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Affective Learning: Empathetic Embodied Conversational Agents to Modulate Brain Oscillations

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Abstract— **Integrating emotional feedback to educational systems has become one of the main concerns of the affective learning research community. This paper provides evidence that Embodied Conversational Agents (ECAs) could be effectively used as emotional feedback to improve brainwave activity towards learning. Further research, integrating ECAs into tutoring systems is essential to confirm these results.**

Keywords— **Affective learning, brain oscillations, Embodied Conversational Agents, emotional feedback.**

I. Introduction

Due to the work of neuroscientists [1], [2] and other humanistic psychologists and educators [3], [4], [5] the role of emotions in learning is more and more acknowledged. Theoretical models of learning support that learning occurs in the presence of emotions [6]. Positive and negative emotional states trigger different types of mental states [7] and this can have an important influence on the learning process.

Certain studies of neurofeedback concerning test anxiety indicated that, the enhancement of the alpha frequency band would probably lead to a significant reduction in test anxiety [8]. Moreover, the stimulation of alpha rhythm seems to improve personal competence [9], while the beta stimulation has appeared to improve attention [10], [11], overall intelligence, short-term stress, and to relieve emotional exhaustion [9]. However, high beta frequencies have been associated with intensity or anxiety [12].

Thus it is logically assumed that a tutoring system capable of providing students with the appropriate emotional feedback could probably help them to improve their emotional state towards learning [13], [14], [15]. A key focus of research concerning any kind of computerized environment, ranging from video games to tutoring systems, are the Embodied Conversational Agents (ECAs), which are digital models determined by computer algorithms as well as the avatars[16], which are digital models guided by real-time humans. In other words avatars' interaction is human-controlled, while embodied agents have an automated, predefined behavior. However, individuals react as in a social context to both human and computer-controlled entities [17], [18],[19].

Commonly humans use empathy to express their affection. According to [20], empathy is the ability to perceive another person's inner psychological frame of report with precision, but without ever losing consciousness of the fact that it is a hypothetical situation. Therefore, empathy is to feel, someone else's emotional state and to perceive the source of this state as perceived by the other person, without setting aside self-awareness. Relatively, several studies support that the existence of empathic emotion in a computer agent has significant positive effects on the user's impression of that agent and consequently will ameliorate human-computer interaction [21].

The aim of this study is to examine the objective impact of an ECA. The aforementioned objectivity is based on the evaluation of the cerebral responses, as they were recorded by the electroencephalogram (EEG), when individuals are exposed to empathy with emotional facial expressions, to empathy with neutral facial expressions, and to an empathetic encouragement with emotional facial expressions, as a feedback to fear, sadness, and happiness, emotions provoked by pictures of the International Affective Picture System collection (IAPS; [22]). While other researches have attempted to study empathy employing brain imaging methods [23], [24], [25] to our best knowledge this is the first brain imaging study that attempts to measure the impact of empathetic agents as feedback to human emotions for improving brainwave activity towards learning.

II. Materials and methods

A. EEG Data

Real EEG data have been obtained from thirty healthy subjects [15 males (mean age: 23.47±3.39) and 15 females (mean age: 22.8±3.74)] during an emotion evocative-stimuli experiment. EEG was recorded by nineteen scalp electrodes placed according to the International 10-20 System. More specific sensors were placed at Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1 and O2 sites.

B. Experimental Procedure

The experiment protocol consisted of an Euler square of order three over three emotions (fear, sad, happy) triggered by IAPS and three ECAs (displaying empathy with emotional facial expressions, empathy with neutral facial expression, and empathetic encouragement with emotional facial expressions) displayed as emotional feedback.

All subjects were exposed to three IAPS images with either fear or sad or joy content for twelve seconds (four seconds each), followed by a female ECA (Fig.1) performing for five seconds. The ECA depicted either empathy with neutral facial expression, or empathy with relevant to the image emotional facial expression, or empathetic encouragement with relevant to the image emotional facial expression for empathy, and then a happy facial expression for encouragement when images had a sad or fearful content. A neutral facial expression was used for encouragement by the "empathetic encouragement" ECA when the images had a happy content. A more detailed description of the protocol as well as the synchronized speech and facial expressions of the ECAs are shown in Tab.1. It has to be mentioned that after each ECA an eight second phase with neutral or relaxing IAPS images intervened (two images four sec each).

In order to evaluate the accuracy of our results, it is very crucial to address if each ECA's facial expression can be assigned to the relevant emotion as well as if the participants were capable of perceiving it. Therefore, we have to evaluate each subject's ability to recognize the ECA's emotions through its facial expression, in order to assess the correctness of the EEG results. So at the end of the experimental protocol, each subject was asked to complete a questionnaire, composed by the images of all ECA's facial expressions. More specific subjects were called to assign in each ECA's image an emotional state among angry, neutral, sad, happy, disgusted, surprised and scared.

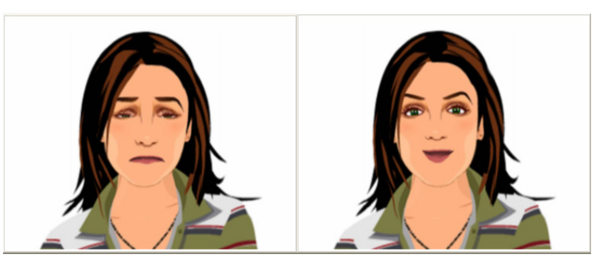

Fig. 1 The ECA in sad and happy facial expressions

Table 1 The above table summarizes our experimental protocol. FEAR, SAD and HAPPY indicate the emotional content of the three displayed images, while 1, 2 and 3 denotes the ECA's behavior in terms of synchronized speech and facial expression

FEAR-1	SAD-2	HAPPY-3
Voice: Somehow these images make you fear. **Facial expression:** Fear	**Voice:** Somehow these images make you sad **Facial expression**: Neutral	**Voice:** Somehow these images make you happy. Continue watching with attention **Facial expression:** Happy and then neutral
SAD-3	**HAPPY-1**	**FEAR-2**
Voice: Somehow these images make you sad. Cheer up, continue watching. **Facial expression:** Sad and then happy	**Voice:** Somehow these images make you happy **Facial expression:** Happy	**Voice:** Somehow these images make you fear **Facial expression**: Neutral
HAPPY-2	**FEAR-3**	**SAD-1**
Voice: Somehow these images make you happy. **Facial expression:** Neutral	**Voice:** Somehow these images make you fear. Cheer up, continue watching **Facial expression:** Fear and then happy	**Voice:** Somehow these images make you sad **Facial expression:** Sad

C. Pre-processing and Artifact Rejection

EEG signals were digitized at a rate of 256Hz and they were further filtered using a band pass filter at 0.5-40Hz and a notch filter at 50Hz for line noise extraction. It has also to be mentioned that, the double banana bipolar montage was used in order to isolate external noise common to neighbor electrodes. Double banana resulted to eighteen electrodes because the Cz site was only used for referencing purposes. A robust version of Second Order Blind Identification (SOBI) algorithm [26],[27] was used to decompose EEG signal to statistical independent components. Then three independent observers marked and rejected the contaminated components by ocular and/or heart artifacts resulting to the artifact-free EEG signals.

D. ERD/ERS

ERD/ERS illustrates the percentage of the power spectrum changes during a test interval compared to a reference interval for certain brainwaves. For the purposes of our analysis the band power method [28] was adopted for the computation of ERD/ERS index. Following this methodology, each EEG signal was band-pass filtered in the alpha1, alpha2, beta1, beta2 frequency bands (8-10Hz, 10-12Hz,12-18Hz and 18-22Hz respectively), squared in order to obtain each band's power and the mean value for each test and reference interval was computed. Finally in order to obtain the ERD/ERS the next typo was used:

$$ERD/ERS = \frac{T - R}{R} \cdot 100\%$$

where T and R denotes the power of a certain brain rhythm during the test and the reference interval respectively. It is obvious that positive ERD/ERS values stand for greater power in test interval rather than in reference interval, and that reveals synchronization (ERS) of the certain brain oscillations, while negative ERD/ERS values denote desynchronization (ERD).

E. Statistical Analysis

Data at all groups were far from the normal distribution. Thus, the non parametric Mann-Whitney test (two sided P-value) was applied to check the null hypothesis that ECAs shown after the fear, the sad, and the happy IAPS images had no significant influence on the alpha1, alpha2, beta1, and beta2 frequency bands.

In order to obtain the confidence interval for the facial expression's emotion recognition a binomial proportion confidence interval was used. The Adjusted Wald interval provides the best coverage for a specified interval, when the number of sample size is small. So, Adjusted Wald was used with a confidence level of 95%.

III. RESULTS

A statistical significant difference ($p<0.05$) at the modulation of the beta2 band power, was observed for the FEAR-1(+10.14%) and FEAR-3(-4%) ECAs. The ECA HAPPY-1 as well, significantly increased the beta2 frequency band power by 5.39%. Concerning the beta1 band, the ECAs SAD-2 and HAPPY-2 resulted in a significant increase by 2.83% and 5.49% respectively. Alpha2 band power was significantly increased by the FEAR-3 (10.06%), SAD-2 (5.85%), and SAD-3 (18%) ECAs. Alpha1 band was significantly increased by the FEAR-3 (9.99%), SAD-2 (1.45%), and HAPPY-1 (48.47%) ECAs. A summary of these results is provided by table 2.

Table 3 summarizes the results for the emotion recognition of the facial expressions shown with their relevant confidence intervals. Happy and sad facial expressions were easily recognized by the participants with high percentages, 93% and 97% respectively.

Scared and neutral facial expressions were recognized with smaller percentages by the participants, 73% and 77% respectively. Scared was mostly confused with surprised, and neutral with angry. Moreover, male percentage is higher than female percentage in all four categories. Scared and neutral are two emotional states that are difficult to be perceived only by showing one image. Most likely, during the experimental procedure the combination of facial expressions with the voice's tone made the recognition easier.

Table 2 Significant differences to beta1, beta2, alpha1, alpha2 due to ECA emotional feedback. "-" signifies non-significant results

	Beta1	Beta2	Alpha1	Alpha2
FEAR-1	-	+10.14%	-	-
FEAR-2	-	-	-	-
FEAR-3	-	-4%	+9.99%	+10.06%
SAD-1	-	-	-	-
SAD-2	+2.83%	-	+1.45%	+5.85%
SAD-3	-	-	-	+18%
HAPPY-1	-	+5.39%	+48.47%	-
HAPPY-2	+5.49%	-	-	-
HAPPY-3	-	-	-	-

Table 3 95% confidence interval for facial expression-emotion recognition

Facial expression	95% confidence interval	95% confidence interval for Male	95% confidence interval for Female
Happy	77% - 99%	76% - 100%	60% - 97%
Sad	81% - 99%	76% - 100%	68% - 99%
Scared	55% - 86%	54% - 93%	41% - 85%
Neutral	59% - 88%	54% - 93%	48% - 89%

IV. DISCUSSION AND CONCLUSIONS

This paper provides evidence that ECAs could be effectively used as emotional feedback to improve brainwave activity towards learning. The empathetic encouragement ECA appeared to be an effective emotional feedback to fear IAPS images as it desynchronizes (- 4%) beta2 oscillations and synchronizes considerably alpha2 (+10.06%) and alpha1 (+9.99%) brain oscillations. Interestingly, the empathetic ECA, showing a fearful facial expression after the fear IAPS images, appeared to increase (+10.14%) the beta2 band power, indicating that its presence provoked even more intense emotions. Concerning the sad IAPS images, the empathetic ECA with a neutral facial expression could be an effective emotional feedback, as its appearance resulted in an increase to beta1 (+2.83%), alpha1(+1.45%), and alpha2 (+5.85%) frequency band powers. The empathetic encouragement ECA could also be an effective emotional feedback to a sad emotional state, as it considerably synchronizes (+18%) the alpha2 oscillations. Regarding happy emotional states and learning, an emotional feedback that would help maintain concentration and avoid excessive relaxation would be preferable. In this context, the empathetic ECA with a neutral facial expression appears to be a good solution, as it increases (+5.49%) the beta1 band power. Surprisingly, the empathetic ECA displaying a happy facial expression appears to increase (+5.39%) the beta2 band power, while it increases excessively (+48.47%) the alpha1 band power. However, these results should be confirmed by further research and be tested in the context of a tutoring system, so as to prove their efficacy as emotional feedback for instructional technology.

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