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Assisting autistic children with wireless EOG technology

Joaquin Rapela[1*], Tsong-Yan Lin[1], Marissa Westerfield[1,2], Tzyy-Ping Jung[1], Jeanne Townsend[2]

***Abstract*— We propose a novel intervention to train the speed and accuracy of attention orienting and eye movements in Autism Spectrum Disorder (ASD). Training eye movements and attention could not only affect those important functions directly, but could also result in broader improvement of social communication skills. To this end we describe a system that would allow ASD children to improve their fixation skills while playing a computer game controlled by an eye tracker. Because this intervention will probably be time consuming, this system should be designed to be used at homes. To make this possible, we propose an implementation based on wireless and dry electrooculography (EOG) technology. If successful, this system would develop an approach to therapy that would improve clinical and behavioral function in children and adults with ASD. As our initial steps in this direction, here we describe the design of a computer game to be used in this system, and the predictions of gaze position from EOG data recorded while a subject played this game.**

I. INTRODUCTION

The major clinical symptoms in autism are difficulties with language and social interaction, and these skills are targets of the most common of behavioral interventions. However, in typical function, these complex higher level social, language and communication skills are not present early in life, but develop over the first few years and depend upon the critical building blocks of sensory-motor, perceptual and attention abilities. Similarly in autism, higher level problems with social communication are not the first to appear, but they too develop over the first two post-natal years. Studies of siblings at risk for autism have found that at six months of age, delayed motor development and abnormalities of visual attention predict ASD [1]. Social and language-based therapies may improve the specific behaviors that are targets of the training, but rarely do they generalize to broader function or other clinical symptoms. We propose that interventions aimed instead at the early deficits that support social and language skills would be more broadly effective. Because disruption of attention is one of the earliest and most persistent symptoms in autism, and because attention is highly subject to improvement with training, it is an important target for intervention [2].

The tight links between the circuitry responsible for planning and launching saccadic eye movements and the redirection of attention suggests that training one might induce benefits of the other. Visual attention appears to be readily trained even through commercial video game play [3]. A major challenge in training attention and motor skills such as eye movement in autism is the amount of time required and the necessity for frequent practice. It is difficult, if not impossible, to administer frequent and lengthy training in a laboratory or clinic where eye movements and behavior can be accurately monitored. Development of a portable, dry and wireless EOG system that can be integrated with a training "game" makes daily training at home possible.

We believe that a brain-computer interface (BCI) based training environment will be an effective means to alter basic motor and attention skills because the desired behaviors (e.g. saccadic speed and accuracy) are directly shaped (reinforced during successful video game play). It is likely, however, that altering fundamental skills such as eye movement or attention can only be achieved through frequent (almost daily) training. The equipment must therefore be easy to use at home (comfortable and simple to operate).

The intervention proposed here is dependent on accurate gaze tracking. The majority of eye gaze trackers are camera based, and many use an infrared (IR) light source to enhance features of the eye such as the boundary between the pupil and the iris, or the corneal reflection. While these systems are the most accurate non-invasive types of eye gaze trackers, the cost and difficulty of use of current commercial systems would prohibit home use. EEG-based BCI devices, on the other hand, are gaining popularity. Our system will use newly-developed EEG technology (a wireless dry electrode system combined with real-time processing) to determine gaze position for purposes of game control.

Here we report initial steps on the development of a wireless EOG system and an accompanying game, targeted to be used at home by ASD children to improve their fixational skills. The article is organized as follows. Section III presents a computer game that, while being entertaining to engage children in their fixational exercises, elicit eye movements sufficiently simple to be predicted from EOG data. Then, Section IV presents initial results of predicting gaze position of a subject playing the previous computer game. Finally, we discuss results in Section V.

II. METHODS

Subjects One subject, male, 25 years old, with corrected vision.

Experimental setup Figure 1 shows the setup for the experiment. We used a chin rest to stabilize the gaze of the subject while he looked at a computer screen located 70 cm away from the chin rest. We recorded EOG and EEG activity (Biosemi B.V., Amsterdam, Netherlands), however the EEG activity was not used in the current analysis. We also recorded video-based eye-tracking data (EyeLink 1000,

[1]Swartz Center for Computational Neuroscience, University of California San Diego. [2]Research on Aging and Development Laboratory, University of California San Diego. *rapela@ucsd.edu

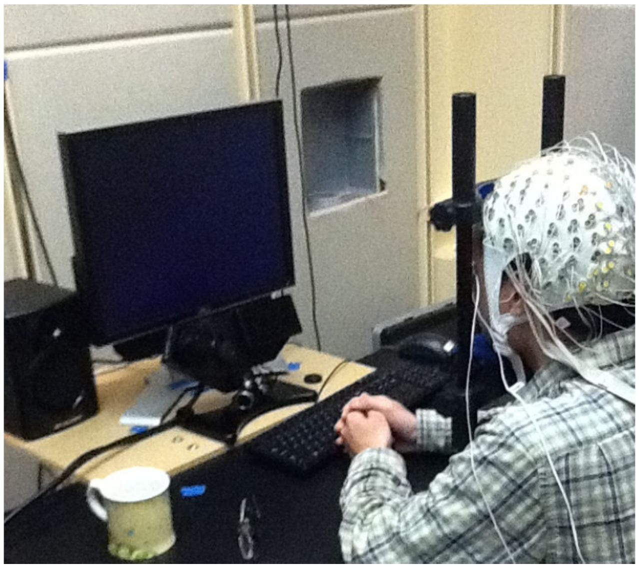

Fig. 1. Experimental setup. We recorded EOG, EEG (not used in the current analysis), and video based eye-tracking data, while the subject played the "friends and foes" gaze contingent computer game.

SR Research Ltd, Mississauga, Ontario, Canada), which was used to control the gaze contingent "friends and foes" game.

Data collection EOG, EEG, and video based eye tracker data were collected in five sessions, with four blocks per session, and 24 fixations in targets per block. Each block lasted approximately 75 seconds. After each session the subject had a break with tea and home-made bread. From the total of 480 fixations, only 364 fixations, corresponding to friend targets, were used to predict gaze position from EOG data.

Wavelet denoising of EOG data To remove noise from the EOG signal, we used a wavelet denoising technique [4]. Separately, each EOG channel was decomposed using a bi-orthogonal wavelet into five levels of approximation (low-passed) and detail (high-pass) coefficients. Then a denoised version of the EOG signal was synthesized using only the approximation coefficients.

Prediction of gaze position from EOG data We estimated the filter w that transforms the EOG channel data A into the target positions B:

$$A\,w = B \tag{1}$$

For a set of N fixations, $A \in \Re^{N\times 6}$ and $A[n,i]$ contains the voltage recorded at the i^{th} EOG channel at the time of the n^{th} fixation, $w \in \Re^{6\times 2}$ and $w[j,k]$ contains the j^{th} filter coefficient used to predict the horizontal (k=1) or vertical (k=2) component of the target position, and $B \in \Re^{N\times 2}$ and $B[n,k]$ contains the target position at the time of the n^{th} fixation along the horizontal (k=1) or vertical (k=2) direction.

To estimate the filter, w, from the recorded EOG voltages, A, and target positions, B, we used the least-square solution [5]:

$$\hat{w} = (A^T A)^{-1} A^T B \tag{2}$$

III. Friends & Foes game

In designing the game that we will use to train the fixational skills of ASD children we strove for a balance between eliciting sufficiently constrained eye movements for efficient gaze prediction with EOG, and developing a game that will engage ASD children in long fixation sessions. For this we developed the following gaze-contingent "friends & foes" game.

The game consisted of a series of progressively more complex stages. A given stage consisted of a series of trials. A trial started by the subject fixating on a central cross and pressing the spacebar in the keyboard. After the game checked steady fixation for a random delay, uniformly distributed between 500 and 1000 msec, a target friend or a foe appeared on one of twenty four pre-specified locations on the top-right quadrant of the computer screen. Foes and friends appeared with a probability of 0.75 and 0.25, respectively. If the target was a foe, the subject task was to kill him with a saccade to the target. But, if it was a friend, the subject should not kill him. The difficulty of a given stage was given by the time targets appeared on screen, i.e., the time subjects could use to decide to saccade or not to a target. The easiest stage displayed targets for two seconds, and this time was reduced (or increased) by five percent as subjects progressed to more difficult (or easy) stages. If a subject killed more than 90% of the foes and avoided killing more than 90% of the friends in a given stage, then he moved to a more difficult stage, if he killed less than 30% of the friends and avoided killing less than 30% of the foes, then he moved to an easier stage, otherwise he stayed in the same stage. The goal of the subject was to maximize his score given by the number of foes minus the number of friends he killed. The score was weighted proportionally to the stage difficulty.

The eye movements elicited by this game are very stereotyped, and consist of only fixations and saccades. In addition, every saccade to a target is preceded by a steady fixation on the cross, which simplifies the predictions of gaze position from EOG data. An important limitation for these predictions is drifting in the EOG signal. However, because each saccade to a target was preceded by a steady fixation, we could minimize this limitation by removing from the saccade EOG data used to predict gaze position a baseline of five samples from the steady fixation preceding the saccade.

By the end of the experiment the subject wanted to continue playing, demonstrating that the game is indeed engaging.

IV. Gaze prediction

After denoising the EOG data, we used a linear regression model to predict gaze position from the EOG data, as described in Section II. We chose a linear model because it is fast to estimate, compared to nonlinear models such as artificial neural networks [6], because several adaptive methods exist to estimate the parameters of this model [7], and because it is know that, for eye movements of amplitude

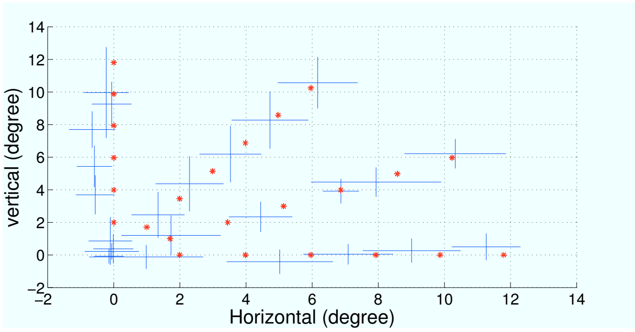

Fig. 2. Predictions of gaze position for different target positions. The red marks indicate the positions where targets were displayed. The intersection of the blue lines mark the mean predicted gaze for the corresponding target location. The width of the horizontal and vertical lines represent one standard deviation in the predictions for the corresponding target position. Besides estimates for the targets closer to the fixation cross, estimates for other targets appear to be unbiased.

less than 30 degrees, the relation between EOG and gaze position is linear.

Figure 2 summarizes the gaze prediction results. The red marks indicate the positions where targets were displayed. These positions occurred either at the 0, 30, 60, or 90 degree meridians, and were separated by 2 degrees on each meridian. The fixation cross occurred in the intersection of all the meridians. The intersection of the blue lines mark the mean predicted gaze for the corresponding target location. The width of the horizontal and vertical lines represent one standard deviation in the predictions for the corresponding target position.

The average error across all target positions was 0.8 and 1.2 degrees in the horizontal and vertical directions, respectively. These figures are comparable with those of previous linear models (e.g., 1.2 degrees horizontally and 2.2 degrees vertically in [8]) and nonlinear models (e.g., 1.09 degrees averaged across vertical and horizontal directions in [6]). Besides estimates for the targets closer to the fixation cross, other estimates of gaze positions appear to be unbiased (i.e., the red targets are located inside the error bars of the mean estimates). Estimates for targets closer to the fixation cross were biased because the gaze-contingent application that implemented the game was configured with a large window around targets to detect valid fixations, and in the case of the targets closer to the fixation cross, this window was activated with almost no movement of the gaze from the fixation cross. In future experiments we will reduce the size of the activation window around the targets and/or locate targets further away from the fixation cross.

V. DISCUSSION

This project uses new technology to implement a novel concept for behavioral intervention in ASD. Current therapies target social and language behaviors. However, due to the high-level nature of these skills any improvement rarely extends beyond the targeted behavior. The goal of this intervention is to improve basic attention and eye movement skills. Because these basic skills form the foundation for good social and communication skills, training these abilities has the potential to improve a broad spectrum of clinical symptoms, and in young children may affect the course of development. Here we described the initial steps in the construction of a system that will allow children with ASD to improve their fixation skills by playing a computer game controlled by an eye-tracker. Because improving fixation skills would probably require substantial training, it is essential that the system is portable, of low-cost, and easy use. For these reasons the proposed system is based on a portable, dry, and wireless EOG system.

We described the design of a computer game that would elicit sufficiently constrained eye movements in ASD children to facilitate gaze prediction from EOG data, while being entertaining to engage these children in long eye fixation training sessions. We used eye movements collected while a subject played this game to test the effectiveness of a simple linear regression method. We showed that this method generates errors comparable with previous linear and nonlinear graze prediction systems, suggesting that a linear model could be a useful component of the portable eye fixation training system for ASD children.

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