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Short communcation

Organization of intrinsic functional brain connectivity predicts decisions to reciprocate social behavior

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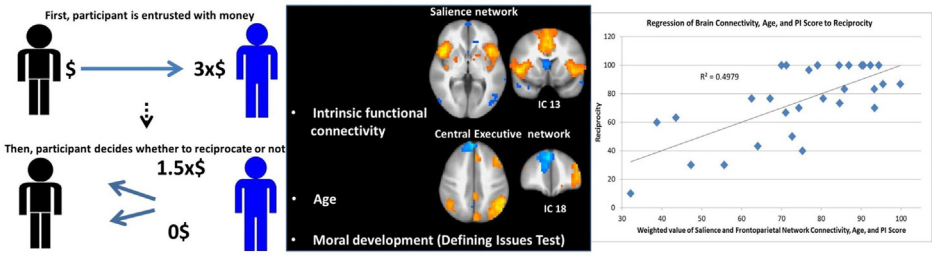
HIGHLIGHTS

- Functional connectivity predicted 20% of the variance in reciprocity behavior.
- rs fMRI, moral development and age explained 49% of reciprocity behavior variance.
- Brain imaging may be valuable to refine models of human behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

Reciprocation of trust exchanges is central to the development of interpersonal relationships and societal well-being. Understanding how humans make pro-social and self-centered decisions in dyadic interactions and how to predict these choices has been an area of great interest in social neuroscience. A functional magnetic resonance imaging (fMRI) based technology with potential clinical application is the study of resting state brain connectivity. We tested if resting state connectivity may predict choice behavior in a social context. Twenty-nine healthy adults underwent resting state fMRI before performing the Trust Game, a two person monetary exchange game. We assessed the ability of patterns of resting-state functional brain organization, demographic characteristics and a measure of moral development, the Defining Issues Test (DIT-2), to predict individuals' decisions to reciprocate money during the Trust Game. Subjects reciprocated in 74.9% of the trials. Independent component analysis identified canonical resting-state networks. Increased functional connectivity between the salience (bilateral insula/anterior cingulate) and central executive (dorsolateral prefrontal cortex/ posterior parietal cortex) networks significantly predicted the choice to reciprocate pro-social behavior ($R^2 = 0.20$, $p = 0.015$). Stepwise linear regression analysis showed that functional connectivity between these two networks ($p = 0.002$), age ($p = 0.007$) and DIT-2 personal interest schema score ($p = 0.032$) significantly predicted reciprocity behavior ($R^2 = 0.498$, $p = 0.001$). Intrinsic functional connectivity between neural networks in conjunction with other individual characteristics may be a valuable tool for predicting performance during social interactions. Future replication and temporal extension of these findings may bolster the understanding of decision making in clinical, financial and marketing settings.

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Abbreviations: rs-fMRI, resting-state fMRI; ICA, independent component analysis; LIM, frontolimbic network; DMN, default mode network; CEN, central executive network; SAL, salience network; OCC, occipital network; SOM, sensorimotor network; ToM, theory of mind; ACC, anterior cingulate cortex; DLPFC, dorsolateral prefrontal cortex; mPFC, medial prefrontal cortex.

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1. Introduction

Reciprocity, defined as responding to a positive action with another positive action, is the basis for interpersonal bonds that define a society and an integral part of traditional virtues in many cultures. Human subjects have been shown to engage in reciprocity and other prosocial behaviors even at their own expense. A challenge in everyday life is to figure out in whom you can place your trust. Decisions about whom to trust are motivated by the evaluation of stable facial traits [1], similarity to kin [2], and perceived trustworthiness [3]. The brain mechanisms that underlie social decision making are less well known and have implications for diverse fields of human behavior including healthcare, economics, politics and even the legal system.

The combination of monetary exchange paradigms and neuroimaging approaches has elucidated individual differences in the cognitive and neural mechanisms underlying interactive social behaviors such as cooperation [4], trust [5], and betrayal [6]. Most of the inferences from these studies are based on behaviors elicited by tasks in which individuals engage in dyadic interactions while undergoing functional magnetic resonance imaging (fMRI). However, brain imaging has been a sought after tool for predicting human behavior, particularly at the individual level. Resting-state fMRI (rs-fMRI) is an increasingly used approach which measures the intrinsic connectivity between functional brain networks in resting, awake individuals who are not engaged in overt tasks [7]. Because resting-state does not require a task (and thus avoids the confound of study-specific task properties), rs-fMRI has been increasingly used to investigate the relationship between the functional organization of neural networks and behavior [8].

Intrinsic functional brain connectivity is proposed to represent the product of individual inner life experience. The default mode (DMN), central executive (CEN), salience (SAL) and frontolimbic (LIM) networks have been associated with different cognitive and behavioral correlates. In the present study, we sought to test the value of rs-fMRI, in conjunction with behavioral measures to predict individual differences in human social behavior. We hypothesized that specific patterns of intrinsic connectivity between these discrete neural networks (DMN, CEN, SAL and LIM) can predict reciprocity behavior.

2. Materials and Methods

We recruited 30 healthy participants, 12 men and 18 women of diverse racial and ethnic backgrounds. Twenty-four participants were full-time students, five were employed and one participant was unemployed. One participant was excluded due to technical error (functional data was misnormalized to anatomic and could not be corrected). Inclusion criteria were: (a) age 18–30, (b) no neurological or psychiatric history, (c) ability to write and speak English, and (d) ability to provide written informed consent. Exclusion criteria were: (a) active substance use disorders, other than tobacco, by self-report; (b) ferromagnetic implants, and (c) history of claustrophobia. Following written informed consent, participants were assessed for personality trait composition using the NEO Five-Factor Inventory (NEO-FFI), moral reasoning development with the Defining Issues Test-2 (DIT-2), dysfunctional attitudes for depression (DAS), and trait impulsivity with the Barratt Impulsiveness Scale-11 (BIS-11). Lastly, participants underwent functional magnetic resonance imagining (fMRI) scanning during resting state and while playing the trustee role in the Trust Game (reported elsewhere). Participants were compensated between $20 and $100, depending on their choices within the Trust Game. All research procedures were approved by the Institutional Review Board of the University of Miami, and took place on the same day.

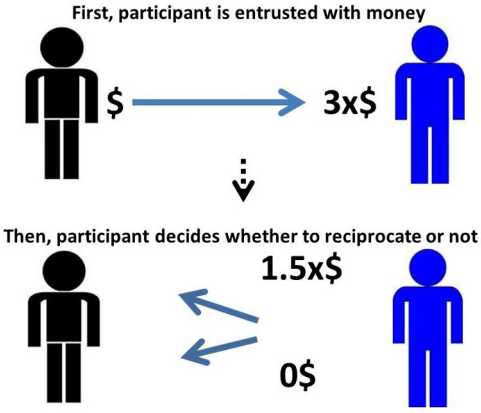

Fig. 1. Trust game. In each of the 30 single rounds the participant played the role of trustee (blue) who received a variable amount of money from the investor (3X) and needed to decide whether to give back some (1.5X) or nothing.

The Defining Issues Test (DIT-2) activates and assesses moral schemas in terms of importance judgments. Based on Kohlberg's theory of moral development, the subjects' task is to read a moral dilemma, and rate and rank corresponding statements in terms of their moral importance. Measures for the following schema are obtained: (a) Personal Interests (PI), focuses on a self-centered utilitarian approach; (b) Maintaining Norms (MN), emphasizes behavior driven by rules; and (c) Postconventional (PC), in which laws are not simply blindly accepted, but are scrutinized in order to ensure society-wide benefit [9]. Completed DIT-2 assessments were scored at the Center for Ethical Development [9].

We used a modified version of the Trust Game in which the participant plays the role of the trustee and decides whether or not to reciprocate the first player's trust. Participants played 30 rounds of the Trust game, each with a different anonymous individual [10]. Participants were informed that they would play the Trust Game with other people who have already played the game whose responses (offers) had been recorded and would be paired with those of the participants themselves. This was to convey to the participants that the investment amounts had been actually proposed by real players, so participants believe they were exposed to realistic offers. The participant (trustee) and the other anonymous individual (investor) were endowed with an initial amount of money, a portion of which ($X) the investor sent to the participant. Next, the participant received three times what the investor sent ($3X), and was asked to choose how much money he/she wanted to give back to the investor, either $1.5X or $0. In our study, reciprocity was operationally measured by the number of times participants gave money back (expressed as a percentage of the total 30 rounds). See Fig. 1.

MRI acquisition: Participants underwent neuroimaging using a Siemens 3T Trio MRI scanner at the University of Miami Applebaum MRI Center. The MRI scan session was as follows: a magnetization-prepared rapid gradient-echo (MPRAGE) T1 anatomic scan (5 min), a resting-state EPI fMRI scan (rs-fMRI, 5 min), an echo-planar imaging (EPI) fMRI scan during the Trust game (15 min). The MPRAGE scan had the following parameters: matrix = 248 × 256, 220 sagittal slices, TR/TE/FA = 2300 ms/3.08 ms/9°, final resolution=0.86 × 0.86 × 1.20 mm^3 resolution. Rs-fMRI was conducted with the following parameters: TR/TE/FA = 2000 ms/30ms/90°, FOV = 220 × 220 mm, matrix=64 × 64, 25 axial slices (acquired parallel to the AC-PC line with interleaved slice acquisition), slice thickness = 5 mm, final resolution 3.44 × 3.44 × 5.00 mm^3, 150 images.

fMRI preprocessing: Image processing and analysis was conducted with AFNI, and Matlab (The MathWorks, Inc.). Functional

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