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# A humanoid robot controlled by neurofeedback to reinforce attention in autism spectrum disorder

Salvatore M. Anzalone<sup>1</sup>, Antoine Tanet<sup>2</sup>,  
Olivier Pallanca<sup>3</sup>, David Cohen<sup>2</sup>, and Mohamed Chetouani<sup>4</sup>

<sup>1</sup> CHArt Laboratory - EA4004,  
Paris 8 University, 93526 Saint Denis, France  
[sanzalone@univ-paris8.fr](mailto:sanzalone@univ-paris8.fr)

<sup>2</sup> Department of Child and Adolescent Psychiatry  
APHP, Groupe Hospitalier Pitie-Salpetriere , 75013 Paris, France

<sup>3</sup> Sleep Disorder Unit  
APHP, Groupe Hospitalier Pitie-Salpetriere , 75013 Paris, France

<sup>4</sup> Institute of Intelligent Systems and Robotics  
University Pierre and Marie Curie, 75005 Paris, France

**Abstract.** Children with Autism Spectrum Disorder can find very difficult focusing their attention towards activities they find less attractive than the ones they like. In this paper we will introduce a prototype designed to reinforce their mental skills through neurofeedback using EEG data and a small humanoid robot to stimulate attention towards a joint activity.

**Keywords:** Social robots, Neurofeedback, Autism Spectrum Disorder, EEG, Attention, Joint activities

## 1 Introduction

As autism Spectrum Disorder is characterized by restricted and repetitive patterns of behaviors, interests and activities [11], children with ASD may be able to maintain firm and durable attention over activities they like and motivates them. At the same time, it can be really hard for them to keep their attention on other, less attractive, activities. Children with ASD can develop their skills through joint activities with an expert clinician that can guide them on improving their attention span [8]. However, it is always difficult also for the most expert clinicians to infer mental states from the behavior of the children. The EEG technology, in this case, can help them by providing in real-time neuro-physiological measures resuming particular mental states, as the attention of the child towards the current joint activity [7]. A companion robot can be a helpful tool in these scenarios, with the role of conveying such neuro-physiological measures to clinicians while acting like a playfellow with the child. At the same time, robots endowed with some kind of intelligent, social skills, can autonomously

act according to particular mental states, providing feedbacks or rewards to the child [10, 9, 5].

Past studies highlighted the possibility of employing a small humanoid robot to elicit joint attention [2]. In this paper we exploit this ability by introducing a robotic system designed to provide feedback to a child with ASD in accord to his mental state, to improve his attention skills toward joint activities. The presented system is still a prototype: the paper will introduce the details on its conception and a the results of a pilot study involving an adolescent with ASD.

## 2 Methodology

The system presented in this paper is a prototype designed to reinforce the attention of a child towards a particular activity, thanks to the feedbacks offered by a small humanoid robot. Among the possible choices of joint activities, paying attention towards a movie or a cartoon has been selected as a simple, stereotyped, joint activity that the child can be reasonably able to perform. A measure of attention is retrieved through the real-time exploitation of EEG signals. The small humanoid robot, as a proactive companion of the child, would return feedbacks in case of attention breakdown, with the goal of re-inducing attention towards the joint activity.

More in detail, the experimental protocol is defined as in Figure 1:

1. A movie or a cartoon, is used as audio-visual stimulus for the child. At the same time, his EEG activity is captured.
2. EEG data is exploited to extract a measure able to represent the attention the child is giving to the current task. The selected metric is able to highlight the child's attention breakdowns.
3. In case of attention breakdown, the robot produces a feedback to trigger back the attention towards the task. The feedback is defined upon a set of well pre-defined mix of verbal and non-verbal behaviours.

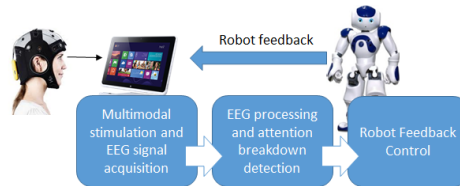


Fig. 1: An overview of the experimental protocol proposed.

As shown in Figure 2, the system integrates different technologies:

- An EEG cap, Enobio from NeuroElectrics;
- A screen for the audio-visual stimulation;

- A small humanoid robot, Nao from Aldebaran Robotics;

Two computer are also employed: one to capture and exploit the EEG data; one to control the robot and store logs and sensors data. All the systems are synchronized through Network Time Protocol.



Fig. 2: The experimental setup.

The session is composed by two main stages:

- *Training stage*: The child watches an audio-visual content that *assures* his attention. This data is used to build the baseline for the child attention measure, to train the system how to recognize attention breakdowns.
- *Test stage*: The child watches an audio-visual content that *does not ensure* his attention. When the system recognizes an attention breakdown, a feedback behavior of the robot is triggered.

At the end of each session, the child behavior is evaluated in terms of information retained, of number of attention breakdowns, and through the average of the attention measure.

## 2.1 Multimodal stimulus selection

The audio-visual content employed to stimulate the child is one of the most important component of the system. A stronger stimulus or a weaker one in terms of attention induced or cognitive load required to understand it, can compromise the capabilities of the system on recognizing the attention breakdowns. Several contents have been selected, distinguishing, in particular, the ones for the training stage of the system. In this case, the stimulus employed should be particularly effective on inducing attention in the children because the data captured will be used as baseline of the attention. Consequently, the stimulus should be very personalized according to the particular preferences of the child. On the contrary, the stimulus employed during the Test stage will be less attractive and engaging.

The developed prototype employed documentaries (Length: 3min) and storytelling videos (Length: 5min), as in Figure 3.



Fig. 3: Two contents employed in the proposed setup to induce attention: a documentary and a storytelling video.

## 2.2 Attention breakdown identification

The EEG signal captured is exploited to identify attention breakdowns. Attention has been characterized through the Theta - Beta ratio of the signals captured by the central, frontal and temporal EEG sensors (c3, c5, f3, f4, t7, t8) [3]. In particular, the average ratio between the channel has been selected as attention feature. The attention model of the child is learned at the beginning of the experimental protocol, during the Training stage, by exploiting the data obtained while an audio-visual content strongly engages the child. More in detail, in the Training stage it is supposed that the child will be attentive towards the stimulus. To model attention, then, an inhibit threshold for the Theta - Beta ratio activity defining the attentive state was set at a power level that the training activity fell over its range for the 50% of time [6]. This model will return a measure between 0 and 1, as *attentive* - *not attentive*, and will be employed by the system as convenient measure to evaluate the attention given by the child to the current activity.

Attention breakdown are identified in a sliding window of 5sec of the real-time attention measure captured. The breakdown is defined by a prevalence (50% of the window) of measures lower than 0.5 (not attentive).

## 2.3 Robot feedback

During the experiment, the robot is placed at the side of the child, attentive towards the screen, to stimulate on him imitation behaviors and joint attention towards the audio-visual stimulus. When the attention breakdown is identified, the system triggers a feedback by executing one of some specific, predefined behaviors, able to re-induce attention towards the joint activity. This set of behaviours mixes gestures, pointing in particular, and voice, as: *Ah!, Look!, I love it!, Ah! I love this!*, as in Figure 4.

In the presented pilot, only 8 behaviors have been implemented: 4 coupling gestures and voice; 4 proposing just non-verbal behaviors. The selection of the behavior after the attention breakdown detection is randomly chosen among the developed behaviors.

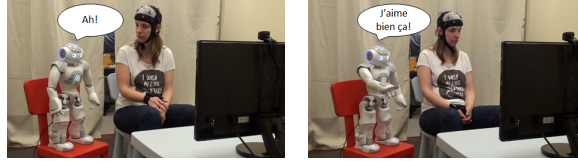


Fig. 4: Two multimodal feedbacks from the robot: “ah” and “I love this”! without and with pointing gesture.

### 3 Preliminary results

To evaluate this pilot system, an exploratory study has been conducted involving an adolescent (17 years old) from the *Ecole Georges Heuyer*, part of the *Child and Adolescent Psychiatry Service* of *Piti-Salpêtrière Medical Hospital* in Paris, France. While not statistically significant, the results obtained in this pilot study are extremely important to evaluate the feasibility of the system, the possible protocols that would be employed, the adverse events that could happen and an appropriate sample size before a more exhaustive experiment. The child has been diagnosed with autism spectrum disorder, with a particular evidence of attentional troubles. The child has been selected because he does not show any motor disability, or any other serious behavioral trouble.

The experiments involving the child have been carried on in 3 sessions during a single week: each session has been divided in an experimental condition and in a control condition.

After a common training stage, in which the system learns the attention model, according to the previous introduced methodology, the child faces the two conditions. In the experimental condition, the child is in front of the screen, side by side with the robot, that eventually intervene by giving feedbacks according to the attentional state revealed by the EEG-based measure. In the control condition, the robot does not intervene: it just stand on the side of the child, watching carefully the audio-visual stimulus. The two condition are opportunely randomized among the days of the week.

In both conditions, a trained clinician ask questions about the content proposed to the child, in order to obtain a rough measure of the retained information. This measure is coupled with the number of attention breakdowns captured by the system and with an attention score, defined as the mean of the attention measure among the whole condition.

Figure 5 shows that the amount of information retained by the child among the different sessions is higher in the case of proactive robot rather than in the case of static robot.

Table 1 shows that the number of attention breakdown events increase among the time. It shows also that these events are more frequent in the control condition than the experimental condition. Table 2 shows how the score of attention

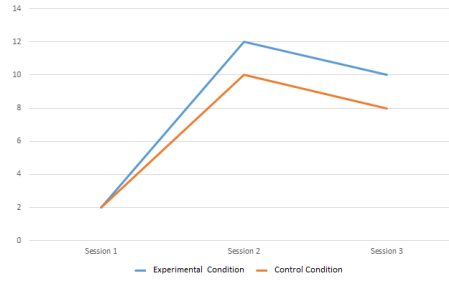


Fig. 5: The amount of information retained by the child in the two conditions among the sessions.

Experiment Day	Control Condition	Experimental Condition
0	19	11
1	6	3
2	24	29

Table 1: Number of attention breakdowns in the two conditions among the sessions.

among the days is almost constant in the control condition while it highlights fluctuations in the experimental condition.

Experiment Day	Control Condition	Experimental Condition
0	0.456512	0.605021
1	0.403154	0.267962
2	0.477982	0.33084

Table 2: Attention score in the two conditions among the sessions.

## 4 Conclusions and Future Works

In this paper we introduced a prototype neurofeedback system designed to stimulate attention of a child towards an audio-visual stimulus. The system exploits data from EEG to estimate the attention, while employs a robot as convenient and natural interface to stimulate attention in the child. Results obtained seem to highlight a perturbing effect of the robot on the attention of the child. Such effect could be a result of the eventual presence of false positives on the attention breakdown detection system. In any case, due to the limited samples collected in this pilot study, it is difficult to obtain statistically reliable conclusion. Those results encourage the development of more precise measures of attention, mixing

together EEG data and behavioral information, as the psycho-motor agitation [1, 4]. In future experiments, several captures would be deployed in the environment, offering the possibility of exploiting the verbal and non-verbal behaviors of the child. These measures would be coupled with the neurological measures obtained by the exploitation of the EEG data, to produce a more accurate and comprehensive description of the attention state of the child and, consequently, of his attention breakdowns. The protocol here introduced, with tailored multimodal stimuli, will be finally introduced in a small classroom of a special school for autistic children to statistically evaluate its effects.

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