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Integration of social status and trust through interpersonal brain synchronization

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ABSTRACT

Trust can be a dynamic social process, during which the social identity of the interacting agents (e.g., an investor and a trustee) can bias trust outcomes. Here, we investigated how social status modulates trust and the neural mechanisms underlying this process. An investor and a trustee performed a 10-round repeated trust game while their brain activity was being simultaneously recorded using functional near-infrared spectroscopy. The social status (either high or low) of both investors and trustees was manipulated via a math competition task. The behavioral results showed that in the initial round, individuals invested more in low-status partners. However, the investment ratio increased faster as the number of rounds increased during trust interaction when individuals were paired with a high-status partner. This increasing trend was particularly prominent in the low (investor)-high (trustee) status group. Moreover, the low-high group showed increased investor-trustee brain synchronization in the right temporoparietal junction as the number of rounds increased, while brain activation in the right dorsolateral prefrontal cortex of the investor decreased as the number of rounds increased. Both interpersonal brain synchronization and brain activation predicted investment performance at the early stage; furthermore, two-brain data provided earlier predictions than did single-brain data. These effects were detectable in the investment phase in the low-high group only; no comparable effects were observed in the repayment phase or other groups. Overall, this study demonstrated a multi-brain mechanism for the integration of social status and trust.

1. Introduction

Trust is the social glue that holds society together (Jones and George, 2007). To successfully manage our social interactions, our trust in the people we interact with must be dynamically modified (Fett et al., 2012; Jones and George, 2007; Mcallister, 2006; Wu et al., 2009). This requires making inferences about their thoughts and intentions and depends on the social information (for example, *social status*) of the individuals who are interacting (Lount and Pettit, 2012). However, investigations on how people develop and modify their social trust by combining their own experiences with the social status of partners, and the underlying neural mechanisms are currently limited.

Trust can be reflected in various situations and thus be accessed in different ways, such as the economic trust game (A.B. King-Casas et al., 2005, 2008), or the Specific Interpersonal Trust Scale (Johnson-George and Swap, 1982). In the laboratory setting, the economic game (also known as the trust game) is a paradigm used to study how social trust is formed and modified over time and has been used widely in previous studies (Blue et al., 2020; Declerck et al., 2020; A.B. King-Casas et al., 2005, 2008; van den Bos, van Dijk, Westenberg, Rombouts, and Crone, 2009). In the trust game, an individual (i.e., an "investor") decides how much money of an initial endowment should be sent to another person (i.e., a "trustee"). The amount sent is then multiplied by three (Blue et al., 2020; A.B. King-Casas et al., 2005, 2008; Sapienza et al., 2013), and the trustee decides how much of the money received should be sent back to the investor. In this game, the amount sent (i.e., the investment ratio) is operationally defined as a behavioral measure of trust (Koranyi and Rothermund, 2012; Krueger and Meyer-Lindenberg, 2019), which can be motivated by various factors such as perception of moral character (Delgado et al., 2005), honesty (Bellucci et al., 2019), race attitudes (Stanley et al., 2011), and network formation (Di Cagno and Sciubba, 2010). Importantly, given that interpersonal trust is typically situated in a social setting, one crucial factor affecting trust is the social status of the individuals involved in the interaction (Blue et al., 2020; Lount and Pettit, 2012).

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Social status is defined as the prominence, respect, and influence that individuals owns in the eyes of others (Anderson et al., 2006) and is crucial for interaction and social behaviors in many species. It can either be elicited by one's socioeconomic status or be attained according to dominance or prestige (Henrich and Gil-White, 2001). Previous studies have demonstrated that social status biases individuals' emotions and social behaviors (e.g., Guinote et al., 2015). However, its impact upon trust is controversial. In a series of studies, it was proposed that individuals with relatively higher (vs. lower) status would show more initial trust toward the partner (i.e., sending more money to the anonymous partner). This was interpreted as the higher-status individuals perceived a higher degree of benevolence from their lower-status partner, which enhanced their willingness to trust. It is referred to as the "*low-status benevolence*" hypothesis (Lount and Pettit, 2012). In contrast, according to the "*high-status credibility*" hypothesis (Blue et al., 2020), individuals would trust a relatively higher-status conspecific, who is perceived as skillful or reliable (Kilpatrick et al., 2007). This hypothesis was supported by a recent study that showed that individuals trusted higher-status partners' promises more than those made by their lower-status partners (Blue et al., 2020).

The inconsistent findings (i.e., individuals trust more towards a higher-status trustee vs. a lower-status trustee) might be related to the difference of experimental paradigm and settings. In the study of Lount and Pettit (2012), participants had no opportunity to communicate or interact with the trustee, thus the finding could only reflect individuals' initial willingness to trust in new relationships. In contrast, participants in the study of Blue et al. (2020) received the promise from the trustee. Such communication or interaction can modulate individuals' perception or behavior towards others (McAuliffe et al., 2018), which might have promoted the trust of the low-status investor towards the high-status trustee (Blue et al., 2020). Therefore, interaction process could be an important factor worthy of concern that modulating the effect of social status on trust. The aforementioned studies focused primarily on initial trust by adopting a trust scale or a single-shot trust game, however, significant social exchanges are rarely single-shot, and trust could be temporally changing as individuals interact with each other across time (Cochard et al., 2004; A.B. King-Casas et al., 2005, 2008). Taken together, a complete understanding of interpersonal trust requires a broad framework that captures both the initial trust and the temporal change of trust, as well as the underlying neural computations that emerge from multiple interacting agents, beyond that which is known so far from single-individual studies. Furthermore, given individuals continuously interact in a social context, concrete knowledge regarding how social information, such as their social status relationships, shapes trust behavior is key to broadening our understanding of how individuals integrate endogenous and exogenous experiences to modify their trust interactions.

Thus, the current study extended the field from two aspects: (1) examining the effect of social status on the temporal change of trust during interaction apart from the initial trust, and (2) characterizing real-time trust interaction from a neurophysiological perspective. We used a multiple-round repeated trust game in a multi-person interactive situation to clarify the effect of social status on trust interaction and the related neural mechanisms. Given the interactive nature of interpersonal trust, it is imperative to adopt the hyperscanning technique (i.e., the measurement of brain activity from two or more individuals simultaneously) (Babiloni and Astolfi, 2014; Koike et al., 2015; Montague et al., 2002). Using functional near-infrared spectroscopy (fNIRS) hyperscanning, it has been demonstrated that synchronous brain activities (i.e., interpersonal brain synchronization, IBS) across two persons can occur with their social behaviors, in particular prosocial or coordination behaviors, such as cooperation (Cui et al., 2012), complementary coordination (Cheng et al., 2019; Liu et al., 2015), and intention sharing (Hu et al., 2017). More importantly, IBS has been observed among interacting persons when they perform economic games. For example, using fMRI hyperscanning, the middle cingulate cortex of investors and the anterior cingulate cortex of trustees were found to be strongly correlated when playing the trust game (A.B. King-Casas et al., 2005). The changes in connectivity patterns of theta band at prefrontal areas may predict individuals' decisions to cooperate in an EEG hyperscanning study (De Vico Fallani et al., 2010). Compared with fMRI and EEG, fNIRS is more tolerant to movement artifacts, which makes it advantageous for studying trust in a naturalistic setting. Based on the hyperscanning technique, IBS could be a useful indicator in studies of interpersonal trust.

In this study, participants first worked together on a math competition task that was intended to manipulate their social status (high or low status) and were subsequently designated as either an investor or a trustee. To extend previous studies (Blue et al., 2020; Hu et al., 2015, 2014), we manipulated the social status of both participants within a dyad. Thus, "social status" in this study referred to the composition of social ranking in an investor-trustee pair (i.e., high-high, high-low, low-low, and low-high). The investor-trustee dyads performed a 10-round repeated trust game, during which their brain activity was recorded using the fNIRS-based hyperscanning technique. The brain regions of interest (ROIs) were the prefrontal cortex (PFC, including the frontopolar cortex and the dorsolateral PFC [DLPFC]) and the right temporal-parietal junction (rTPJ). These two brain regions are closely related to interpersonal interactions (Cui et al., 2012; Hu et al., 2017; Jiang et al., 2015; Nguyen et al., 2021). Specifically, the rTPJ is often associated with self-other representation and perspective-taking (Saxe and Kanwisher, 2003), while the PFC plays an important role in monetary reward, cognitive control, and decision-making (Kahnt et al., 2011; Minati et al., 2012).

The goal of the present study was twofold. First, we examined the effect of social status on trust behaviors (including both initial trust and the temporal change of trust during interaction). Following the "low-status benevolence" hypothesis, the high (investor)-low (trustee) group would elicit the greatest degree of initial trust and/or the increased tendency of trust. Alternatively, according to the "high-status credibility" hypothesis, the low-high group would elicit the greatest degree of initial trust and/or the increased tendency of trust. Noted that interaction/communication might promote the trust of the low-status investor towards the high-status trustee (Blue et al., 2020). It is also possible that the effects of social status on trust depend on the situation, i.e., individuals trust more in lower-status trustee initially, and show a greatly increased tendency of trust in high-status as interacting with each other across time. The two equal-status groups (i.e., high-high and low-low) were included as control groups. Second, we computed IBS during the trust game to characterize real-time trust interactions from a "two-person neuroscience" perspective (Ellingsen et al., 2020; Pan et al., 2021; Pan and Cheng, 2020). Given that IBS may be a useful indicator of interpersonal trust (B. King-Casas et al., 2005), we hypothesized that an increased tendency of IBS would be observed either in the high-low group, based on the "low-status benevolence" hypothesis, or the low-high group, based on the 'high-status credibility' hypothesis. We conducted parallel computations of individual brain data to explore the potential added value of a two-brain vs. single-brain analysis. Finally, to identify whether and to what extent trust behavior can be decoded from brain data, we applied a machine-learning algorithm (i.e., support vector regression) to each group.

2. Methods

2.1. Participants

Two hundred and two right-handed female students (age: 21.05 ± 2.47 years) were recruited via flyers spread throughout East China Normal University, forming 101 investor-trustee dyads. Following previous evidence and recommendations (Pan et al., 2018; Tang et al., 2016), we recruited only females in the current study to reduce the variability of our sample and to mitigate the confounding effects elicited by gender compositions that proven to affect social

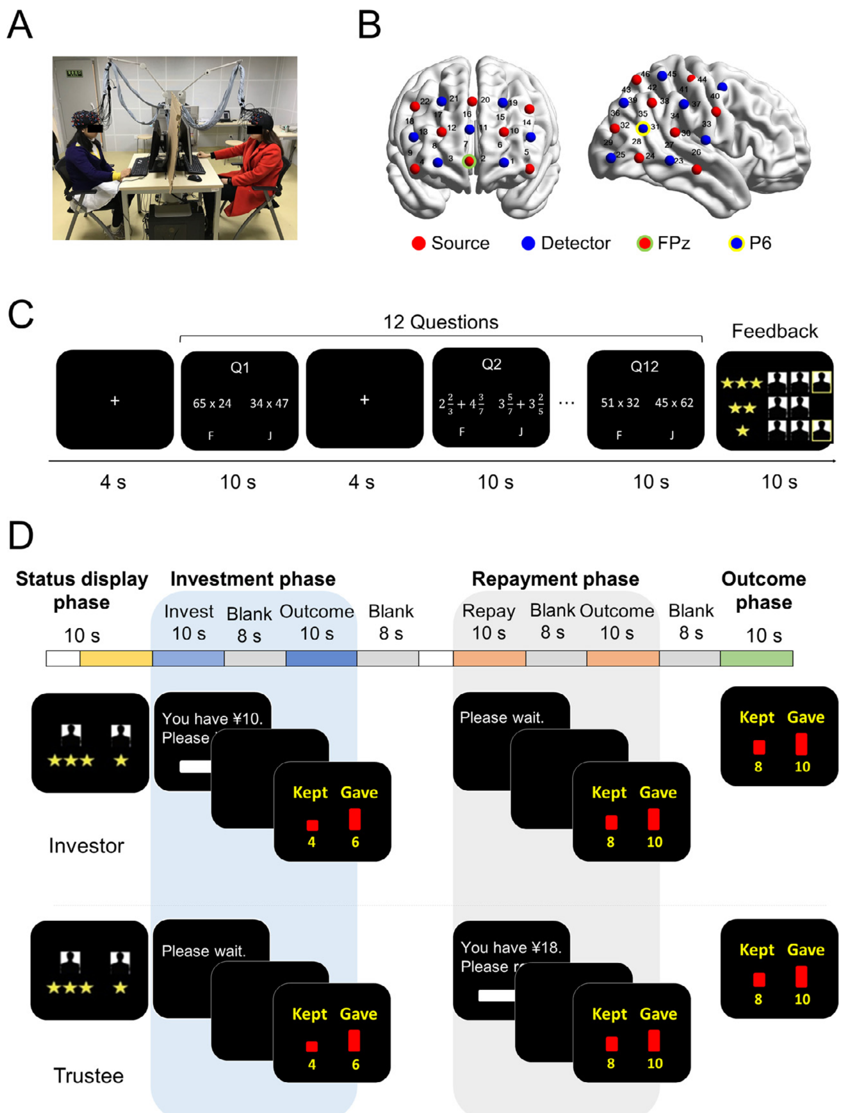

Fig. 1. Experimental design and task procedures. (A) Experimental setup. (B) Probe configuration. The integers on the cerebral cortex indicate the recording channels (CHs). The BrainNet Viewer toolbox was used to visualize the locations of the CHs (Xia et al., 2013). (C) The math competition task. Participants solved 12 math questions and received feedback on their rank at the end of the task. During the feedback, the screen would show the photos of the two current interacting participants, the other six participants and their corresponding number of stars. Specifically, the photos of the two interacting participants are indicated by the yellow frame. (D) The trust game. Events and time flow in a round. In the status display phase, the photos shown were real photos of the current participants.

interactions (Baker et al., 2016; Cheng et al., 2015). The two participants in a dyad were unacquainted prior to the experiment. All participants had normal or corrected-to-normal vision and had no history of medical, psychiatric, or neurological diagnoses. Written informed consent was obtained from every participant. Participants were compensated for their participation. The study was approved by the University Committee on Human Research Protection of East China Normal University.

2.2. Experimental tasks and procedures

Upon arriving at the laboratory, two participants briefly met each other and confirmed that they had not been previously acquainted. They were then seated on opposite sides of a table and separated by two computer monitors in a quiet room (Fig. 1A). Participants were told that they would play a two-person economic exchange game during the experiment, acting as either an investor or a trustee (randomly assigned by the experimenter). Before performing the economic game, they were asked to solve several math questions; this was referred to as the status-inducing task. A total of three sessions were included in the current experiment: (1) a 3-min resting session in which participants were required to relax and remain still, (2) a status-inducing session, and (3) a trust game session.

In the status-inducing session, two participants were required to complete a math competition task, i.e., solving 12 math questions under a time constraint (10 s per question) (Blue et al., 2020; Hu et al., 2015). For each question, participants were asked to compare two arithmetic expressions (e.g., 65 × 24 and 34 × 47) that were displayed on the left and right sides of the screen and determine which was greater in value by pressing the 'F' (indicating the left side has a greater value) or 'J' key (indicating the right side has a greater value). Expressions were either complex fraction additions (e.g., $2\frac{2}{3} + 4\frac{3}{4}$) or two-digit multiplications (e.g., 65 × 24). Participants were told that their performance would be calculated according to their question-solving accuracy (in reality, the performance was manipulated by the experimenter) and that they would receive performance feedback after completing all questions. We presented six easy questions (i.e., those that could be solved within 10 s) and six difficult questions (i.e., those that would be difficult to solve within 10 s) during the task to manipulate participants' status by assuring participants that they could provide correct and incorrect responses. After completing all questions, participants were informed of their own and partner's performance status: either high status (indicated by three stars) or low status (indicated by one star; Fig. 1C). Specifically, in our study, two participants of 50 dyads were assigned the same status: high-status investor and high-status trustee (the high-high group, 25 dyads) or low-status investor and low-status trustee (the low-low group, 25 dyads). Two participants in the other 51 pairs were assigned different statuses: high-status investor and low-status trustee (the high-low group, 26 dyads) or low-status investor and high-status trustee (the low-high group, 25 dyads).

Following the status-inducing session, participants performed a 10-round trust game (**Fig. 1D**). Each round began with a 4-s fixation, followed by the presentation of the two participants' statuses for 10 s. Participants then completed three phases: the investment, repayment, and outcome phases. In the investment phase, a decision display informed the investor that they received 10 monetary units as an endowment. The investor then decided on an amount (ranging from 0 to 10) to invest in the trustee. At the same time, another display instructed the trustee to wait for the investor's decision. Once the decision was made, there was a delay during which a blank black screen was displayed for 8 s. This was followed by a feedback display revealing the number of monetary units each person had, which was displayed for 10 s. The number of monetary units was represented graphically and numerically. In the repayment phase, the trustee was informed of the number of monetary units she had after receiving the investment (the number was tripled) before deciding how much to repay the investor. Meanwhile, the investor was instructed to wait for the trustee's decision. The feedback display revealed the number of monetary units each player had after the trustee's decision, which was displayed for 10 s. In the outcome phase, a 10-s display was presented that revealed the number of monetary units each participant had in that round after the investment-repayment decisions had been made (i.e., the total outcome). This constituted one round of gameplay.

The status-inducing task and the trust game were implemented through E-prime 2.0 software (Psychology Software Tools, Inc., Pittsburgh, PA). Before completing the tasks, participants were provided with a detailed introduction to ensure they were familiar with the procedures. In addition, we did not inform participants of the exact number of rounds in the trust game to reduce the possibility that they would exploit others' trust during the final rounds. Following previous studies (Blue et al., 2020; Hu et al., 2015), we checked the validated manipulation of social status after the trust game by asking participants to report their self-perceived social ranking on a seven-point Likert scale, where 1 = very low status and 7 = very high status. The manipulation of social status was checked after the trust game instead of immediately after the status-inducing task to avoid explicitly leading the participants to infer the purpose of the study, which might contaminate trust behaviors.

2.3. Data acquisition

We used an ETG-7100 optical topography system (Hitachi, Japan) to measure the oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) concentrations of the dyads simultaneously. Each participant had two patches (positioned with a distance of 3 cm between emitter probes and detector probes) covering the ROIs of the rTPJ and frontal cortex (**Fig. 1B**). One patch was a 3 × 5 probe patch placed over the participants' forehead with 22 recording channels (CHs 1~22). The lowest probe row of the patch was aligned with the horizontal reference curve with the middle optode located on the frontal pole midline point (Fpz). The other patch was a 4 × 4 probe patch, which was placed at P6 forming 24 recording CHs (23~46). This patch covered the participants' right temporal, parietal and occipital areas (the regions around P6 and CP6; Jurcak et al., 2007). In the current study, a three-dimensional (3D) digitizer and NIRS-SPM software were used to reveal the anatomical locations of the CHs. Specifically, we used the 3D digitizer to obtain the locations of CHs on the participants' head (see more details in Xiao et al., 2017), and the NIRS-SPM software for MATLAB validated the location data (Jang et al., 2009; Singh et al., 2005; Ye et al., 2009). The possible MNI coordinates and corresponding brain region of each CH were then obtained. Each CH in both patches had a sampling rate of 10 Hz.

2.4. Data analysis

2.4.1. Behavioral data

In each round, we calculated the behavioral performance of each participant in the pair playing the trust game, i.e., the investor's investment ratio and the trustee's repayment ratio. To examine the effect of social status on initial trust, we conducted a linear mixed-effects model on the investment ratio and the repayment ratio of the first round with investor and trustee statuses as fixed factors and dyad as a random effect. Furthermore, to explore the effect of social status on trust development, the dependence of the investment and the repayment ratios on round and social status (including investor and trustee statuses) was modeled using linear mixed-effects models. The round number was considered a continuous independent variable. Investor and trust statuses, each had two levels (high and low), were considered to be fixed effects of the model. Dyad was considered a random effect in the model. Model fitting was conducted using the *lme4* package in the R statistical environment (Bates et al., 2020).

2.4.2. fNIRS data

Both HbO and HbR signals were extracted. However, we mainly focused on the HbO signal, because of its sensitivity to regional cerebral oxygenation changes (Hoshi, 2003) and its higher signal-to-noise ratio compared with that of HbR (Goldstein et al., 2018; Mahmoudzadeh et al., 2013). The selection of brain signals was in accordance with our previous studies using the same technique (Cheng et al., 2019; Hu et al., 2017). During preprocessing, the raw HbO data were passed through a 0.01–0.5 Hz bandpass filter to remove longitudinal signal drift and the noise from the instrument. We then used the correlation-based signal improvement (CBSI) procedure to reduce motion artifacts caused by head movement (Cui et al., 2010). The approach based on the hypothesis that the two signals (i.e., HbO and HbR) will become more positively correlated when motion artifacts occur. Finally, a wavelet-based denoising method was employed to remove the global physiological (Duan et al., 2018). Specifically, a wavelet transform coherence algorithm was performed to automatically search for the time-frequency points that were related to systemic noises. The wavelet energy of the contaminated time-frequency points was then separated from the neural time series. During preprocessing, the fNIRS data of two dyads (one from the high-low group and one from the low-high group) could not be viewed due to recording error. Therefore, the data of these two dyads were excluded in the sequence analysis that evaluated brain activity.

Interpersonal brain synchronization (IBS). As we were more interested in time-synced relationship between two interacting individuals, we explored the relationship between the brain signals in the temporal domain instead of the spectral domain following previous studies (Dai et al., 2018; Liu et al., 2021, 2017, 2015). Specifically, Pearson's correlation was used to evaluate the relationship between the two signals from the matched CHs of the two participants in a dyad (e.g., CH 10 from the investor and CH 10 from the trustee). For each CH, we calculated the r values between the two participants' signals during the resting-state and the task (including both the investment and repayment phases). The *r* values were Fisher-z transformed before further analysis. For each dyad, task-related IBS was defined as $Z_{task} - Z_{rest}$. Consistent with previous studies (Goldstein et al., 2018; Reindl et al., 2018), the IBS analysis procedure included two steps. First, a series of one-sample *t*-tests were applied for each group on task-related IBS to identify the CHs that demonstrated significant IBS. The false discovery rate (FDR) method was used to correct for multiple testing (Benjamini and Hochberg, 1995). Only CHs showing significant task-related IBS in at least one group were regarded as a CH of interest and included in subsequent analyses. This step aimed to identify the CHs specific to the task and exclude those with a null effect. Second, we examined IBS at CHs of interest across different groups to explore the effect of social status on trust. In this step, we examined the effects of round, investor status, and trustee status on the task-related IBS detected in Step 1. Applying this two-step procedure allowed us to reduce the risk of spurious findings and thereby increase the robustness of the results. To provide a complete picture of the underlying neural features, we also analyzed the IBS based on the HbR signal (see Supplementary Materials).

Brain activation. We calculated the mean HbO concentration for each round and each CH for each participant. Specifically, the preprocessed signals were converted into z-scores using the mean and the standard deviation of the signals of the rest (baseline) session (Liu et al., 2015; Yang et al., 2016). Similar to the analysis of IBS, the analysis procedure included two steps. First, we compared the cortical response z-scores averaged across 10 rounds in each CH against those of rest (i.e., Z_{task} - Z_{rest}) to determine the CHs that showed significant responses. The FDR method was used to correct for multiple testing. Only CHs that showed significant brain activation in at least one participant group were regarded as a CH of interest and included in subsequent analyses. Second, we examined brain activation at CHs of interest across different groups to explore the effect of social status. For these CHs, the effects of round, investor status, and trustee status on brain activity were examined by using linear mixed effect models with dyad as the random effect.

2.4.3. *Predictive relationship between brain activation/IBS and behavioral performance*

We tested whether and how IBS or brain activation in the low-high group was associated with behavioral performance. A machine-learning algorithm (i.e., linear SVR) was used to train the IBS or brain activation data to predict the investment ratio. Specifically, IBS or brain activation for all 46 channels was used as classification features to examine the generalization of prediction and avoid inflation of the prediction. The inclusion of all channels as features has the advantages of (1) avoiding bias in prediction accuracy and (2) allowing us to investigate whether data from other brain regions would provide additional information for the prediction. A leave-one-out cross-validation approach was employed. Prediction performance was quantified using the Pearson correlation coefficient (r) between the observed and predicted relative accuracy (Hou et al., 2020; Kosinski et al., 2013) and the coefficient of determination (R^2) (Poldrack et al., 2019). In the current study, the prediction analysis was performed round-by-round to examine the potentially dynamic relationship between IBS and the investment ratio and further identify the crucial rounds from which investment behavior could be decoded by IBS/brain activation. The ten p-values were corrected using the FDR method (Benjamini and Hochberg, 1995).

3. Results

3.1. *Manipulation check for social status*

The post-experiment questionnaire suggested that the number of stars used to denote the participants' rank in the math competition task strongly influenced their perception of social status. Two two-way ANOVAs (participants' star ranking x partners' star ranking) on the participant's evaluation of the extent that they saw themselves as having a higher status than their partner were conducted separately for the investors and the trustees. Noted that one dyad from the low-high group did not complete the evaluation so that a total of 100 dyads were included in the analysis.

For trustees, the results showed a significant interaction effect between their own star-ranking and the partner's star-ranking, F (1, 96) = 4.43, p = 0.038, partial η^2 = 0.044. Further analysis showed that when participants received three stars and their partner received one star, participants perceived higher status over their partner.

For investors, the results showed significant main effects of their own star-ranking, F (1, 96) = 6.95, p = 0.01, partial η^2 = 0.067, partners' star-ranking, F (1, 96) = 5.44, p = 0.022, partial η^2 = 0.054, and the interaction of both star rankings, F (1, 96) = 8.59, p = 0.004, partial η^2 = 0.082. Further analysis showed that when participants received one star and their partner received three stars, the degree that they saw themselves as having a higher status than their partner decreased significantly. These results indicate that the manipulation of social status was valid.

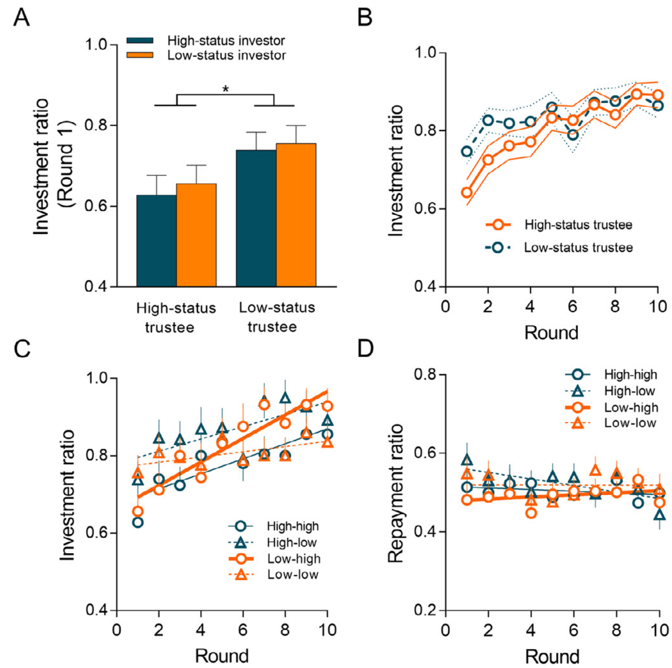

Fig. 2. Behavioral performance. (A) In the initial trust phase (i.e., Round 1), investors gave more money in the trust game when paired with low-status trustees. (B) The investment ratio increased as the number of rounds increased when paired with high-status trustees. (C) The investment ratios of the four groups as the number of rounds increased. (D) The repayment ratios of the four groups as the number of rounds increased.

3.2. *Social status modulates both initial trust and temporal change of trust during interaction*

We first examined the effect of social status on initial trust. For the investment ratio, there was a significant main effect of trustee status (F (1, 97) = 5.24, p = 0.024, η^2 = 0.051), with investors having a greater investment ratio when facing a low-status trustee (**Fig. 2A**). No main effect of investor status or interaction effect between investor status and trust status was found. For the repayment ratio, no effect of social status was found.

We then explored the effect of social status on the temporal change of trust during. For the investment ratio, when round was included in the model, the main effects of round, investor status, and trustee status were not significant (ps > 0.05). However, we found a significant interaction effect of round × trustee status (β = 0.026, SE = 0.006, t = 4.34, p < 0.001), which indicated that the investment ratio increased faster as the number of rounds increased when the investor was paired with a high-status trustee (β = 0.026, SE = 0.003, t = 8.89, p < 0.001) compared with when the investor was paired with a low-status trustee (β = 0.011, SE = 0.003, t = 3.62, p < 0.001; **Fig. 2B**). Furthermore, there was a significant interaction effect of round × investor status × trustee status (β = −0.022, SE = 0.008, t = −2.62, p = 0.009). Post hoc analysis revealed that a round × trustee status interaction was found in low-status investors (β = 0.026, SE = 0.006, t = 4.66, p < 0.001). When a low-status investor was paired with a high-status trustee, the investment ratio increased rapidly as the number of rounds increased (β = 0.033, SE = 0.003, t = 9.80, p < 0.001). However, when a low-status investor was paired with a low-status trustee, the investment ratio did not show an increasing trend (β = 0.007, SE = 0.004, t = 1.52, p = 0.13; **Fig. 2C**).

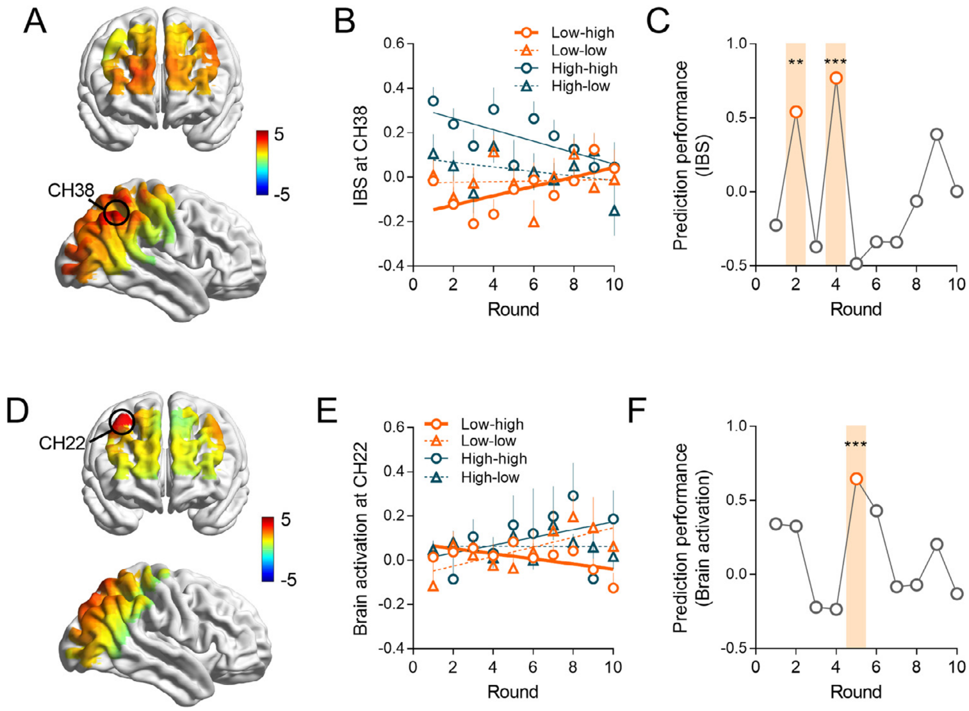

Fig. 3. fNIRS data. (A) *T*-value maps of task-related IBS (IBS during task minus IBS during rest) during trust interaction. (B) The task-related IBS at CH38 for the four groups as the number of rounds increased. (C) The prediction of the investment ratio based on task-related IBS in the low-high group as the number of rounds increased. (D) *T*-value maps of brain activation during trust dynamics. (E) Brain activation at CH22 in the four groups as the number of rounds increased. (F) The prediction of the investment ratio based on brain activation in the low-high group as the number of rounds increased.

These results indicated that the investment ratio could be modulated by social status. In particular, trustees' status mainly affected low-status investors' investment ratio, with the low-high group showing the most rapid rate of growth.

For the repayment ratio, however, we did not find any effect of round, investor status or trustee status (Fig. 2D). Therefore, in the subsequent analyses regarding behavioral performance, we mainly focused on the investment ratio.

3.3. Social status-dependent IBS during trust interaction

For the investment phase, we first identified CHs that showed significantly increased IBS by performing a series of one-sample *t*-tests on the task-related IBS (i.e., $r_{\text{task}} - r_{\text{rest}}$) for the four experimental groups. After FDR correction, CH38 showed a significant increased IBS (Fig. 3A). CH38 was roughly located at the rTPJ. We then performed linear mixed-effects models for the IBS at CH38 to explore the effects of round, investor status, and trustee status. Results revealed a significant interaction effect of investor status × trustee status on IBS ($\beta = 0.370$, $SE = 0.120$, $t = 3.08$, $p = 0.002$). Moreover, there was a significant interaction effect of round × investor status × trustee status on IBS ($\beta = -0.035$, $SE = 0.017$, $t = -2.03$, $p = 0.043$). Further analysis revealed that IBS decreased as the number of rounds increased in the high-high group ($\beta = -0.026$, $SE = 0.009$, $t = -2.96$, $p = 0.003$) and increased as the number of rounds increased in the low-high group ($\beta = 0.021$, $SE = 0.008$, $t = 2.80$, $p = 0.006$; Fig. 3B). For the repayment phase, none of the CHs showed significant task-related IBS following FDR correction. Similar results were found for the analyses of the HbR signal (see Supplementary Materials).

3.4. Social status-dependent brain activation during trust interaction

For the investment phase, we first conducted a series of one-sample t-tests on task-related brain activity (i.e., Z_{task} - Z_{rest}). Only CH22 showed a significant effect in activation after FDR correction and in the linear mixed-effects model (Fig. 3D). CH22 was roughly located in the right DLPFC (rDLPFC). We performed a linear mixed model analysis on brain activation at CH22 to explore the effect of round status, investor status, and trustee status. Results revealed a significant effect of round ($\beta = 0.022$, $SE = 0.010$, $t = 2.23$, $p = 0.026$), which indicated a general increase in brain activation over time. Additionally, there was a significant interaction effect of round × trustee status ($\beta = -0.03$, $SE = 0.014$, $t = -2.40$, $p = 0.016$), with a faster increasing tendency when facing a low-status trustee. Finally, there was a significant interaction effect of round × investor status × trustee status ($\beta = 0.051$, $SE = 0.020$, $t = 2.61$, $p = 0.009$). Further analysis revealed that the round × trustee status interaction effect was present among low-status investors: in the low-low group, investors' brain activation tended to increase as the number of rounds increased ($\beta = 0.02$, $SE = 0.01$, $t = 1.93$, $p = 0.055$); however, in the low-high group, investors' brain activation decreased as the number of rounds increased ($\beta = -0.012$, $SE = 0.005$, $t = -2.19$, $p = 0.029$; Fig. 3E). For the repayment phase, none of the CHs showed significant increases in brain activation following FDR correction, which constrained further analyses.

3.5. Prediction of behavior performance based on brain data

The results from the SVR analysis showed that IBS could successfully predict investment ratio at Round 2 ($r = 0.54$, $R^2 = 27.69\%$, $p = 0.006$, corrected $p = 0.03$) and Round 4 ($r = 0.77$, $R^2 = 59.12\%$, $p < 0.001$, corrected $p < 0.001$) (Fig. 3C). These results indicate that we could successfully infer investment behaviors based on IBS even at an early stage (before the trust reached a stable level, see Figure S1 in Supplementary Material). The brain activation of the investor could also predict the investment ratio at Round 5 ($r = 0.65$, $R^2 = 16.81\%$, $p < 0.001$, corrected $p = 0.006$) (Fig. 3F). The findings demonstrate that both the interpersonal brain synchronization and the brain activation could predict investment performance at an early stage, with two-brain data providing an earlier prediction compared to single-brain data.

4. Discussion

In this study, we explored the effect of social status on trust and the related brain mechanisms by asking two individuals play a 10-round repeated trust game while simultaneously recording their brain activity. Results showed that in the initial round, individuals invested more in low-status partners. However, during the interaction, the investment ratio increased faster when individuals were paired with a high-status partner. This increasing trend was particularly prominent in the low (investor)-high (trustee) status group. Accompanied by the increased tendency of trust, the IBS between the investor and trustee in the low-high group during interaction increased as the number of rounds increased, while brain activation of the investor decreased as the number of rounds increased. Both IBS and brain activation predicted investment performance at an early stage, and two-brain data provided earlier predictions than did single-brain data.

This work contributes to our understanding of trust in several important ways. Previous work that examined the influence of social status on trust primarily focused on initial trust (Blue et al., 2020; Lount and Pettit, 2012). We build upon this research by showing that social status plays different roles at different stages of trust development. In the first round of the trust game, investors sent more money to a low-status trustee. According to the “low-status benevolence” hypothesis, individuals expect the lower-status partner to exhibit greater benevolence (Lount and Pettit, 2012), so that they trust more in the lower-status trustee. This hypothesis emphasizes a relative social status relationship. However, in our study the enhanced initial trust was observed not only in the high-low group but also in the low-low group, which suggested that the low-status trustee would generally obtain more trust. Low-status investors would likely empathize with a low-status partner because they would consider their partner as an in-group member of the same status. Beliefs and expectations could modulate subsequent behaviors and experiences (Masten et al., 2011), which explains why low-status trustees received a greater investment in the initial trust phase.

However, when individuals repeatedly performed the trust game, the low-high group showed a significant increase as the number of rounds increased. The finding was consistent with the “high-status credibility” hypotheses (Blue et al., 2020). It seemed that partners’ credibility likely becomes a more important factor. Individuals were more likely to believe the promise of a high-status partner (Blue et al., 2020), so that a greater increase in the investment ratio was found in investors paired with a high-status trustee. Moreover, it was found that individuals with low status cooperated more (Osman et al., 2018). When continually interacting with a high-status trustee, compared with that of a high-status investor, a low-status investor might perceive a greater status gap, behave more prosocially, and thus show greater increased trust in high-status trustee. Our behavioral data suggested that both “low-status benevolence” and “high-status credibility” hypotheses are reasonable. Interaction processes could modulate the effect of social status on trust—individuals trust more in a low-status trustee initially and exhibit greatly increased tendency of trust in a higher-status trustee during the interaction. These findings advance our understanding of the social world of high- and low-status individuals.

We employed a fNIRS-based hyperscanning technique to uncover the brain mechanisms underlying the temporal change of trust. Results showed that in the low-high group, the IBS at the rTPJ (CH38) significantly increased as the number of rounds increased. The rTPJ is frequently associated with different capacities to shift attention toward unexpected stimuli and understand others’ mental states (Krall et al., 2015). Numerous studies have revealed the involvement of the rTPJ during social cognitive tasks, such as imitation and perspective-taking tasks (Santiesteban et al., 2012), lie detection tasks (Sowden et al., 2015), and economic games (Fujino et al., 2020; Speitel et al., 2019). Specifically, the role of the rTPJ in economic games is to differentiate one’s own perspective from another’s perspective (Speitel et al., 2019), which leads to an intergroup bias (Fujino et al., 2020). Studies that used a two-person neuroscience approach have also reported increased IBS at the rTPJ during economic exchanges (Tang et al., 2016), face-to-face communication (Jiang et al., 2015), and interpersonal cooperation (Xue et al., 2018). During social interactions, the IBS may reflect shared attention (Koike et al., 2016), mutual understanding (Hu et al., 2017), and successful information transfer (Stephens et al., 2010) between interacting

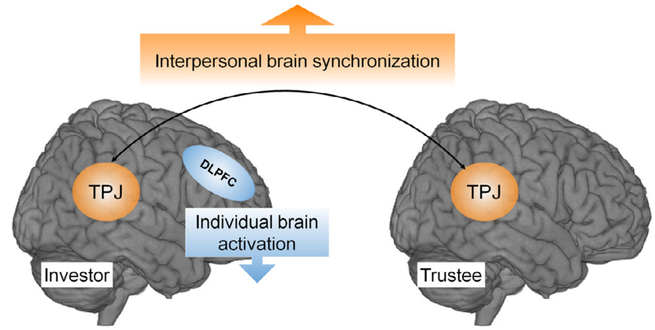

Fig. 4. A multi-brain model for trust in the low-high group. During trust development, as the investment ratio increases, investor-trustee brain synchronization at the right temporal junction (rTPJ) enhanced, while brain activation at the right dorsolateral prefrontal cortex (rDLPFC) in investors decreased.

individuals. In our study, the increased trend of IBS was observed most prominently in the low-high group, which indicated that the social status relationship is a key factor that shapes the alignment of neural processes between the investor and trustee. A trustee with high status is considered skillful or reliable (Kilpatrick et al., 2007), which may enhance a relatively low-status investor’s willingness to cooperate during an interaction. Thus, the increasing trend of IBS underlying trust dynamics may reflect enhanced social connections or real-time information transfer between the investor and trustee in the low-high group during dynamic interactions.

While the IBS increased, we found a decreasing trend of brain activation in the rDLPFC (CH22) in the investor of the low-high group as the number of rounds increased. The DLPFC participates in numerous mental functions involving cognitive control and plays a specific role in the process of general decision-making (Fecteau et al., 2007; Fleck et al., 2006; Knoch et al., 2006; Wout et al., 2005). Specifically, the rDLPFC may be involved in the regulation of the amount of information necessary to reach a decision and the regulation of the speed/rate of data collection (Cho et al., 2010). Continuous theta burst stimulation (cTBS)-induced modulation of cortical excitability of the rDLPFC has been shown to reduce impulsive decision-making (Cho et al., 2012, 2010). Thus, the decreasing trend of rDLPFC activity observed in the current study may reflect a decrease in the effort of toward calculation and control during the economic exchange. In other words, during trust development, individuals might rely less on brain areas involved in the common process of decision-making. This finding is consistent with several studies from other fields. For example, individuals showed decreased brain activation of the PFC after being trained in tasks that require working memory (Landau et al., 2004; Milham et al., 2003; Sayala et al., 2006).

The present brain activity findings suggest a neural mechanistic model of trust that is specific to the low-high group (**Fig. 4**). That is, during the trust interaction, the neural network changes included two aspects: decreased brain activation in brain areas (i.e., the rDLPFC) that are commonly involved in decision-making or value evaluation processes and increased interpersonal connectivity (i.e., IBS) in brain areas (i.e., the rTPJ) related to theory of mind. The down-regulation of DLPFC and increased interpersonal brain synchronization of TPJ with the trustee in the investor might reflect a re-configuration of brain processing: when interacting with a higher-status trustee, the investor’s decision-making or value evaluation is deemed to be more efficient with more resources allocated to the theory of mind. The transformation of neural systems may start in the early stage of trust development, as we observed a significant prediction of investment performance by IBS at Rounds 2 and 4 (**Fig. 3C**) before trust reached a stable level (see **Figure S1** in Supplementary Material). Although brain activation also predicted investment performance, two-brain data (i.e., IBS) provided earlier predictions than did single-brain data (i.e., brain activation of the investor).

These findings highlight the key role of information flow between brains during social interactions, and the initial consensus between the interacting individuals may be achieved during this time. Consensus may reflect a shared understanding between investor and trustee, which has been linked with IBS in previous study (Hirsch et al., 2021). It is worth noting that we did not observe such an effect in the high-high group, despite the inclusion of a high-status trustee in that group, which suggested that the relative social status rather than the social status of the trustee or the investor matters. However, more evidence is needed to verify the brain model.

Several limitations of this study should be addressed. First, in our study, the status of the investor was not constant throughout the different conditions. Future studies might include groups containing middle-status investors/trustees to better understand the effect of social status. Second, manipulation of social status was checked after the trust game rather than right after the status-inducing task, so that the rating reflects the influences of both the manipulation and trust tasks. To mitigate this issue, we randomized both groups and the participant roles, albeit we could not completely exclude the potential impact of the trust task or the carry-over effects from the math performance feedback. Third, we used the economic game (i.e., the trust game) to capture interpersonal trust. Additional studies are needed to determine whether the effect can be replicated in other situations that involve interpersonal trust. Finally, the brain ROIs in the current study only included the PFC and rTPJ. Thus, it is possible that other participant groups would exhibit significant behavior-related brain activity in other brain regions.

In summary, the present study extended the field by examining the effect of social status on the temporal change of trust during interaction apart from the initial trust and characterizing real-time trust interaction via a “two-person neuroscience” approach. We found interaction process did modulate the effect of social status on trust—individuals trust more in a low-status trustee initially and exhibit increased tendency of trust in a higher-status trustee during the interaction. The increasing trend of investment in the low-high group during the interaction was accompanied by an increase in IBS at the rTPJ and a decrease in brain activation of the rDLPFC. These findings improve our understanding of how social status modulates trust. Our study also exemplifies the hyperscanning approach to examine the effect of human economic exchanges. Future studies may investigate neural signatures underlying trust dynamics from a developmental perspective and explore the observed effects in individuals with a social deficit, such as autism spectrum disorder.

Declaration of competing interest

The authors declare no conflict of interest.

Data and code availability

The Data needed to evaluate the conclusions in the paper are present in the paper, Supplementary Materials, and/or the OSF repository (https://osf.io/a2cqh/). Further inquiries can be directed to the corresponding authors.

Credit authorship contribution statement

Xiaojun Cheng: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Yujiao Zhu:** Data curation, Visualization. **Yinying Hu:** Data curation. **Xiaolin Zhou:** Conceptualization. **Yafeng Pan:** Conceptualization, Methodology, Validation, Writing – review & editing. **Yi Hu:** Conceptualization, Supervision, Writing – review & editing.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2021.118777.

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