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Frontal Alpha Asymmetry Neurofeedback for Brain-Computer Interfaces

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Abstract

We report the development of an affective BCI based on frontal alpha asymmetry neurofeedback, which has previously been used in clinical experiments. Our results evidence a pattern of high-performance for some subjects, combined with high illiteracy, with 52.3% of subjects succeeding in the neurofeedback task. We suggest that individual asymmetry baseline values may be one of the factors explaining BCI illiteracy in this context.

1 Introduction and Rationale

Frontal alpha EEG asymmetry (henceforth FAA) was identified by Davidson [2] as a correlate of approach/avoidance, a high-level emotional dimension that plays an important role in many aspects of human psychology. FAA was later demonstrated to be a marker of clinical depression, which led to the proposed use of neurofeedback (NF) techniques for depression therapy [6], demonstrating this marker to be amenable to NF.

We have explored the use of FAA to implement an affective BCI for interactive media based on NF [5]. In this system, a virtual narrative is generated in the form of a real-time 3D animation, in which the user can intervene to support the central character by expressing positive thoughts, which in turn will drive the evolution of the narrative towards a happier ending for the character. A previous feasibility pilot has demonstrated a success rate of 50% for an all-male sample of 12 subjects. Furthermore, these experiments were carried out under an EEG/fMRI installation to provide a first level of anatomical validation, which confirmed our original hypothesis [4]. In this paper we present the results of follow-up work in which we explore the determinants of successful NF, using a larger number of subjects and analysing training data.

Following previous work we decided to use the A_2 score $(F_4 - F_3)/(F_4 + F_3)$ (with $F_4(R)$ and $F_3(L)$ electrodes) as a measure of FAA for NF input. However, because of the intrinsic fluctuations in A_2 and the need to provide a stable signal to support visual feedback (here, the central character's skin colour saturation) that reduces jitter, we used a 4-point moving average as a simple low-pass filter (henceforth MA_2). As a baseline, we used the A_2 average value obtained during a 2min calibration period (which was discussed by Allen et al. [1] as the minimum reliable calibration time).

Since our NF signal is visual and continuous, we defined a mapping function between each subject's individual baseline and an empirically determined "maximum" value for MA_2 onto the 0-100% saturation range. The rationale for determining such a maximum was that the activity in the right hemisphere cannot be reduced infinitely hence the A_2 score should be seen as asymptotic. We conducted a calibration experiment with 16 subjects to empirically determine

the mapping of MA_2 values to saturation, where we used the variation in the subject's MA_2 values to determine maximum saturation. In order to avoid a few high scores raising the value where maximum saturation occurs (thereby decreasing the amount of feedback received for scores that are likely to occur more frequently) we decided to define the maximum feedback below the maximum of MA_2 values (~ 0.7, across all subjects). When applying a $mean + 1.64SD$ filter[1], the average difference between subjects' maximum MA_2 value and their MA_2 mean (i.e. baseline) was 0.23 ($SD = .06$). It should be noted that this finding is consistent with Zotev et al. [8] setting variations to A_2 of 0.2 as a success criterion in their own NF experiments. This led us to determine the MA_2 value resulting in maximum saturation for each subject as $min(0.7, baseline_{subject} + 0.2)$, making saturation scores subject specific.

The next step was to define a success score for a NF trial. This consists in the ability to increase MA_2 and to sustain this increase over a non-trivial amount of time (so as to distinguish it from spontaneous fluctuations). In order for the success score to be normalised across subjects, we used the above saturation scores instead of raw MA_2 since they already incorporate the individual's A_2 baseline. We assign a maximum score of 100 to an ideal result of 100% saturation over the full 30s NF window. This score is meant to account for any combination of above-threshold amplitude and time, essentially integrating above-threshold values over time. For instance, a score of 10 would correspond to either 100% saturation over 3s, 50% saturation over 6s, 30% saturation over 10s ... this is meant to cover the very different NF patterns observed across subjects, while appearing a stricter criterion than that of [3] who imposed above threshold values to be sustained for 500ms as well as Rosenfeld [6] and its "number of hits above threshold" metric.

Finally, a trial can only be considered successful if MA_2 actually increases during NF over its previous resting value. Following several authors (including Zotev et al. [8] who have used as a reference the average asymmetry scores during the preceding 40s), we have defined as a criterion for success for a NF trial that it reaches a score of 10, such score being also higher than that of the preceding resting period of 15s in-between trials (scores being normalized for respective durations of resting and NF periods during trials), as shown in Figure 1.

2 Methods

We recruited 36 subjects (17 male, 19 female), whose average age was 30.4 years ($SD = 9.25, range : [20, 52]$). Experiments were approved by our local ethics committee, and subjects were issued detailed consent forms; all data were anonymised. Subjects were sat in a comfortable armchair in a quiet room with dimmed lighting, and they were given instructions on how to relax to minimise muscular artefacts as well as avoiding blinking as much as possible. They were introduced to the concept of a NF loop in simple terms, with the character's skin colour saturation introduced as a visual indicator of the magnitude of mental support (as shown in Figure 2). Instructions were deliberately generic ("*express positive thoughts towards the character.*"), in order to avoid influencing users cognitive strategies towards any implicit or explicit one.

Each training block consisted of a 30s NF session preceded by a 15s resting period during which subjects were instructed to relax and remain staring at a black screen (Figure 2–a). Each subject performed 12 successive training trials for a total duration of 9min. All subjects completed the training session. We defined a subject as successful in training if s/he succeeded in 6 out of 12 trials. After the training session, each subject participated in one session of the

[1] Filtering out the top 5% values assuming near normality after [6].

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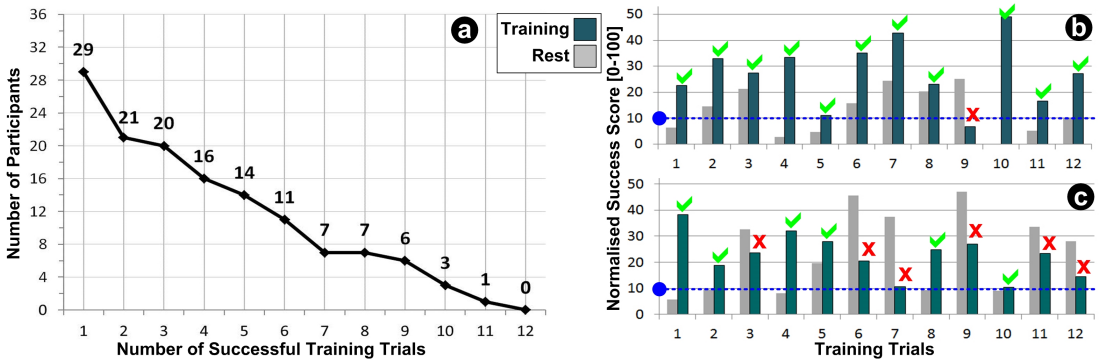

Figure 1: Training results. (a) Number of successful training trials per participant, (b) comparing scores to previous resting periods for each trial for one subject, and (c) for another subject, rest values are greater than NF for trials 3, 6, 7, 9, 11, 12, which are all rated "failed". The blue line represents success threshold as a score of 10 (see text).

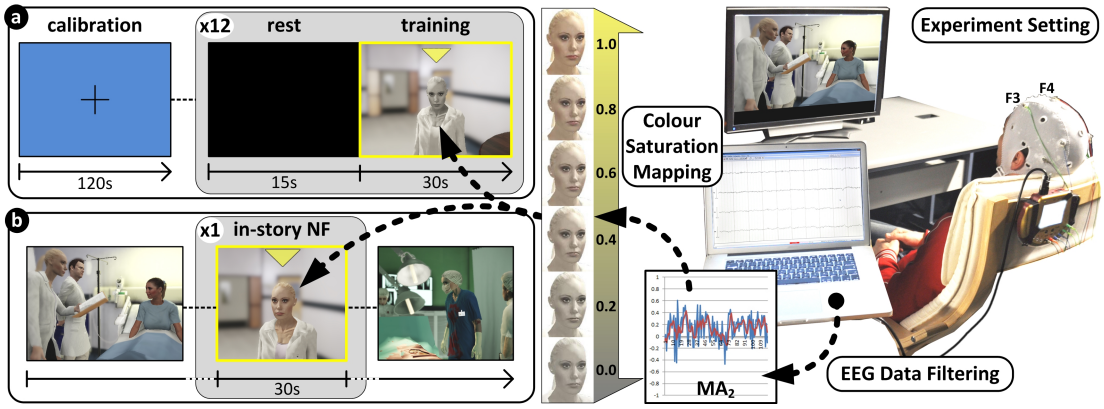

Figure 2: Experiment setup. (a) Initial calibration, followed by 12 training trials pairs (Rest/NF). (b) BCI-based narrative. During NF, MA_2 is mapped to the colour saturation of the character in need of support by the user (see text).

BCI-enabled Interactive Narrative [4] (Figure 2–b).

EEG data was acquired using an 8-channel Brain Products V-Amp system. Data was recorded at a sampling rate of 250Hz and collected on a PC running BrainVision RecView[2]. Alpha band (8–12 Hz) power was extracted online from electrodes F_3 and F_4, sampled at 1Hz with a reference electrode at FCz. The pre-processing algorithm was compiled from Matlab R2013b to Microsoft .NET, so that it could be executed within the BrainVision RecView EEG Recorder system. The Matlab.NET compiled DLL calculated the A_2 instantaneous value once filtered through the calculation of MA_2 and passed this value back to the NF system, which in turn was used to drive the feedback visuals.

[2]http://www.brainproducts.com/

3 Results and Discussion

Figure 1–a plots the number of subjects that performed successfully on a given number of trials during NF training. The most striking finding is to observe FAA NF as a high-performance, high-illiteracy BCI: the average in-story score for successful subjects is actually 20, twice the success threshold we have defined, together with a global success of 52.3%. However, the proportion of subjects failing the task (although not all failure can be assimilated to BCI illiteracy) is much higher than previous reports of BCI illiteracy, which were in the region of 20-30% [7]. Since BCI illiteracy is considered to be specific to the BCI technique considered, we investigated the role of the A_2 baseline as a possible determinant of illiteracy by calculating the biserial correlation between the individual threshold value and training success, $r_b = -.69, p = .002$, which suggested a strong and statistically significant negative relationship between baseline and training success. On the other hand, the contribution of training, or lack thereof, to the observed illiteracy failure rate figures, is more difficult to assess without extending our experiments to the same level of training as the one described for clinical applications (previous authors having reported hours of training over multiple sessions). However, our ethical approval was limited to one short session, as these are unlikely to alter subjects trait variables over a prolonged period. Another possible direction to explore to improve performance consists in the baseline measure itself. Following previous literature, we have alternated epochs of eyes open and closed during baseline measures, but we have observed by retrospective analysis[3] that only using eyes open signals (as Davidson reported for experiments with films [2]) would have resulted in a lower baseline, hence potentially higher success rates.

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[3] Repeated measures t-test confirmed that eyes-open baseline ($M = .25, SD = .13$) was significantly lower than eyes-closed baseline ($M = .35, SD = .14$), $t(35) = 6.61, p < .001, r = .75(large)$.