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Structural balance within and between functional brain networks in autism during development

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Abstract

First study: Intra analysis of resting-state brain networks

Goal: Studying balance energy of the brain networks and energy distributions of balanced and unbalanced triads in autism spectrum disorders compared to healthy individuals during development.

Method: Functional brain networks are constructed based on resting-state functional magnetic resonance imaging (rs-fMRI) of individuals for healthy (CON) and autism spectrum disorders (ASD) in three age ranges, namely, children (7 to 12 years), adolescents (13 to 18 years) and adults (19 to 30 years). The following networks are studied: The whole-brain network, the left and right hemispheres, the visual network (VN), the somatomotor network (SMN), the dorsal attention network (DAN), the salience network (SN), the central executive network (CEN), and the default mode network (DMN). For each of these networks, balance energy and energy distributions of balanced and unbalanced triads are analyzed. Moreover, for the whole brain ASD networks, the brain regions with zero participation in high energy triads are identified. Finally, the brain-behavior relations are presented based on the correlations between the balance energy levels and ADOS behavioral scores.

Findings: First, compared with null models, in the whole brain networks of both ASD and CON during development the balanced triads are over-represented while the unbalanced triads are under-represented. Second, the results of the Mann-Whitney U tests on the balance energy distributions depicts that in ASD networks there are no statistically significant differences during development. Yet, in CON networks balance energy differs significantly between childhood and adolescence as well as adulthood, forming a U-shaped pattern of a decrease followed by an increase. Third, the same pattern is observed in DAN, SN, and DMN sub-networks. Fourth, the energy distributions of weakly unbalanced and balanced triads in CON have more high energy triads. These high energy triads are interestingly from three sub-networks in the triple network model, i.e., SN, CEN, and DMN. Last but not least, there is a negative correlation of -0.5 and -0.46 between the balance energy of ASD networks and ADOS total as well as social scores.

Conclusion: The over-representation of balanced triads and under-representation of unbalanced triads in both ASD and CON brain networks during development, is in line with the notion of strong structural balance. Moreover, the fact that the balance energy of the ASD brain networks is not statistically changing during development may be a manifestation of their disclination to change. In addition, the absence of higher energy weakly balanced and unbalanced triads from SN, CEN, and DMN in ASD brain networks is a shred of evidence that supports the theory of the triple network model from a new perspective.

Keywords: Resting-state functional brain networks, Structural balance theory, Autism spectrum disorders, Development.

Second study: Inter analysis of resting-state brain networks

Goal: Studying balance energy of the interbrain networks and energy distributions of balanced and unbalanced triads in autism spectrum disorders compared to healthy individuals during development.

Method: First, the interaction networks between two and three combinations of networks from the previous study are constructed. This results in 15 and 20 pair interactions networks and triple interaction networks, respectively. To construct these interaction networks only the triads in between sub-networks are considered. Afterward, the balance energy and distribution of balanced and unbalanced triads for ASD and CON interaction networks are computed and analyzed during development. According to triads' functionality in brain networks, three types of triads are defined, namely, directing, segregating, and integrating triads. The interaction networks with a maximum difference in balance energy between the ASD and CON networks are presented symbolically as participation graphs. The changes in these graphs during development for both the ASD and CON networks are investigated.

Findings: First, among the 15 pair interaction networks the balance energy of the following three interaction networks are statistically different between ASD and CON: DMN-CEN, CEN-SN, and SN-VN. In addition, this pattern holds for 12 triple interaction networks out of 20, among which is the crucial triple network, i.e., DMN-SN-CEN. Second, energy distributions of integrating triads contain higher balance energy triads for seven triple networks in the CON group during adolescence. This is followed by higher balance energy segregating triads in 11 triple networks of CON group during adulthood. This is while for ASD group only three triple networks contain higher balance energy integrating triads during childhood. This is then followed by higher balance energy segregating triads during adolescence.

Conclusion: First, according to changes in balance energy of the interaction networks during development, the triple network model seems to be part of a bigger picture in describing autism spectrum disorders. That is, not only the balance energy of DMN-SN-CEN interaction network but also 10 others are different between ASD and CON. Additionally, the rate of participation of each sub-network in maximum difference graphs depicts the undeniable importance of internetworks analysis, especially when dealing with an extremely heterogeneous disorder such as ASD. Second, the early and sparse occurrence of functional integration which is followed by functional segregation in ASD interbrain networks provides evidence for altered functional integration and segregation in autism from a new approach. Altogether, these results provide insight into the atypical structural balance of ASD, both within and between brain networks. It also highlights the potential value of SBT as a new perspective in functional connectivity studies, especially in the case of neurodevelopmental disorders.

Keywords: Interaction networks between brain sub-networks, Fuctional segregation, Functional integration