair afterwards. And (iv) **Reliable and accurate results**: the technology produces and measures cognitive enhancement and brain changes, emerging as a complementary intervention to existing cognitive stimulation or brain-training tools based on exercises or apps.

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