Early Screening for Children with Fetal Alcohol Spectrum Disorder via Natural Viewing Behavior

Chen Zhang[1], James Reynolds[2,4], Douglas P. Munoz[2,4], Laurent Itti[1,3]

[1]Neuroscience Graduate Program, University of Southern California, [2]Department of Biomedical and Molecular Science, Queen's University, [3]Dpartment of Computer Science, University of Southern California, [4]Center for Neuroscience Studies, Queen's University

Abstract

Fetal alcohol spectrum disorder (FASD) is one of the most prevalent neurodevelopmental disorders caused by prenatal alcohol consumption [1]. Children with FASD may suffer from growth retardation, structural and functional brain abnormalities, and cognitive and behavioral impairments [2-4]. Costs associated with FASD, in areas such as medical care, special education and facilities, and social services, can run into billions of dollars annually [5,6], placing high psychological pressures and large economic burdens on families and society. An easy, objective and widely-deployable early screening procedure is of significant importance because it can lead to earlier intervention and treatment, which is crucial for neurodevelopmental disorders, to mitigate the disruptive effects of the disorder and/or frequency of secondary comorbidities. Yet, the current diagnostic process or proposed screening tools are challenging and time- and money- consuming, vary across clinics and countries, leading to inconsistent diagnoses and treatments [7]. A large proportion of the at-risk population cannot receive timely diagnosis, particularly individuals with limited access to clinical resources. Thus, an objective, time- and cost-efficient screening and diagnosis system with globally unified standards is desperately needed in order to help target the at-risk population, accelerate the clinical process, and improve diagnostic accuracy and efficiency.

Children with FASD show altered natural viewing behaviors compared to the age-matched typically developing controls (TD) [8,9]. The recording of natural viewing behaviors can be applied to individuals as young as 2 months old, without any requirement of professionals. Previous studies have shown that oculomotor and attentional features extracted during free viewing of videos or static images could help differentiate clinical populations with various high-prevalent neurodevelopmental disorders [10, 11]. However, those studies based on SVM or convolutional neural networks either required a longer experiment time or didn't achieve the state-of-art classification accuracy [8,10]. In this study, we hypothesis that the entire eye movement dynamic and its temporal dependencies, together with the local visual attentional parameters and the global visual scene understanding which might reflect the internal viewing strategies, can further help the detection of children with FASD during less than 5-minute video watching. We used deep neural networks (DNN) containing multiple long-short-term-memory (LSTM) layers followed by a video selection classifier to give out the final prediction of the risk of having FASD.

We recorded the eye movements of participants while they naturally watched short video clips of various contents (Figure 1). Those raw eye traces (x, y coordinates) were treated as the oculomotor features of the inputs of networks. The local bottom-up attentional features were acquired on the scanpath of eyes from the saliency maps derived using the *Itti-Koch* saliency model [12,13], while the top-down attentional features were derived from the inter-observer map of a group of healthy young adults along the eye traces. We used the multi-resolution gist vectors of each video frames (which were used to accurately classifying the scenes) around the eye positions as another group of global features to reflect the understanding of the video [14]. The inputs of each participant were down-sampled and augmented 10 times to maintain an appropriate length while approximately preserving the natural viewing dynamics. The network structure of each video clips is shown in Figure 2. The masking layer was used to mask out any blinks or ocular drifts and the multiple LSTM layers were used to learn the temporal dependencies along the oculomotor, attention and visual understanding domains. The fully connected layer was used for a prediction and a voting step was followed to get one label and prediction probability for each participant

per video clip. A final video clip selection and L1-regularized logistic regression were used to make the ultimate prediction and the profile of distinguishing videos.

We achieved a classification accuracy of above 78%, with sensitivity and specificity to be 73% and 83% on a completed separated testing set of almost equal size of the training, which is comparable to or better than the results of other studies strongly rely on demographic, behavioral, physical, psychometric, face morphometric and neuroimaging analysis, and history of maternal alcohol consumption [9,15-18]. We also discovered that eliminating any feature group or reversing the eye sequences resulted in a significantly drop of the testing accuracy, indicating that the disorder has impacts on all the aspects of oculomotor control, attention allocation and visual understanding, and the FASD and TD groups had different viewing strategies. Further analysis of distinguishing videos showed that the FASD group demonstrated different visual processing regarding color, motion, flicker of texture of the video and altered behaviors in top-down modulation.

The proposed screening procedure only takes a few minutes to run with almost no age restriction. Anyone who is trained to use the eye tracker, which is just a laptop connected to a high-speed camera, can administrate this procedure. Compared to the standard diagnostic process, our proposal is much more accessible and easier to implement with early or pre-school age children, and could be widely used at clinics, schools, or health units where young children are seen routinely, across different regions and areas. The data can be analyzed through the same pipelines and thus all the screening estimations are achieved through the same standards. Such a screening tool could be applied as an annual screening tool for children at risk of FASD with high-capacity and low-cost, which is particularly beneficial for populations with limited healthcare resources. It can also have substantial impact of the referral and diagnostic process, and expected maximized long-term benefits to the tested individuals and to society.

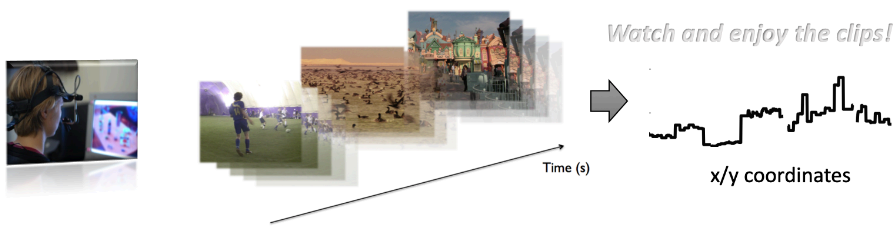

Figure 1. Natural viewing behavior recording.

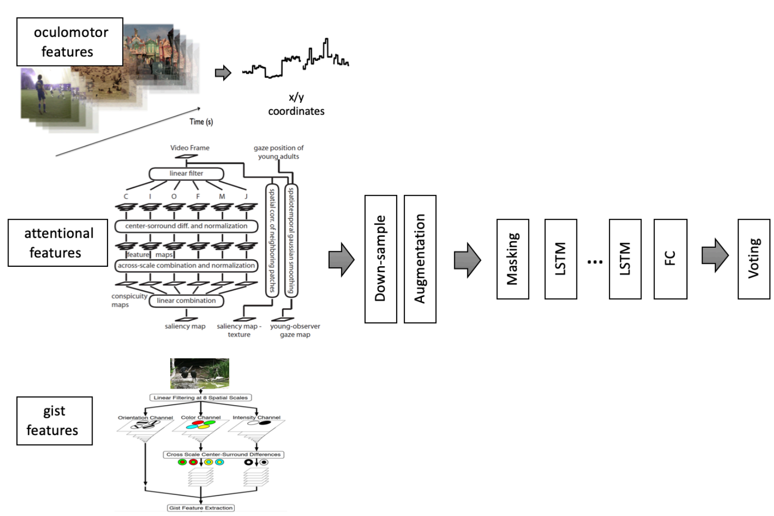

Figure 2. DNN architecture.

References

[1] Jones K & Smith D. Recognition of the fetal alcohol syndrome in early infancy. The Lancet 1973; 302(7836): 999–1001.
[2] Nuñez SC, Roussotte F, Sowell ER. Focus on: structural and functional brain abnormalities in fetal alcohol spectrum disorders. Alcohol Res Health (2011) 34:121–31.
[3] Mattson SN, Riley EP, Delis DC, Stern C, Jones KL. Verbal learning and memory in children with fetal alcohol syndrome. Alcohol Clin Exp Res (1996) 20:810–6.
[4] Mattson SN, Riley EP. A review of the neurobehavioral deficits in children with fetal alcohol syndrome or prenatal exposure to alcohol. Alcohol Clin Exp Res (1998) 22:279–94.
[5] Popova S, Lange S, Burd L, Rehm J. The burden and economic impact of fetal alcohol spectrum disorder in Canada. Centre for Addiction and Mental Health Toronto, Canada; 2015.
[6] Popova S, Lange S, Burd L, Rehm J. Burden and social cost of fetal alcohol spectrum disorders 2016.
[7] Chudley AE, Conry J, Cook JL, Loock C, Rosales T, LeBlanc N. Fetal alcohol spectrum disorder: Canadian guidelines for diagnosis. Canadian Medical Association Journal (2005); 172(5 suppl): S1–S21.
[8] Tseng PH, Paolozza A, Munoz DP, Reynolds JN, Itti L. Deep learning on natural viewing behaviors to differentiate children with fetal alcohol spectrum disorder. In: Intelligent Data Engineering and Automated Learning–IDEAL 2013 Springer; 2013.p. 178–185.
[9] Zhang C, Paolozza A, Tseng PH, Reynolds JN, Munoz DP, Itti L. Detection of children/youth with fetal alcohol spectrum disorder through eye movement, psychometric and neuroimaging data. Front Neurol (2019) 10:80.
[10] 29. Tseng PH, Cameron IG, Pari G, Reynolds JN, Munoz DP, Itti L. High-throughput classification of clinical populations from natural viewing eye movements. J Neurol (2013) 260:275–84.
[11] 31. Wang S, Jiang M, Duchesne XM, Laugeson EA, Kennedy DP, Adolphs R, et al. Atypical visual saliency in autism spectrum disorder quantified through model-based eye tracking. Neuron (2015) 88:604-16.
[12] Itti L, Koch C, Niebur E. A model of saliency-based visual attention for rapid scene analysis. IEEE Transactions on Pattern Analysis & Machine Intelligence (1998) 11:1254–1259.
[13] Itti L, Koch C. A saliency-based search mechanism for overt and covert shifts of visual attention. Vision research (2000) 40(10):1489–1506.
[14] Siagian C, Itti L. Rapid biologically-inspired scene classification using features shared with visual attention. IEEE transactions on pattern analysis and machine intelligence (2007) 29(2):300-312.
[15] Goh PK, Doyle LR, Glass L, Jones KL, Riley EP, Coles CD, et al. A Decision Tree to Identify Children Affected by Prenatal Alcohol Exposure. J Pediatr (2016) 177:121–7.
[16] Burd L, Klug MG, Li Q, Kerbeshian J, Martsolf JT. Diagnosis of fetal alcohol spectrum disorders: a validity study of the fetal alcohol syndrome checklist. Alcohol (2010) 44:605–14.
[17] Mutsvangwa TE, Meintjes EM, Viljoen DL, Douglas TS. Morphometric analysis and classification of the facial phenotype associated with fetal alcohol syndrome in 5-and 12-year-old children. Am J Med Genet A (2010) 152:32–41.
[18] Kalberg WO, May PA, Blankenship J, Buckley D, Gossage JP, Adnams CM. A practical testing battery to measure neurobehavioral ability among children with FASD. Int J Alcohol Drug Res (2013) 2:5.