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Multi-way Multiscale Brain Network Interaction: Insights from Birth to 6 Months

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Significant Statements: The information interaction in a complex brain is beyond pairwise interaction, and usually pairwise functional connectivity ignores high-order information interaction. Therefore, in this study, we estimated high-order functional connectivity to capture how it is associated with age and how the pairwise interaction may fail to capture some interaction, and we supplied evidence that multi-way multiscale brain functional network interaction indeed occurs in infants from birth to 6 months and has the strongest association with age compared to pairwise interaction.

Background: During infancy, the dynamics of information exchange undergo significant changes as age progresses, particularly during the period from birth to 6 months. Understanding the intricate multi-way information exchange is crucial for comprehending brain development and certain early childhood brain disorders because the brain is a complex system that cannot be fully characterized by pairwise interactions [1-3]. This study investigates multi-way multiscale brain functional network interactions from birth to 6 months, elucidating how these interactions evolve over age.

Objectives: 1) Introduce an approach to capture multi-way multiscale brain network interaction. 2) To examine the impacts of gestational age at birth on the multi-way multiscale brain information interaction.

Methods: Participants were 64 typically developing infants (age range 4-179 days, mean (SD) gestational age = 38.7(1.8) weeks, 50 scans from females), and the data were collected from each infant at up to 3 randomized time points between birth and 6 months, for a total of 126 scans. After standard Neuromark preprocessing [4], the subject-specific intrinsic connectivity networks (ICNs) and time course were estimated using Multivariate-Objective Optimization ICA with Reference (MOO-ICAR) with 105 multiscale brain network templates obtained from over 100k subjects [5]. Next, we employed total correlation (TC) to estimate the triple brain network interaction, resulting in a 105×105×105 matrix per subject. The triple interaction tensors were flattened and concatenated across the subject dimension. Independent component analysis with model order 20 was applied to identify triple components from the infant brain. Furthermore, a general linear model was employed to estimate

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their dependencies. Subsequently, we replicated the preceding analysis employing pairwise interaction metrics, specifically Mutual Information (MI) and Pearson Correlation coefficients (PC).

Results: The selected top two ICN triple components from all 20 triple components are illustrated in Fig.1. Firstly, we noticed that triple interactions mainly occur among the visual, subcortical, sensorimotor, and high-level cognitive domains, suggesting that these brain networks are the strongest and develop the fastest during the first 6 months of infancy. Secondly, we observe that triplet interactions among DMN (ICN^{102}, ICN^{90}) and salience network (SN, ICN^{94}) increase with age advancement (R-squared: 0.2418), while interactions among DMN (ICN^{102}), SM (ICN^{68}), and CEN (ICN^{89}) show a negative association with age (R-squared: 0. 2929), as depicted in Fig.2. Notably, the pairwise interactions among these triplets exhibit weak age association patterns because they ignore some hidden high-order interactions.

Conclusions: We show multi-way brain network interaction in early infancy brain development. Our results reinforce growing evidence that high-order information interaction can capture information that might be hidden from pairwise interactions.

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Appendix:

Fig.1: Top 2nd Triple interaction from each triple component. The numbers (left panel, 1–105) refer to the specific ICNs.

Fig.2. Age trajectories with tiple interaction functional connectivity strength, and pairwise functional connectivity strength (Pearson correlation).

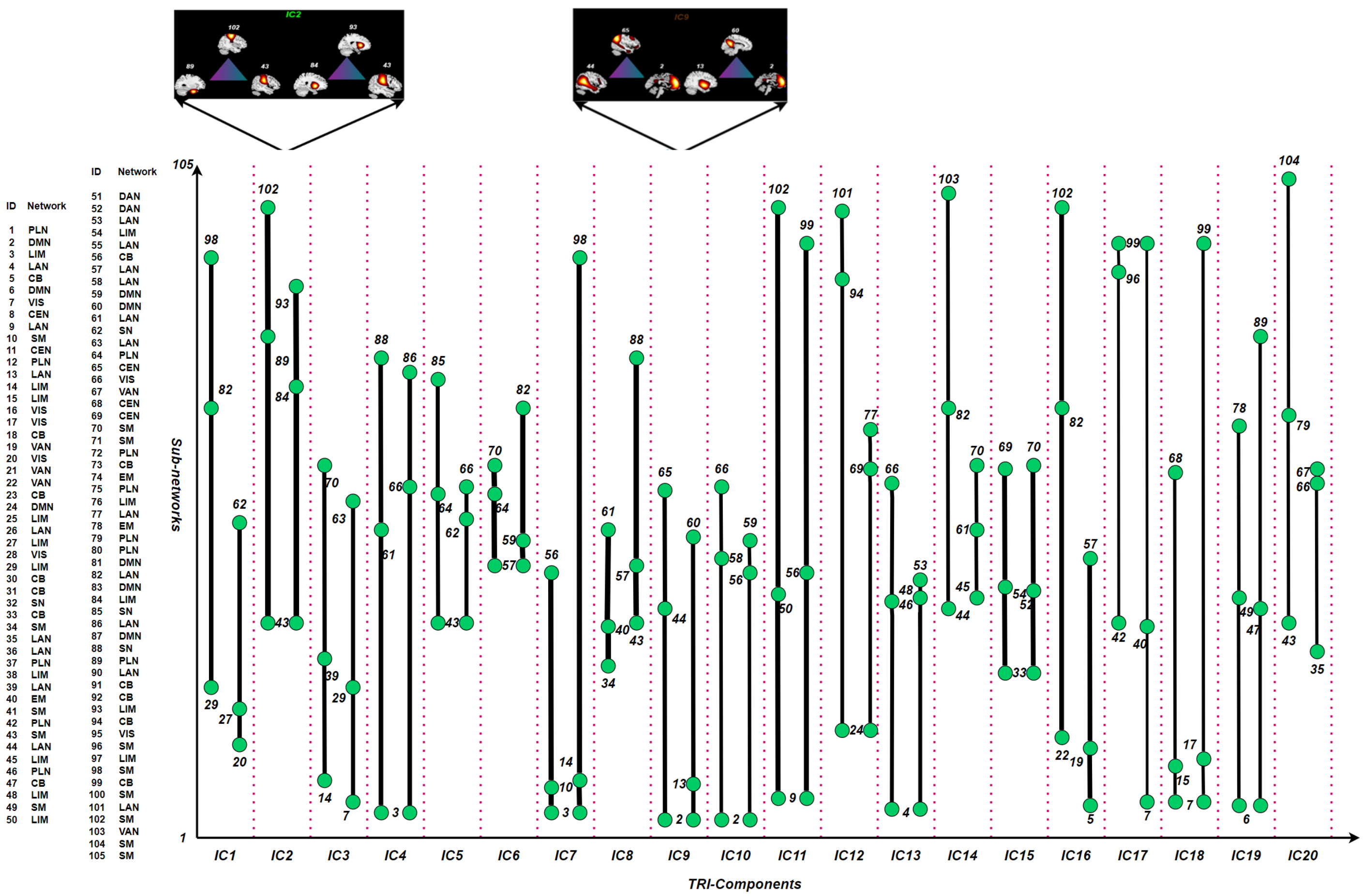

Fig.1

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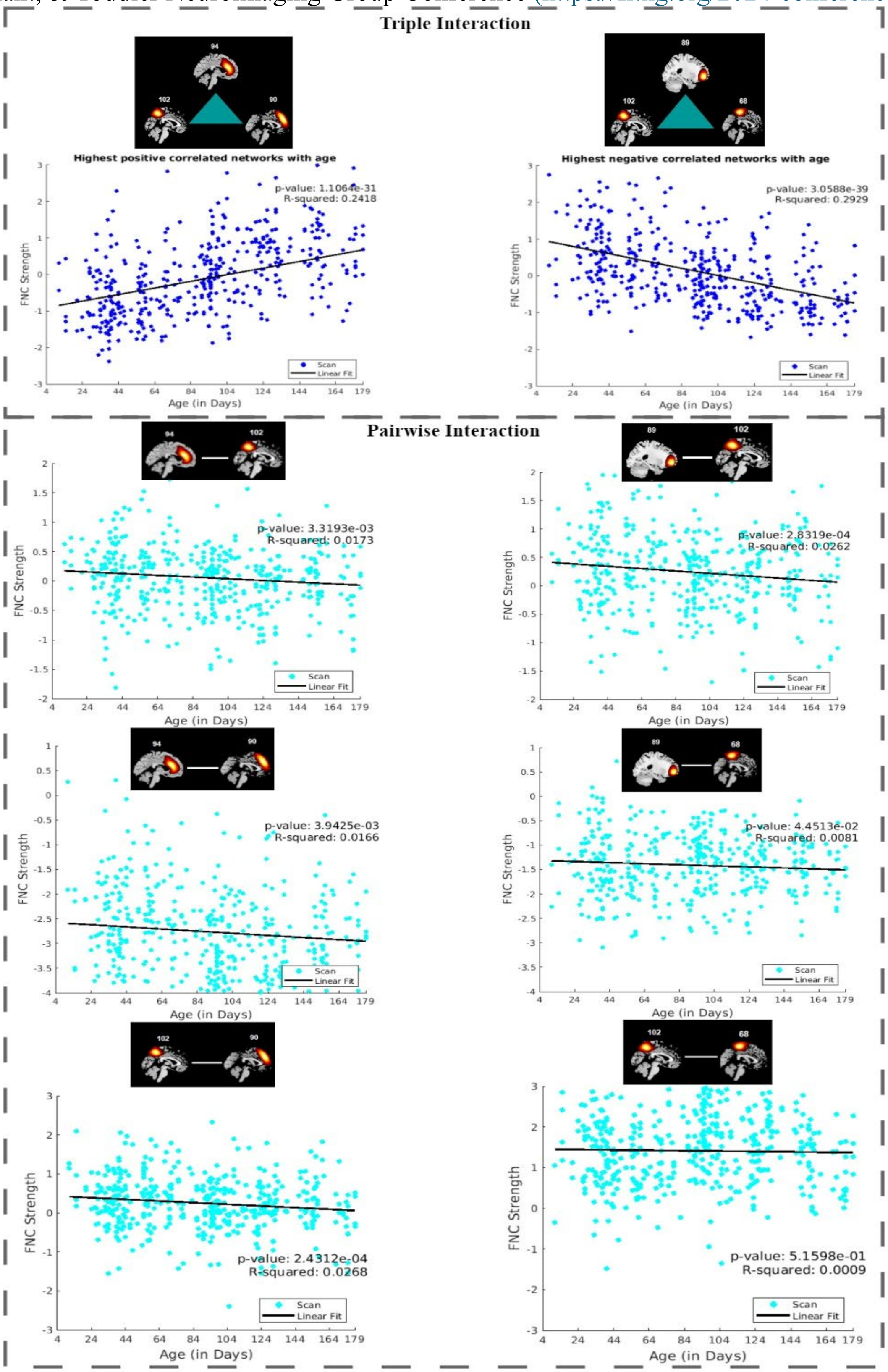

Fig.2

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