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Interpersonal neural synchronization could predict the outcome of mate choice

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ABSTRACT

Although mate choice is crucial for adults, its neural basis remains elusive. In the current study, we combined the functional near-infrared spectroscopy (fNIRS)-based hyperscanning and speed-dating to investigate the inter-brain mechanism of mate choice. Each participant was paired with two opposite-sex partners (participants) in separate speed-dating sessions and was asked to decide whether to engage in a further relationship with the paired partner after each session. The physical attraction of the daters was rated by their partners at the beginning of the dating whereas the social attraction was rated after the dating. Interpersonal neural synchronization (INS) at the dorsolateral prefrontal cortex during speed-dating rather than reading task predicts the outcome of mate choice. Moreover, social attraction rather than physical attraction affects INS during speed-dating. These findings demonstrate for the first time that INS predicts the outcome of mate choice of interacting daters in ecologically valid settings during their initial romantic encounter.

1. Introduction

Mate choice is a fundamental process of species evolution (Darwin, 1871). Humans choose their mates by rejecting some potential candidates while accepting or soliciting others (Crawford and Krebs, 2013). Many factors can influence mate choice. Among them, physical attraction and social attraction of potential partners, which are the two dimensions of interpersonal attraction concerning with “the judgment of whether people ‘like’ another or whether people feel good in another’s presence” (Berscheid and Hatfield, 1969; McCroskey and McCain, 1974), play important roles in determining whether the potential partners will be chosen. The effect of physical attraction refers to the fact that one with attractive physical appearance would be preferred in mate choice (Janz et al, 2015; Luo and Zhang, 2009; Todd et al., 2007). Social attraction is based on social considerations, such as social status (Katsena and Dimdins, 2015), perceived similarity with oneself (Tidwell et al., 2013), etc. Social attraction of potential partners can motivate individuals to establish social associations with their partners and further sustain the associations in future (Edles and Appelrouth, 2015; Hogg, 1992).

In addition, neuroimaging studies examined the neural correlates of mate choice–the insula, paracingulate cortex, and prefrontal cortex were identified as crucial brain regions of mate choice under relatively unnatural settings (Turk et al., 2004; Cartmell et al., 2014; Cooper, Dunne, Furey and O’Doherty, 2012). For instance, participants were asked to make their mate choice from a set of opposite-sex face photos rather than partners in real life (Funayama et al., 2012; Turk et al., 2004; Cartmell et al., 2014). Since a successful date usually begins with a mutual choice, mate choice contains social interactions that involve two individuals acting upon each other via inter-individual correlations of behavior and neural activity (Hari et al, 2015; Koike et al., 2015). Such a complex mutual interaction cannot be reduced to the summation of effects in single isolated brains. Previous neuroimaging studies have not adequately addressed the question of how two brains interact with each

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other during the ecologically valid dating process. In this study, we took advantage of the functional near-infrared spectroscopy (fNIRS)-based hyperscanning technique, which used fNIRS to record two-brain activity simultaneously during mate choice, to investigate the inter-brain neural mechanism underlying mate choice.

The interpersonal neural synchronization (INS), which computes the correlation between the hemodynamic signals of two brains, has been observed in many successful interactions, including joint action (Funane et al., 2011), and verbal or emotional understanding (Liu et al., 2017; Anders et al., 2011). Especially, the INS emerged between romantic couples when they conducted gestural communication or held hands during pain administration (Goldstein et al., 2018; Schippers et al., 2010). A previous EEG-based hyperscanning study (Kinreich et al., 2017) observed an INS between romantic couples, but not between strangers, when male-female dyads talked about a plan to spend a fun day together, suggesting that the relationship between interacting daters could affect the inter-brain neural activity. However, little is known about whether potential romantic relationships affect the inter-brain neural activity during initial romantic interactions.

In the current study, we aimed to investigate the inter-brain neural activity (i.e., INS) of mate choice as well as the relationship between INS and interpersonal physical and social attraction under natural settings. Speed-dating was used as the venue for initial romantic interaction (Finkel and Eastwick, 2008). During speed-dating, men and women rotated to meet and interact with each other over a brief period (5 min), during which their brain activities at the prefrontal cortex were measured by fNIRS. After the interaction, they were required to decide whether they wanted to engage in future dates with the partners. If both daters made a positive choice, the experimenter would send each other's contact information to the daters after the experiment. In the current study, we also included a non-social control condition in which participants simply read popular sciences without communicating with each other. We hypothesized that INS generated by initial romantic interaction would appear between couples with mutual positive decisions during speed-dating and could predict the outcome of mate choice. Moreover, participants' ratings on potential partners' physical attraction (in pre-event Questionnaire) and social attraction (in post-event Questionnaire) were recorded. The possible relationship between interpersonal attraction and INS was examined.

2. Materials and methods

2.1. Participants

Seventy-six single, heterosexual college students (38 male and 38 female, M_{age} = 22.5 years, SD_{age} = 2.5 years) who wanted to find a couple participated in the experiment (more details of age and education level are in *supplementary materials*). Written informed consent which contained video recording permission was obtained from each participant before the experiment. Participants were each paid 40 yuan after the experiment. The study was carried out in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of East China Normal University.

2.2. Experimental procedures

Overview: A total of 19 speed-dating events were conducted. For each event, there were four participants, two men and two women. Each event consisted of two sessions: DateI and DateII. In the first session, each pair was instructed to complete two tasks: speed-dating and reading. Then two male participants switched their seats, and the second session with the same tasks was completed.

Procedure: Upon arrival, each participant received a tag showing their assigned participant ID. They were not allowed to talk to each other, although they could see each other. Then they were instructed to find their seats, which were marked with participant ID numbers. Each pair (i.e., 1 man and 1 woman) was seated face-to-face in relaxed gestures. There was a folding screen between the two pairs to avoid visual interference from the other pair during interaction (Fig. 1A). One experimenter briefly explained the procedures and asked the participants to complete the pre-event questionnaire regarding physical attraction of the opposite-sex participants on a 7-point scale (1 = not attractive at all, 7 = very attractive). After completing the questionnaire, experimenters attached the fNIRS cap to the participants' heads, checked and adjusted signal levels, initiated fNIRS data acquisition, and then Date I started. The pairs of participants were instructed to perform a reading task and speed-dating, the order of which was counterbalanced across the groups. Before each task, a 30-s rest was taken as the baseline for later fNIRS data analysis, during which participants were asked to close their eyes and sit still. At the end of the speed-dating, the participants were asked to complete a printed social attraction questionnaire (McCroskey et al., 2006) containing 12 items (e.g., "I think she/he can get into my social circle") with a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). They were also asked in the questionnaire whether they wanted to request a future date. If both interacting participants responded with "Yes", contact information would be exchanged through the experimenter within 48 h after the experiment. After completing the two tasks, the two male participants swapped their seats, and Date II began with the same procedure after the device has been recalibrated. The whole process was video recorded.

Speed-dating task: Each speed-dating session lasted 5 min. A bell signaled the beginning and the end of each session. During speed-dating, each pair of participants could talk about any topics, and the discourse content was not stipulated (Fig. 1B).

Reading task: This control task also lasted 5 min. Each pair took turns to read aloud a scientific article sentence-by-sentence, and the male participant always read the first sentence.

2.3. fNIRS data acquisition

The fNIRS signals were acquired at a sampling rate of 10Hz by NIRS system (ETG-7100, Hitachi Medical Corporation, Japan). A 3 × 5 probe patch (3 cm distances between emitter probes and detector probes) was placed over the frontal area of each participant. The placement of the patch followed the international 10–20 system. The middle optode of the lowest row of probe was placed on the frontal pole midline point (FPz as the reference site), and the middle column of the probe was aligned with the sagittal reference curve (Fig. 1C). The locations of the optodes and channels on the head were obtained by a 3D magnetic digitizer system after the experiment was completed, which measured the placement of each optode and channel relative to five reference points on the participant's head (nasion, left and right preauricular points, vertex, and inion).

We measured the relative changes of absorbed near-infrared light at two wavelengths of 695 nm and 830 nm. These changes were transformed into the relative concentration changes of oxygenated hemoglobin (Hbo), deoxygenated hemoglobin (Hbr) and total hemoglobin using a modified Beer-Lambert law, allowing measurement of brain activity.

3. Data analysis

3.1. Date outcomes at the individual level

The data consists of two observations on each of 76 participants yielding 152 observations in total. A binary logistic multilevel (mixed-effects) model was constructed using IBM SPSS Statistics 25 to measure the effect of interpersonal attraction ratings on future date decision with social attraction ratings and physical attraction ratings as fixed effects and group as well as dyad and participant ID as random factors.

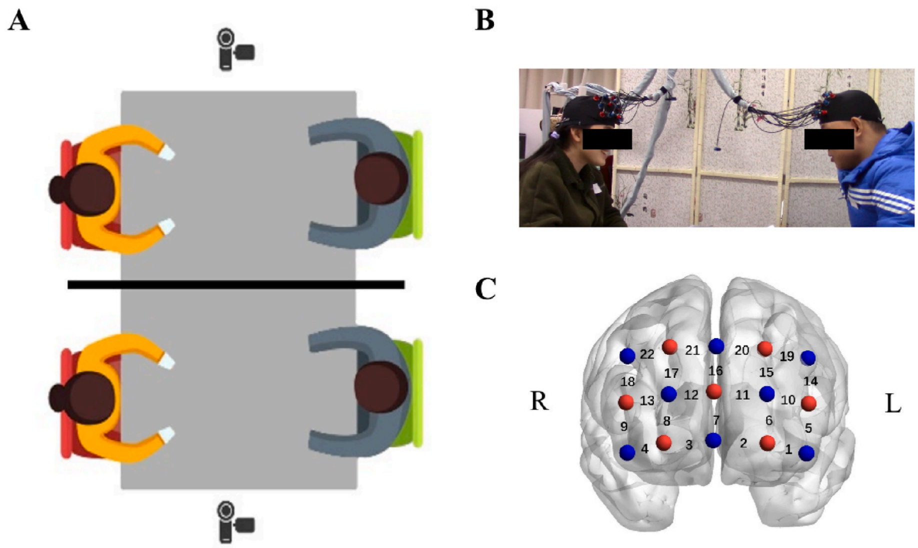

Fig. 1. Experimental Setup. (A) The sitting positions of the four participants. Each pair of the participants was seated face-to-face, with a folding screen placed between the pairs. Two cameras recorded each pair's behaviors during the experiment. (B) One dyad conducted speed-dating. (C) Cap configuration. The fNIRS data were simultaneously recorded in the prefrontal region of each participant. The placement of probes was based on the international 10–20 system. Red circles represent emitters; blue circles represent detectors. The numbers in black represent the measured channels. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Date outcomes at the dyad level

Based on the date decision questionnaire after each session, dyads were divided into two groups: (1) successful date group, in which both paired participants answered "yes" to the question (i.e., "Yes-Yes"); and (2) unsuccessful date group, in which one participant in a dyad answered "yes" to the question and the other answered "no" (i.e., "Yes-No"). The group of dates in which both paired participants answered "no" was not included in data analysis because there were only 6 dyads within this group.

Interpersonal neural synchronization: Since Hbo signal is more sensitive to the changes in cerebral blood flow than Hbr signal (Hoshi, 2003) is, only Hbo time series were analyzed (Cheng et al., 2015; Pan et al., 2017; Dai et al., 2018). No filtering or detrending procedures were applied during preprocessing (Cui et al., 2012).

Wavelet coherence (WTC) MatLab package (provided by Grinsted et al., 2004, http://noc.ac.uk/using-science/crosswavelet-wavelet-coherence) was used to compute the wavelet coherence of two time series on the same channel from two brains, which measures the synchronous activity between the two brains (i.e., interpersonal neural synchronization, INS; Grinsted et al., 2004; Murphy et al., 2009). The Morlet wavelet was used for the WTC method. The bad channels that did not show normal signals in the time-frequency image generated during WTC analysis were excluded from analysis (1.8% of the recorded channels for the reading task were excluded, 1.24% of channels for speed-dating were excluded). A frequency band between 0.56 Hz (period 1.8 s) and 0.31 Hz (period 3.2 s) was identified by visual inspection where the coherence was higher during speed-dating task than that during rest period for successful date group based on the time-frequency image. Because the participants needed time to get into the steady state, we deleted the first 10 s from the rest period. We calculated the coherence value on time-averaged and frequency-averaged data during each task block (5 min) and during the rest period (20 s). The task-related INS is defined as the averaged coherence value in each task block minus the averaged coherence value in the rest block. The values of INS were converted into z-scores by Fisher z-statistics prior to any statistical tests (Chang and Glover, 2010; Cui et al., 2012). To identify the channels showed task-related INS that to be used in the logistic model, we first examined the significant INS during speed-dating and reading, separately, for all dyads ($N = 76$). To this end, the one-sample *t*-test was performed for each channel with false discovery rate (FDR) correction (Benjamini-Hochberg procedure, Benjamini and Hochberg, 1995). Then a binary logistic multilevel (mixed-effects) model was fitted to predict the date outcome (i.e., successful date or unsuccessful date) with task (speed-dating vs. reading), channel, INS, task × INS, channel × INS, and task × channel × INS as fixed effects and group as the random factor. The "No–No" dyads were not included in the model.

The interpersonal attraction rating and INS: To examine the relationship between interpersonal attraction and INS, we firstly reduced the two dependent data points of interpersonal attraction ratings within each participant to one by calculating the difference score of social attraction rating and physical attraction rating. For each participant (e.g., FEMALE1), we calculated the difference between social/physical attraction rating of each participant to the other two opposite-sex daters (i.e., difference of social/physical attraction). We also calculated the difference between the INSs obtained by each participant and his/her two opposite-sex daters respectively (i.e., difference of INS). Fig. 2 shows an example of the difference scores regarding "FEMALE1". The way of using the difference of behavioral data and difference of INS to examine the behavior-INS relation is appropriate for the hierarchical data structure in the current study and has been used in other hyperscanning studies (Cheng et al., 2015; Pan et al., 2017). The data consists of 65 observations of data, that is, four observations in each group, and eleven different scores were excluded because they were obtained from

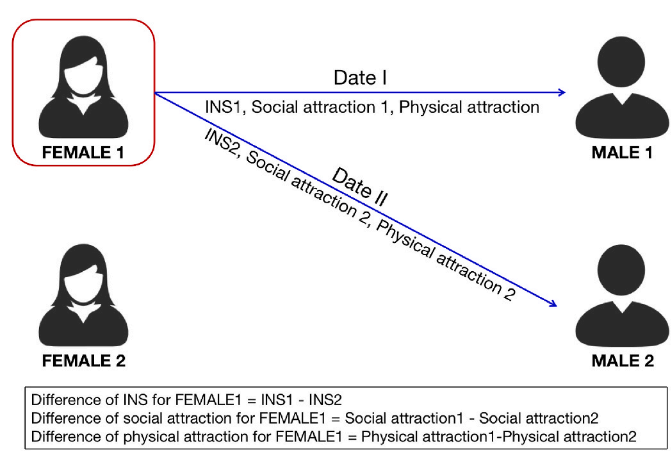

Fig. 2. The relation between the interpersonal attraction rating and INS. In this example, FEMALE1 was regarded as the target participant. The "Social attraction1-Social attraction2" and "Physical attraction1-Physical attraction2" were predictors in the mixed linear regression model to predict "INS1-INS2". The difference scores were also calculated for FEMALE2, MALE1, and MALE2.

"No–No" dyads. Then, a mixed-effects linear regression model was used to measure the effects of difference of interpersonal attraction rating on difference of INS. The model was fitted with the difference of physical attraction and difference of social attraction as fixed effects, and group as a random factor.

4. Results

Based on participant's future date decision in the post-event questionnaire, 45 participants accepted both of their assigned opposite-sex daters; 16 participants rejected both of their assigned opposite-sex daters; 15 participants accepted only one opposite-sex dater out of the two. From 76 pairs in total, 35 successful dates (SD) and 35 unsuccessful dates (USD) were identified.

4.1. Interpersonal attraction and future date decision

In the mixed effects binary logistic model, social attraction rating was a significant predictor for the future date decision (β = 0.12, F (1,149) = 17.55, $p < 0.001$). However, physical attraction rating could not significantly predict the future date decision (β = 0.35, F (1,149) = 2.58, p = 0.110). See Fig. 3.

4.2. Interpersonal neural synchronization of mutual mate choice

During the 5-min speed-dating task, dyads (N = 76) showed significant INS (relative to zero) at channel 3 (M = 0.029, SD = 0.076, t (75) = 3.275, p_{corr} = 0.022, ES = 0.376) located at orbitofrontal area, as well as CH13 (M = 0.025, SD = 0.077, t (74) = 2.866, p_{corr} = 0.0367, ES = 0.325), CH17 (M = 0.033, SD = 0.082, t (73) = 3.463, p_{corr} = 0.022, ES = 0.402), and channel 21 (M = 0.028, SD = 0.091, t (72) = 2.672, p_{corr} = 0.050, ES = 0.308) located at the right dorsolateral prefrontal area (Fig. 4A). Moreover, during the 5-min reading task, dyads (N = 76) only showed significant INS at Channel 22 located at the right dorsolateral prefrontal area (M = 0.041, SD = 0.088, t (75) = 4.124, p_{corr} = 0.002, ES = 0.466, Fig. 4B).

To examine whether INS could predict the date outcome, we conducted a binary logistic multilevel (mixed-effects) model with task (speed-dating and reading), channel (CH3, CH13, CH17, CH21, and CH22), INS, task × INS, channel × INS, and task × channel × INS as fixed effects and group as the random factor. There was no significant main effect of task (F (1,676) = 0.062, p = 0.803), channel (F (4,676) = 0.342, p = 0.850), and INS (F (1,676) = 1.625, p = 0.203). There was no significant two-way interaction effect of task × 0.20 (F (1,676) = 0.197, p = 0.657) and channel × INS (F (4,676) = 0.812, p = 0.517), either. However, the three-way interaction effect of task × channel × INS was significant (F (4,676) = 2.502, p = 0.041). Especially, INS at CH21 during speed-dating rather than reading could predict the date outcome (β = 10.764, SE = 4.047, t = 2.660, p = 0.008). These findings suggested that INS at the right dorsolateral prefrontal area (CH21) during speed-dating could discriminate the date outcome.

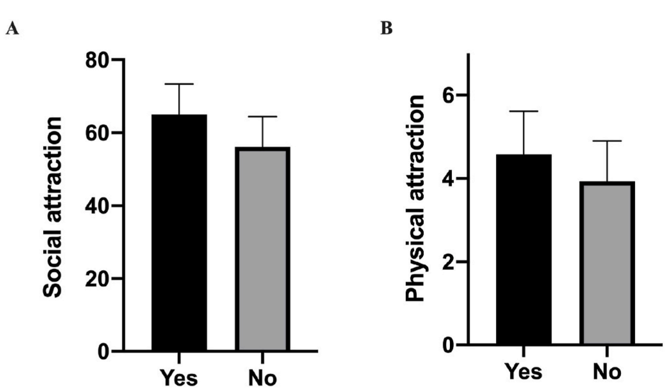

Fig. 3. Social attraction and physical attraction rating after speed-dating. (A) Social attraction rating for different future date decisions. (B) Physical attraction rating for different future date decisions. The error bars indicate the standard deviations.

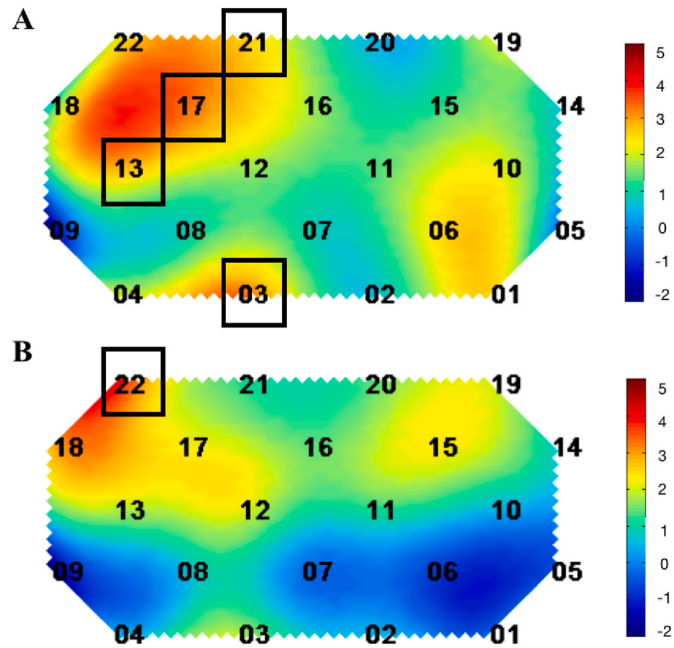

Fig. 4. Interpersonal neural synchronization. (A) t-map for all dyads (N = 76) during speed-dating. (B) t-map for all dyads (N = 76) during the reading task.

4.3. Interpersonal attraction and INS

Mixed-effects linear regression model was used to measure the effect of interpersonal attraction ratings on INS during speed-dating. The difference of social attraction was a significant predictor for difference of INS at CH21, β = 0.007, F (1,56) = 21.37, $p < 0.001$, Fig. 5A. However, the difference of physical attraction could not significantly predict difference of INS at CH21 during speed-dating, β = 0.001, F (1,56) = 0.007, p = 0.934, Fig. 5B. These results showed that social attraction, rather than physical attraction could predict interpersonal neural synchronization during speed-dating. In addition, the Spearman correlation analysis showed a significant positive correlation between the difference of social attraction and the difference of physical attraction, r = 0.298, p = 0.016.

5. Discussion

In the current study, we used the fNIRS-based hyperscanning technique to explore the neural basis of mate choice during speed-dating under a natural condition. Interpersonal neural synchronization (INS) at the dorsolateral prefrontal cortex (DLPFC) during speed-dating rather than reading task predicts the outcome of mate choice. Moreover, we found that social attraction, rather than physical attraction could predict INS during the initial encounter. These findings extend our understanding of the neural basis of mate choice with a high-level ecological validity.

Kinreich et al. (2017) observed the neural synchronization at temporal-parietal regions when romantic dyads, instead of stranger dyads, conducted verbal communications. Our findings extended the previous findings by showing that not only existing romantic relationships but also potential romantic relationships influence inter-brain synchronization. In the current study, we only focused on the INS at the prefrontal cortex and identified the DLPFC as a key region for mate choice in potential romantic relationships. The neural synchronization

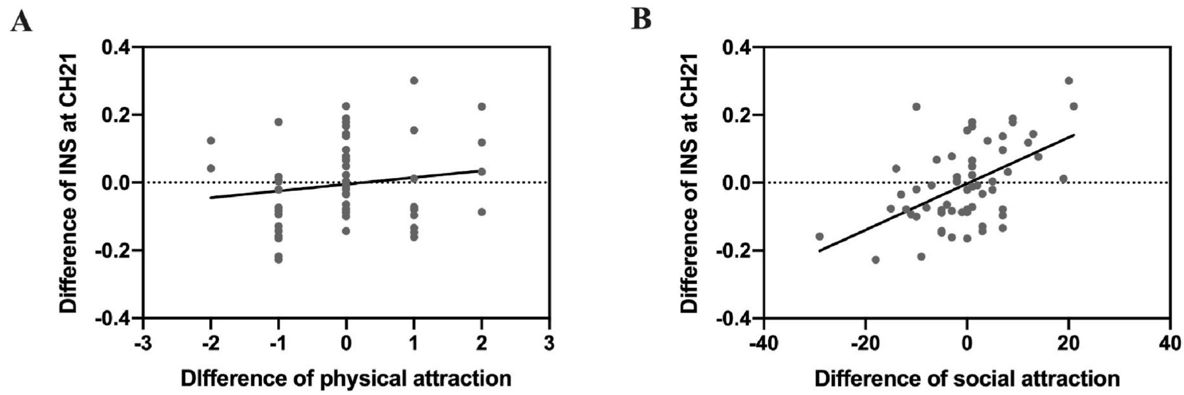

Fig. 5. Scatter plots indicate (A) the relationship between the difference of social attraction and difference of INS at CH21, and (B) the relationship between the difference of physical attraction and difference of INS at CH21.

at the DLPFC has been found in previous social interaction studies. For example, it emerged with a time lag between a speaker and a listener during successful verbal communication, and the listener's brain activity preceded the speaker's brain activity (Stephens et al., 2010). It has also been found in a bonded group during an out-group attack (Yang et al., 2020). In the current study, INS emerged at the DLPFC offers support for the bonding between potential lovers during their verbal communication.

Interpersonal attraction has been well demonstrated to be an important determinant of successful date (Eastwick et al., 2014; Lundy et al., 2010; Cotton et al., 2006). However, in the current study, social attraction rating rather than physical attraction rating influenced one's future date decision. In our study, speed-dating was conducted in a natural setting. Compared to previous studies in which the participants could only see photos of their partners, participants in our study had the opportunity to interact with their partners face-to-face during which they could dynamically receive and update social information from each other. It is not strange that social attraction outweighed physical attraction in initial romantic interaction, explaining why "love grows over time". However, our results did not negate the importance of physical attraction during mate choice. In the previous speed-dating studies, a dating event usually included more than 20 participants (Valentine et al., 2014; Luo and Zhang, 2009). In the present study, only four participants were included in an event. The effect of physical attraction on mate choice in our study might be relatively too small to reach a significant level. Moreover, we used difference of interpersonal attraction and difference of INS to examine the effect of interpersonal attraction on INS, which allowed us to reduce the dimension of data to meet the independent assumption. Such a method might underestimate the inter-individual differences and the effect of physical attraction on INS.

Moreover, the current study found that social attraction significantly predicted INS at the DLPFC during initial romantic interaction. In the previous studies, INS has been widely proved to be correlated with interpersonal indicators. For example, the strength of speaker-listener coupling during verbal communication was highly correlated with the level of understanding (Stephens et al., 2010). The strength of oscillatory coupling between couples during romantic kissing was reliably correlated with partner-oriented kissing satisfaction (Muller and Lindenberger, 2014). The neural synchronization between lovers during cooperation was correlated with their cooperation performance (Pan et al., 2017). The correlation between INS and social attraction in our study highlights the relation between INS at DLFPC and social interactions.

Limitations need to be noted for this study. First, "No–No" dyads were not analyzed in the current study due to insufficient sample size. Second, the patch only covered the prefrontal cortex in the current study because of the restriction on the number of optode probes. Subcortical brain structures which are also closely related to mate choice such as the amygdala and insula (Cartmell et al., 2014) cannot be measured by fNIRS. The role of these brain structures during dating needs to be studied using other approaches. Third, our ecologically valid settings sacrificed the control of environmental variables to some extent. The screen between two pairs in each group could not prevent audio interference from each other pair during interaction although we checked the video to ensure that each participant focused on the partner instead of others.

To conclude, our findings demonstrate that INS could be a neural marker to predict the outcome of mate choice and shed light on the importance of social attraction during the dynamic initial encounter.

Credit author statement

Xianchun Li, Di Yuan and Yanmei Wang designed research; Di Yuan and Danyang Feng performed research; Xianchun Li, Di Yuan, Ruqian Zhan and Jieqiong Liu analyzed data; Xianchun Li, Di Yuan and Xiaolin Zhou wrote the paper; and all the authors edited the paper.

Declaration of competing interest

The authors declare no competing interests.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2021.108112.

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