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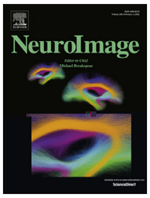

# Integration of social status and trust through interpersonal brain synchronization

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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

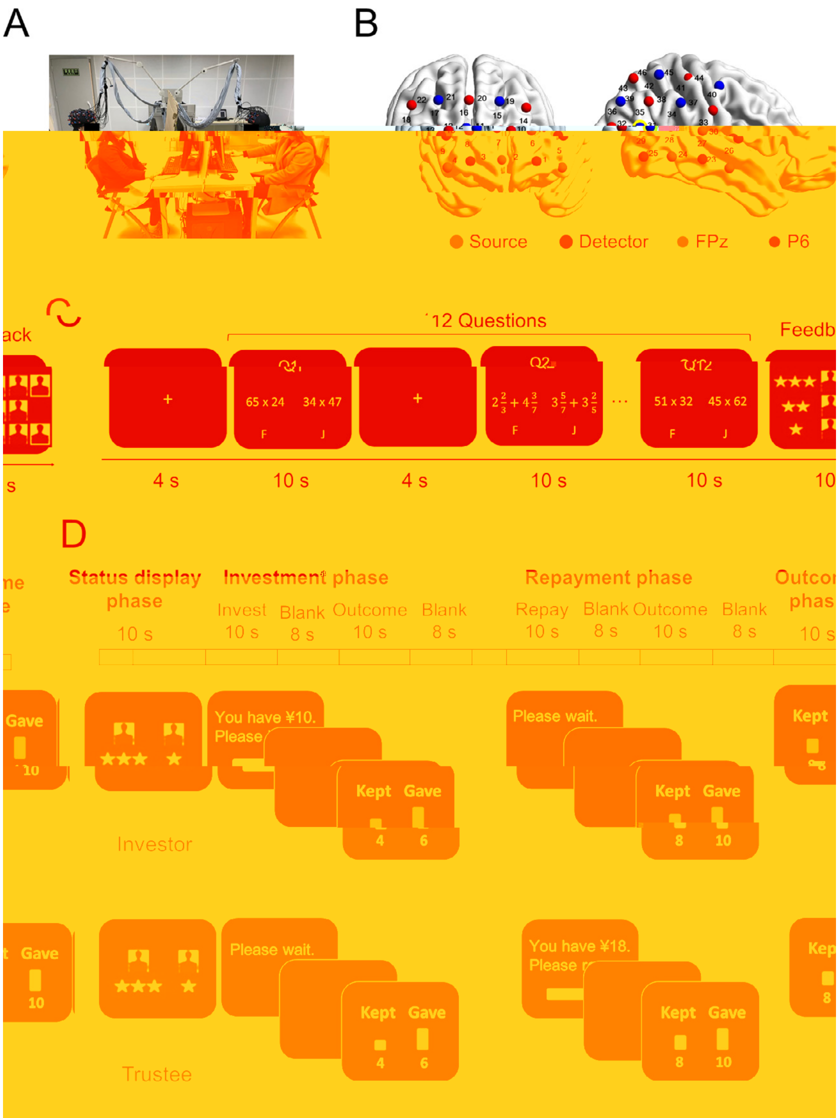

**Fig. 1.** Experimental design and task procedures. (A) Experimental setup. (B) Probe configuration. The integers on the cerebral cortex indicate the recording channels (CHs). The BrainNet Viewer toolbox was used to visualize the locations of the CHs (Xia et al., 2013). (C) The math competition task. 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 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 $\eta^2$ = 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 $\eta^2$ = 0.067, partners' star-ranking, $F$ (1, 96) = 5.44, $p$ = 0.022, partial $\eta^2$ = 0.054, and the interaction of both star rankings, $F$ (1, 96) = 8.59, $p$ = 0.004, partial $\eta^2$ = 0.082. Further analysis showed that when participants received

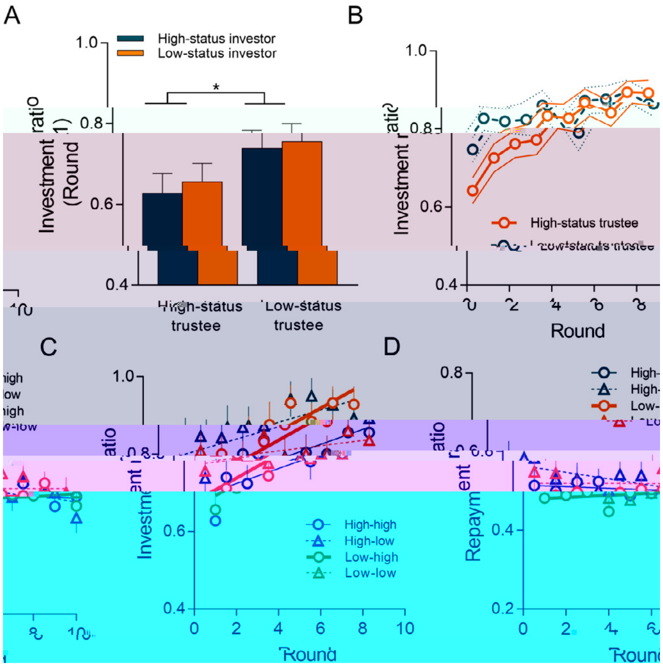

**Fig. 2.** Behavioral performance. (A) In the initial trust phase (i.e., Round 1), investors gave more money in the trust game when paired with low-status trustees. (B) The

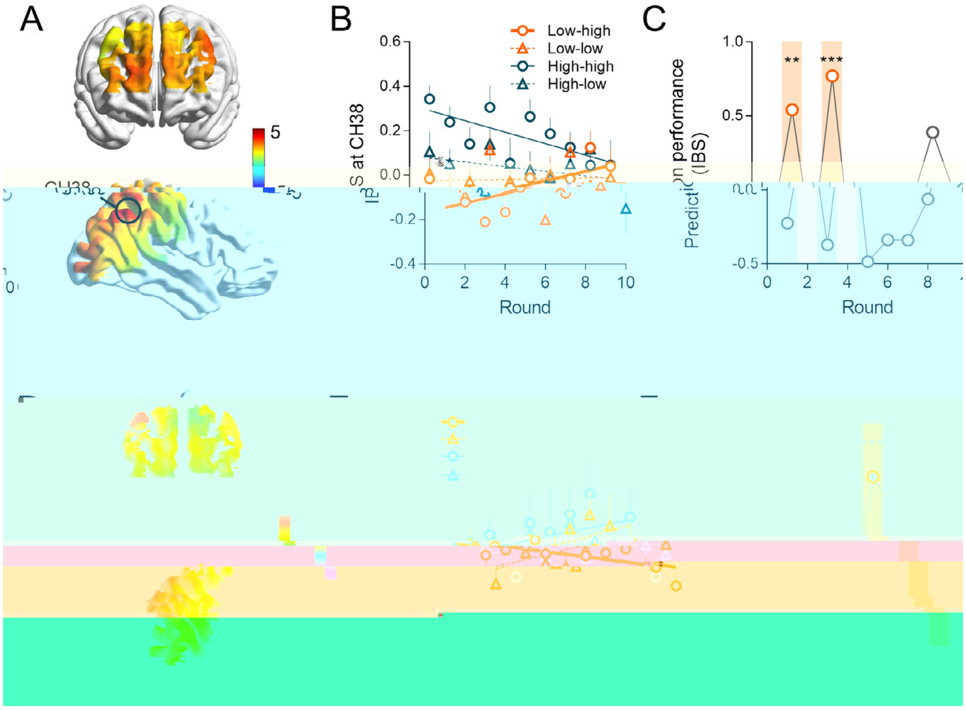

**Fig. 3.** fNIRS data. (A) *T*-value maps of task-related IBS (IBS during task minus IBS during rest) during trust interaction. (B) The task-related IBS at CH38 for the four groups as the number of rounds increased. (C) The prediction of the investment ratio based on task-related IBS in the low-high 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., $r_{task} - r_{rest}$) 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

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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