A training scheme for autism rehabilitation based on language comprehension using real-time fMRI neurofeedback

Huaping Zhu\(^1, 2\), Yangbo Cao\(^1\) and Zuo Zhang\(^3\)

\(^1\)Department of Electronics and Information Engineering, Tongji Zhejiang College, Jiaxing, China
\(^2\)Tongji University Taicang High-Tech Institute. Suzhou, China
\(^3\)Suzhou Huaji Information Technology Co., Ltd. Suzhou, China

*Corresponding author e-mail: huapingzhu@tongji.edu.cn

Abstract. Language comprehension deficiency is common in autistic children. Language problems in autism are attributed to abnormalities in the function of Broca’s area and underconnectivity between language regions. Neurofeedback has been proved effective in regulating brain activity and has potential use in language comprehension training in autism. In this paper, we described a propose potential training schemes of language comprehension based on real-time fMRI to improve the function of Broca’s area and its connections with posterior language regions. It is promising that the training schemes can improve language comprehension in autistic children.

1. Introduction

Language and communication problems are of great challenges for autistic people. Autism involves impairment in both language use and comprehension, which comes in a broad range of aspects and severities [1]. Autistic children show abnormalities of word use, syntactic structure, and prosody in their speech and difficulty in comprehending speeches and passages [1-3], although some of them have normal or even precocious abilities in single word reading [4].

Previous studies using functional MRI (fMRI) have identified characteristic features of blood oxygen level dependant (BOLD) activity during language processing in autism [5, 6], such as abnormal asymmetry of activation in Broca’s area and Wernicke’s area [7], underconnectivity between brain regions [8] and differences in semantic organization [9, 10]. Theory of underconnectivity [11] has been recently proposed to account for disorders of autism. Underconnectivity implies underservice of information integration in neural processing and a lack of coordination between brain regions, which could account for difficulties in language comprehension and other high level cognitive functions. Just et al. [8] found weaker coordination between Broca’s area and Wernicke’s area in the autistic group than the control group during sentence comprehension, which was characterized by a lower level of synchrony between their activation time series. Further studies of various tasks provided consistent findings of underconnectivity between frontal and posterior brain regions in autism [9, 12].

Previous studies [13-15] also suggested abnormal semantic organization in individuals with autism. Word semantic functions relied more on frontal language regions with increase in age and language experience for typically developed children, which was reflected in an increase of activation in frontal language areas and decrease in posterior brains areas [16-18]. Autistic children seemed to face
problems with this critic shift during their development. In lexical-semantic tasks, the autistic group entailed more activity in extrastriate visual cortex and less in frontal language areas [10, 19]. It implied a strategy employed by autistic people in lexical-semantic tasks, which relied more on visual perceptual functions in absence of intact frontal language functions [10, 19].

On the basis of the above-mentioned findings, we hypothesise that language comprehension training schemes with real-time fMRI as neurofeedback may improve language comprehension in autistic children. Brain activity during language tasks is fed back to the participants, so that they can regulate their brain activity toward a favourable pattern through training. There are two targets of the regulation: the synchronization between Broca’s area and Wernicke’s area in reading comprehension and the activation of Broca’s area in lexical-semantic processing. The training aims to enhance inter-cortical coordination in language comprehension and regulate the semantic processing to more reliance on frontal language regions. Test procedures are proposed to verify the efficacy of the proposed training schemes.

2. Potential training schemes

It seems that the function of the language system in autism could be enhanced by regulating the brain activity through some subtle training schemes. The brain activity, especially the functional connectivity and collaboration between inter-cortical networks (e.g. the synchrony level of Broca’s area and Wernicke’s area) can be observed by neurofeedback of real-time fMRI (rtfMRI). As figure 1, a description of training schemes for autism rehabilitation using real-time fMRI in this proposal are described here.

**Figure 1.** Overview of training schemes for autism rehabilitation using real-time fMRI

First, it is expected to enhance the functional connectivity and collaboration between inter-cortical networks and improve the ability of reading comprehension by increasing the synchrony level of Broca’s area and Wernicke’s area. Second, by increasing the activation of Broca’s area and decreasing
that of extrastriate areas, it is promising to enhance language functions of Broca’s area and help with the shift of autistic children’s strategy in lexical-semantic processing from less dependence on perceptual functions of posterior brain areas to more dependence on frontal language areas.

3. Evaluation of training schemes

Neurofeedback has been used as a non-invasive approach for evaluation and intervention of autism [20]. EEG signal is a traditional method of neurofeedback with advantages of high time resolution, low expenses and convenience for implementation. Previous studies used EEG patterns (band power, etc.) as feedback in treating disorders of autism and improvements were shown in attention, motor and social behaviours after the training [21, 22].

Real-time fMRI (rtfMRI) is a new method of neurofeedback that has developed rapidly in recent years [23]. MRI scans can cover the whole-brain dynamics and the BOLD signals have the advantages of intuitive display and interpretation. rtfMRI has been used in therapy of clinical disorders that have characteristic BOLD patterns such as pain [24, 25]. According to our knowledge, no published work has used rtfMRI for autism therapy. Only a few studies have used rtfMRI for enhancing language related brain activity. Rota et al. [26, 27] had their participants (all healthy males) regulate activity of the right inferior frontal gyrus – an area related to emotional prosody processing – through rtfMRI training. The participants gained improved performance in identifying emotional information in speeches after the training.

Previous research has proved the efficacy of neurofeedback of EEG in autism intervention and has shown potential use of rtfMRI in regulating high-level functions such as language. The response patterns that characterize autism in language tasks have been consistently identified [5]. Our proposed schemes have potential in enhancing language comprehension by regulating these patterns.

We propose the following approach for testing the efficacy of the training schemes. High functioning autistic children are recruited. They should be diagnosed with autism according to the criteria of the fourth edition of the Diagnostic and Statistical Manual (DSM-IV) [28] and have an IQ of 80 or above. The participants are randomized to a treatment group and a control group with matched age, gender, IQ and language abilities. The treatment group participate in the language tasks with the proposed training schemes, while the control group undergo the same tasks with sham feedback as described by Rota et al.[27]. Performances of reading comprehension and lexical-semantic judgement are evaluated under fMRI without neurofeedback both before and after the training sessions. It is expected that the activation level of Broca’s area and its synchronization with Wernicke’s area will get significant enhancement in the treatment group after training, compared with those before the training and the control group. We can also expect more improvement in the performance of the treatment group than the control group after the training.

4. Conclusion

Autism pathogenesis, real-time fMRI, and their application systems of computer-based interventions method is one of the cutting-edge research fields in neurophysiology, cognitive science and informatic technology with both important theoretical and application values. In this paper, potential langue training schemes based on real-time fMRI to enhance language comprehension in autistic children are proposed, as well as possible implementations for autism therapy. Task dependant BOLD patterns of Broca’s area and its synchronization with Wernicke’s area are fed back to the participants and serve as the targets to be regulated through training. It is promising that our proposed language training schemes will produce a shift of strategy for language related neural processing and improve language comprehension in autism.

Acknowledgments

This work was financially supported by Taicang Grand Academic Innovation and leading Project.

References

[1] H. Tager-Flusberg, R. Paul and C. Lord, Language and communication in autism, Handbook Autism& Pervasive Dev. Dis, 1 (2005) 335-364.
[2] I. Rapin and M. Dunn, Update on the language disorders of individuals on the autistic spectrum, Brain Dev., 25 (2003) 166-172.

[3] K. Nation, P. Clarke, B. Wright, and C. Williams, Patterns of reading ability in children with autism spectrum disorder, J. Autism & Dev. Dis., 36(2006) 911-919.

[4] T. M. Newman, D. Macomber, A. J. Naples, T. Babitz, F. Volkmar, and E. L. Grigorenko, Hyperlexia in children with autism spectrum disorders, J. Autism & Dev. Dis., 37(2007) 760-774.

[5] N. J. Minshew and T. A. Keller, The nature of brain dysfunction in autism: functional brain imaging studies, Curr. Opin. Neurol., 23(2010) 124-130.

[6] R. C. M. Philip, M. R. Dauvermann, H. C. Whalley, K. Baynham, S. M. Lawrie, and A. C. Stanfield, A systematic review and meta-analysis of the fMRI investigation of autism spectrum disorders, Neurosci. Biobehav. R., 36(2012) 901-942.

[7] M. R. Herbert, G. J. Harris, K. T. Adrien, D. A. Ziegler, N. Makris, D. N. Kennedy, et al. Abnormal asymmetry in language association cortex in autism, Ann. Neurol., 52(2002) 588-596.

[8] M. A. Just, V. L. Cherkassky, T. A. Keller, and N. J. Minshew, Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity, Brain, 127(2004) 1811-1821.

[9] T. A. Knaus, A. M. Silver, K. A. Lindgren, N. Hadjikhani, and H. Tager-Flusberg, fMRI activation during a language task in adolescents with ASD, J. Int. Neuropsych. Soc., 14(2008) 967.

[10] M. S. Gaffrey, N. M. Kleinmans, F. Haist, N. Akshoomoff, A. Campbell, E. Courchesne et al., A typical participation of visual cortex during word processing in autism: An fMRI study of semantic decision, Neuropsychol., 45 (2007) 1672-1684.

[11] A. Minichino, F. Singh, J. Pineda, E. Friederich, and K. S. Cadenhead, Biological motion induced mu suppression is reduced in Early Psychosis (EP) patients with active negative symptoms and Autism Spectrum Disorders (ASD), Psychiat. Res., 238(2016) 374-377.

[12] F. Guo, Q. Xu, H. M. A. Salem, Y. Yao, J. Lou, and X. Huang, The neuronal correlates of mirror therapy: A functional magnetic resonance imaging study on mirror-induced visual illusions of ankle movements, Brain Res., 1639 (2016) 186-193.

[13] S. Braeutigam, S. J. Swithenby and A. J. Bailey, Contextual integration the unusual way: a magnetoencephalographic study of responses to semantic violation in individuals with autism spectrum disorders, Eur. J. Neurosci., 27 (2008) 1026-1036.

[14] K. M. Wilkinson and C. Rosenquist, Demonstration of a method for assessing semantic organization and category membership in individuals with autism spectrum disorders and receptive vocabulary limitations, Augment. Altern. Comm., 22(2006) 242-257.

[15] W. B. Groen, C. Tesink, K. M. Petersson, J. Van Berkum, R. J. Van der Gaag, P. Hagoort, and J. K. Buitelaar, Semantic, factual, and social language comprehension in adolescents with autism: an fMRI study, Cereb. Cortex, 20(2010) 1937-1945.

[16] T. T. Brown, H. M. Lugar, R. S. Coalson, F. M. Miezin, S. E. Petersen, and B. L. Schlaggar, Developmental changes in human cerebral functional organization for word generation, Cereb. Cortex, 15(2005) 275-290.

[17] J. P. Szalatvsky, V. J. Schmithorst, M. Altaye, A. W. Byars, J. Ret, E. Plante, and S. K. Holland, A longitudinal functional magnetic resonance imaging study of language development in children 5 to 11 years old, Ann. Neurol., 59(2006) 796-807.

[18] B. L. Schlaggar, T. T. Brown, H. M. Lugar, K. M. Visscher, F. M. Miezin, and S. E. Petersen, Functional neuroanatomical differences between adults and school-age children in the processing of single words, Science, 296(2002) 1476-1479.

[19] C. P. Sahyoun, J. W. Belliveau, I. Soulieres, S. Schwartz, and M. Mody, Neuroimaging of the functional and structural networks underlying visuospatial vs. linguistic reasoning in high-functioning autism, Neuropsychol., 48(2010) 86-95.

[20] R. Coben, M. Linden and T. E. Myers, Neurofeedback for autistic spectrum disorder: A review of the literature," Appl. Psycho. & Biofeedback, 35(2010) 83-105.

[21] R. Coben and T. E. Myers, The relative efficacy of connectivity guided and symptom based EEG biofeedback for autistic disorders, Appl. Psycho. & Biofeedback, 35(2010) 13-23.
[22] A. Koul, A. Cavallo, F. Cauda, T. Costa, M. Diano, M. Pontil, and C. Becchio, Action observation areas represent intentions from subtle kinematic features, Cereb. Cortex, 28 (2018) 2647-2654.

[23] N. Weiskopf, Real-time fMRI and its application to neurofeedback, Neuroimage, 62(2012) 682-692.

[24] H. Chapin, E. Bagarinao and S. Mackey, Real-time fMRI applied to pain management, Neurosci. Lett., 520(2012) 174-181.

[25] R. C. DeCharms, F. Maeda, G. H. Glover, D. Ludlow, J. M. Pauly, D. Soneji, et al., Control over brain activation and pain learned by using real-time functional MRI, P. Natl. Acad. Sci. USA., 102 (2005) 18626-18631.

[26] G. Rota, G. Handjaras, R. Sitaram, N. Birbaumer, and G. Dogil, Reorganization of functional and effective connectivity during real-time fMRI-BCI modulation of prosody processing, Brain Lang., 117 (2011) 123-132.

[27] G. Rota, R. Sitaram, R. Veit, M. Erb, N. Weiskopf, G. Dogil, and N. Birbaumer, Self-Regulation of regional cortical activity using real-time fMRI: The right inferior frontal gyrus and linguistic processing, Hum. Brain Mapp., 30(2009) 1605-1614.

[28] American psychiatric association, Diagnostic and statistical manual of mental disorders: DSM-IV-TR., 4th Ed. Washington, DC: American Psychiatric Publishing, Inc., 2000.