



## Your smiles inspired my smiles: the interpersonal neural coupling of positive emotion contagion during social interactions

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### ABSTRACT

Emotional contagion refers a process that by which the emotions of a perceiver become more similar to those of others as a result of exposure to these emotions. The present study investigated the behavioral and interpersonal neural coupling mechanisms underlying positive emotional contagion. We recruited forty-six stranger dyads and created an emotional contagion task using the fNIRS-based hyper-scanning technique to track brain activities of interactive partners (the sender, the perceiver), examining brain regions such as the prefrontal cortex and temporo-parietal junction, which are parts of the cognitive control and mirroring brain networks. In each dyad, the senders were demanded to watch positive/neutral clips or imitate the actor's non-emotional facial actions, the perceivers were demanded to observe the senders' positive/neutral facial expressions or non-emotional facial movements passively. Results revealed that interactive partners exhibited more synchronous facial expressions, higher interpersonal brain synchronizations (IBS) associated with the mirror neuron system (IFG, SMG) and the cognitive control system (DLPFC) and reported more positive emotions in the positive condition than neural condition or facial movements condition, indicating positive emotional contagion has occurred. Furthermore, the perceiver's self-rated valence scores positively mediated the relationship between facial expression synchrony and IBS of mirror neuron system between dyads ( $IFG\_TRI_{sender} - left\_SMG_{perceiver}$ ). Our findings revealed that automatic mimicry of other's positive emotional expressions (indicating by facial expression synchronization) might be one of the mechanisms responsible for the contagion of positive emotions among strangers. We discussed the evolutionary benefits of positive emotional contagion adhering to an automatic mimicry process.

### 1. Introduction

On a sunny afternoon, you find yourself lying on the grass in the park, basking in the warmth of the sun. Around you, children play with carefree joy, their laughter ringing through the air. As you watch their bright smiles and playful energy, a smile tugs at the corners of your own mouth. Unknowingly, you've caught their happiness. This is emotional contagion—others' emotional feelings infect you, making you experience similar feelings. Emotional contagion refers the process by which

the emotions of a perceiver become more similar to those of others as a result of exposure to these emotions (Hatfield et al., 1993; Goldenberg and Gross, 2020). Emotion contagion was regarded as one of three interconnected levels of social alignment (Shamay-Tsoory et al., 2019).

Emotion contagion has been shown to occur via at least three mechanisms (e.g., Goldenberg and Gross, 2020; Parkinson, 2020). The first is automatic mimicry, in which an emotional expression (facial expressions, vocal expressions, postures, movements) activates synchronous behavior on the part of the perceiver, this feedback then elicits

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the perceiver's corresponding emotional state (Oliveros et al., 2025; Prochazkova and Kret, 2017; Paz et al., 2022). Emotion contagion initiated by facial mimicry is an automatic process. The second mechanism is category activation, in which exposure to the sender's emotional expressions primes an emotion category, which in turn leads to activation of the perceiver's specific emotional states (e.g., Goldenberg and Gross, 2020). Category activation is differentiated from mimicry because it does not necessarily involve behavioral copying of an emotional expression. Finally, the third mechanism is social appraisal, in which the perceiver uses the emotions of the sender as a guide for his/her own emotion appraisals, leading to synchronous emotional states (e.g., Parkinson, 2011, 2020). In contrast to facial mimicry, social appraisal is a conscious assessment of the sender's facial expression to grasp the emotional meaning of these situations (Bruder et al., 2014; Parkinson, 2011). If social appraisal is the reason to evoke emotion contagion, the type of social connection between senders and perceivers seems to affect emotional contagion. The probability of emotion contagion is higher in close relationships (e.g., close friends, family members) than in a nonaffiliated relationship (e.g., strangers) (Lin et al., 2024). There is no consensus in the literature that emotion contagion is a replicative process automatically (automatic mimicry) or appraisal process related to cognitive control consciously (category activation or social appraisal). Furthermore, it still remains unknown observing what kind of facial movement of the sender could evoke the perceiver's facial mimicry or facial movement synchrony, then evoking a similar corresponding emotional state (i.e., emotion contagion). We suggest that only observing the sender's emotional expressions could trigger the perceiver's automatic mimicry, over which the perceivers have little or no control which would be associated with the interactive partner's facial expression synchrony and interpersonal brain synchrony in the corresponding neural circuit, resulting in emotional contagion. Therefore, one of the main purposes of the present study was to investigate this assumption.

The mechanisms of emotional contagion might differ when triggered by positive versus negative emotions, or basic emotions versus social emotions. For example, the sender expressing negative emotion (e.g., anger) may not evoke the same feeling in the receiver, who might be expected to display fear or submission (Dezecache et al., 2015). The contagion of positive emotion among strangers was more important to the human's evolution to boost positive/cooperative relationship, to acquire new skills or to obtain more survival resources (e.g., the availability of food, potential mates, or safe shelters). Recent research identified the adaptive function of positive emotional contagion (especially the contagion of basic positive emotions, e.g., joy) and highlighted its pivotal role in social learning and environmental adaptation (Brosnan and Knapska, 2024). Positive emotion contagion has been characterized in animal models, synchronous cheerful tails in rodents might be the sign of positive emotional contagion (Brosnan and Knapska, 2024). Considering the evolutionary benefits of positive emotional contagion, we suspected the basic positive emotional contagion more likely to be a replicative process, that is the perceiver's emotional state is always the same as that experienced by the sender, however, the contagion of negative emotion (e.g., anger) was a more complicated process which depends on the personality of the individuals involved, the nature of their relationship (e.g., ingroup members vs. outgroup members), and the context of their interaction. Automatic mimicry of the senders' positive emotional expressions, accompanied with positive facial expression synchrony might be the main mechanism responsible for the contagion of positive emotions. Therefore, the first aim of the present study is to explore the mechanism of basic positive emotional contagion during face-to-face interaction of stranger dyads, specifically, what factor (the sender's positive facial expressions vs. the sender's non-emotional facial movements) could trigger the perceiver's automatic mimicry, then lead to positive emotional contagion (the perceiver's similar positive emotion with the sender's) among stranger dyads.

Until now, we have limited knowledge regarding the neural mechanisms of positive emotional contagion. The available data on the interpersonal neural coupling of positive emotional contagion are still scarce. In addition, it is important to point out that most of the available studies regarding emotional contagion employed experimental tasks in which participants viewed visual emotional stimuli (emotional faces, emotional pictures or short videos) to investigate whether participants' emotions aligned with the emotional intensity of the stimuli (e.g., Harada et al., 2016; Kastendieck et al., 2021; Kuang et al., 2021; Nummenmaa et al., 2012; Pelowski et al., 2018;). These studies mainly focused on the single-person brain of the perceiver and revealed a co-occurrence between emotional contagion and mimicry but not a causal relationship. However, in real life, as a typical social interaction, emotional contagion involved in two communicators (the sender, and the perceiver), it is reasonable to assume that traditional single-person experimental/neuroimaging paradigms may not adequately reveal the interactive neural dynamics involved in positive emotional contagion. Recently, researchers proposed a social alignment model that viewed synchronized movement, emotional contagion, and social conformity as interrelated processes that relied on shared neural networks (Shamay-Tsoory et al., 2019). According to the 'second-person neuroscience' approach, the hyperscanning technique could be used to explore how the core systems of emotion contagion may be coupled between multiple brains (De Felice et al., 2025; Schilbach et al., 2013; Shamay-Tsoory et al., 2019). Some researchers have employed pseudo-hyper-scanning techniques to closely examine the neural mechanisms of interpersonal emotional contagion (e.g., Anders et al., 2020; Smirnov et al., 2019). In these studies, the senders' emotional behaviors were pre-recorded and later presented to the perceivers. This methodology essentially involves the perceivers engaging in pseudo-interaction with "the sender on the screen," which still lacks proximity to the actual process of emotional contagion that occurs in real social interactions. This further underscores the necessity of introducing multi-brain neuroscience approaches, such as hyper-scanning, which can simultaneously record neural signals from two-person brains in the research of emotional contagion. Researchers viewed interpersonal neural coupling - the synchronization of brain signals during social exchanges - as the phase alignment of the neural activities across individuals, which may also associate with interpersonal cognitive, emotional, and motor alignments and facilitate efficient interbrain information transfer across multiple individuals (Lu and Hao, 2024; Pan et al., 2023; Reindl et al., 2024). Therefore, to address the gaps in previous research, another aim of the present study is to explore the interpersonal neural coupling patterns of the contagion of positive emotion using hyper-scanning technology in a more realistic face-to-face interpersonal emotional contagion task.

In the present study, we focus on these key brain networks involved in emotional contagion: the mirror neuron system (e.g., the visual cortex, the inferior frontal gyrus, IFG; the supramarginal gyrus, SMG; the primary somatosensory cortex, PSC), which was critical for observing and imitating other's emotional expressions, might be closely related with emotional empathy (Harada et al., 2016; Imai et al., 2023; Prochazkova and Kert, 2017; Schmidt et al., 2021; Zhao et al., 2023); the executive control and mentalizing system (e.g., the dorsolateral prefrontal cortex, DLPFC; the temporoparietal junction, TPJ), which was involved in differentiating self from others, understanding of other's emotional states, misalignment detection, alignment execution, might be associated with cognitive empathy or cognitive control (Avnor et al., 2025; Gan et al., 2024; Lois et al., 2024; Shamay-Tsoory et al., 2019; Tei et al., 2020; Xu et al., 2023). When the emotional sender and the emotional perceiver showed higher emotional similarity - a mark of emotional contagion, the similarity between neural states (interpersonal brain synchrony) located in above these brain networks might be evoked (Smirnov et al., 2019).

As a capacity to be affected by and share the emotional state of another; assess the reasons for the other's mental state; and infer with

the other, adopting his or her perspective, empathy is closely associated with emotion contagion (De Waal and Preston, 2017; Paz et al., 2022; Nitschke and Bartz, 2023; Nummenmaa et al., 2008). Empathy can be split into two different types, emotional empathy, and cognitive empathy (De Waal and Preston, 2017; Paz et al., 2022). Emotional empathy is considered more primitive, described as the tendency to simulate/mirror others' sensory, motor, physiological and emotional states (Drimalla et al., 2019; Olszanowski et al., 2020; Nitschke and Bartz, 2023). Cognitive empathy involves perspective-taking and cognitive monitoring processes that allow us to relate to other people's emotions, thoughts, and intentions (Nitschke and Bartz, 2023; Paz et al., 2022). Emotional empathy engages brain areas involved with self-other mirroring and affective processing, such as the anterior cingulate cortex, somatosensory cortex, inferior frontal gyrus (e.g., Abramson et al., 2020; De Waal and Preston, 2017). On the other hand, cognitive empathy will engage brain areas involved in executive, working memory, and visuo-spatial processes, such as the dorsolateral region of the prefrontal cortex and temporoparietal junction and temporal pole (Abramson et al., 2020; De Waal and Preston, 2017; Paz et al., 2022). Some researchers considered automatic mimicry as a synonym of emotional empathy (Drimalla et al., 2019; Ma et al., 2024; Paz et al., 2022), and cognitive empathy was conceptually linked with emotion recognition and emotion understanding of others (e.g., Abramson et al., 2020; Drimalla et al., 2019). To sum up, in our study, we speculated that the interpersonal brain synchronization of the brain networks related to emotional empathy (e.g., MNS, the visual cortex, the IFG; the primary somatosensory cortex, PSC) was enhanced during positive emotional contagion, then automatic mimicry might be the main mechanism responsible for positive emotional contagion. On the other hand, if the contagion of positive emotions triggered the increased interpersonal brain synchronization of the brain regions related to cognitive empathy (e.g., TPJ, dlPFC), the cognitive control or mentalizing brain network related to category activation or social appraisal might be the mechanism of positive emotional contagion.

In summary, the present study aimed to reveal the mental and interpersonal neural coupling substrates underlying positive emotional contagion during face-to-face interactions among stranger dyads using the functional near-infrared spectroscopy system. The first purpose of our study is to examine what characteristic of the sender's face (positive facial expressions vs. non-emotional facial movements) would evoke the perceiver's automatic facial mimicry and whether the perceiver's automatic facial mimicry would be associated with the contagion of positive emotions between interactive partners. Is automatic mimicry confined to facial expression or does it extend to non-emotional facial movements? The second purpose of the present study is to reveal the neural coupling mechanism underlying the contagion of positive emotion, to investigate the mental mechanism of positive emotional contagion through locating the targeted brain networks (emotional empathy/automatic mimicry vs. cognitive empathy/cognitive control).

To do so, we recruited forty-six stranger dyads to complete an emotion contagion task, combined with a new dual-brain fNIRS paradigm, to simultaneously scan the brain activities of the sender (whose positive emotions were induced by watching a positive video) and the perceiver (who observed the sender's positive facial expressions) during face-to-face interactions. For each stranger dyad, one participant was designated as the sender, the other person was assigned as the perceiver. We manipulated three experimental conditions: observing the sender's positive facial expression, observing the sender's neutral expression and observing the sender's non-emotional facial movements. In observing positive (neutral) expression condition, the senders were asked to watch a positive (neutral) video and express their positive (neutral) facial expressions as possible as they can, the perceivers were demanded to observe the senders' positive (neutral) facial expressions. In observing facial movements condition, the sender was asked to imitate a video actor's facial movements that were non-related to facial expressions, the perceivers were demanded to observe the senders' facial movements

passively. This experimental condition was manipulated to examine whether automatic mimicry could be triggered by observing other's non-emotional facial movements, and to explore the possible behavioral and neural mechanisms differences between observing senders' facial actions unrelated to emotions and observing senders' positive facial expressions. Observing neutral expression condition was designed as a control condition to reveal the unique behavioral and neural correlates of positive emotional contagion. We hypothesized that, (1) Observing the senders' positive facial expression could evoke the perceiver's automatic mimicry and the similar emotional states with the sender (i.e., the contagion of positive emotions), specifically, both the sender and perceiver's positive emotions were increased and they expressed more positive facial expressions. (2) Contagion of positive emotions between interactive partners might enhance IBS at brain regions involving in the mirror neuron system (related to mimicry/emotional empathy) (e.g., IFG, SMG, STS, the visual cortex), or the mentalizing system/executive control system (related to emotion recognition/cognitive empathy) (e.g., TPJ, dlPFC). (3) We hypothesize that automatic mimicry is associated with synchronization of facial expressions, which would be accompanied with the similarity in emotional states between the sender and the perceiver and the enhanced IBS patterns between partners at relevant brain regions.

## 2. Method

### 2.1. Participants

A power analysis was conducted using G\*Power 3.1 (Faul et al., 2007) for a within-subjects design. The analysis was based on a repeated-measures ANOVA (within subject design), with one within-subject factor (Condition: observing positive expressions, observing neutral expressions, and observing facial movements). This analysis indicated that 43 pairs of participants would be required to achieve a power of 0.95 ( $f = 0.25$ ,  $\alpha = 0.05$ ). The present study recruited 55 stranger dyads of university students (110 participants,  $M_{\text{age}} \pm SD_{\text{age}} = 21.54 \pm 2.24$ ), including 12 male dyads and 43 female dyads. For each dyad, one participant was randomly assigned to be the emotional sender, and the other person was designated as the emotional perceiver. The emotional sender and perceiver in each pair were strangers and of the same gender. To control for potential confounding variables related to gender differences in emotional contagion, only same-gender dyads were recruited. Nine dyads were excluded due to poor signal quality in the functional near-infrared spectroscopy (fNIRS) data, characterized by an excessive number of bad channels (more than half of the channels had poor signals). The final sample included 46 dyads ( $M_{\text{age}} \pm SD_{\text{age}} = 21.39 \pm 2.20$ ; 10 male pairs and 36 female pairs). All participants had normal or corrected-to-normal vision, were heterosexual, and had no history of psychiatric disorders. Informed consent was obtained from all the participants before the start of the experiment. The study protocol was approved by the University Committee on Human Research Protection of Local University.

### 2.2. Experimental design

The present study employed a within-subjects design with task type as the independent variable, consisting of three conditions: (1) neutral expression condition: the sender watches a neutral video and displays neutral facial expressions; (2) positive expression condition: the sender watches a positive emotion video and displays positive facial expressions; (3) facial movements condition: the sender imitates the facial movements of an actor as instructed by the video. In all three experimental conditions, in each dyad, the perceiver's task was to observe the sender's facial expressions (positive/neutral) or facial movements attentively. The non-emotional facial movements and the neutral expression conditions were set to ascertain the perceiver's automatic mimicry was triggered by the sender's spontaneous positive facial

expressions rather than the sender’s non-emotional facial movements or social cues (human partner’s face), thereby identifying the critical factor that underlies positive emotional contagion.

2.3. Experimental material

We manipulated three experimental conditions: (1) neutral expression condition, (2) positive expression condition, (3) facial movements condition. Each experimental condition was consisted of two blocks, with each block containing one video clip. In total, six video clips (each 3 min duration) were used, i.e., there were six blocks, corresponding to six clips, with two same types of clips in each experimental condition.

2.3.1. Emotional videos

The positive and neutral video materials were selected from online comedy videos and handmade craft tutorial videos, respectively. A total of 43 university students were recruited (18 males,  $M_{age} = 20.38, SD_{age} = 1.68$ ; 25 females,  $M_{age} = 19.78, SD_{age} = 2.23$ ). Participants rated the emotional valence, emotional arousal, and familiarity of ten videos (five neutral and five positive) on a 9-point scale. Ultimately, two positive and two neutral videos were selected as experimental materials in the formal experiment. The selecting and rating methods for the materials are detailed in the supplementary materials (See S1; Table S2). A paired-sample *t*-test was conducted on the valence and arousal scores of the selected positive and neutral videos. The results showed that the valence of the positive videos ( $M_{valence} \pm SD_{valence} = 7.167 \pm 1.224$ ) was significantly higher than that of the neutral videos ( $M_{valence} \pm SD_{valence}$

$= 5.033 \pm 0.876$ ),  $t_{(42)} = 9.492, p < 0.001$ , Cohen’s  $d = 2.005$ . The arousal of the positive videos ( $M_{arousal} \pm SD_{arousal} = 6.547 \pm 1.467$ ) was also significantly higher than that of the neutral videos ( $M_{arousal} \pm SD_{arousal} = 2.779 \pm 1.109$ ),  $t_{(42)} = 13.572, p < 0.001$ , Cohen’s  $d = 2.898$ .

2.3.2. Facial movements videos

As for the facial action videos, we recruited two college students majoring in performing arts (one male and one female, both aged 22) to generate the facial movement clips. Each actor was demanded to pose 9 facial actions unrelated to facial expressions, such as opening the mouth, squinting both eyes, making the “e” sound, or forming an “o” shape with the mouth, resulting in a total of 18 facial actions (9 produced by the male actor, 9 made by the female actor).

Two facial movement clips were created by varying the duration of each facial action (3 s, 6 s, 9 s or 12 s) and the duration of intervals among facial actions. During each interval between two facial actions, a neutral face of the actor would appear (also lasting 3 s, 6 s, 9 s or 12 s), with subtitles and voice prompts instructing the sender to “Please wait”. Each clip was consisted of 9 facial actions and each clip last 3 min. The sender was requested to imitate each facial movement of the actor in the video. Subtitles and voice prompts accompanied each facial action, instructing the sender to perform the corresponding action, such as “Please make an O-shaped mouth”. Fig. 1B shows screenshots from the facial action videos of the two actors. Forty-three university students were recruited to rate these facial movement clips’ emotional valence and arousal on a 9-point scale. The mean valence of these two clips was  $4.16 \pm 0.89$ , the mean arousal of these two clips was  $2.38 \pm 1.05$ ,

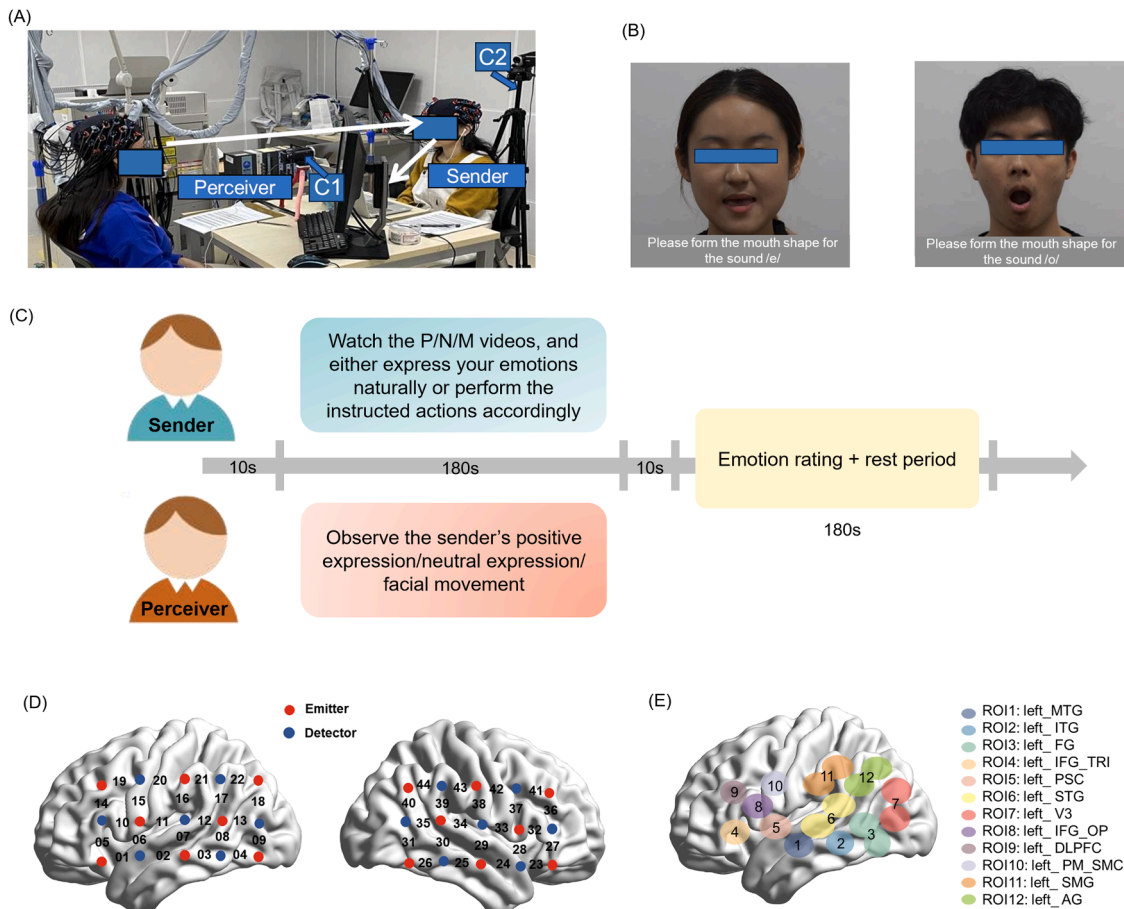


Fig. 1. (A) Laboratory Setup; the sender’s facial expressions were captured by camera C1, while camera C2 recorded the perceiver’s facial expressions. (B) Screenshots from the facial movement clips. (C) An example experimental procedure of a single block. “P” represents positive expression condition; “N” represents neutral expression condition; “M” represents facial movement condition; (D) Placement of the optical plates. (E) Region of interest brain regions (left hemispheres were shown in the figure).

indicating these two facial action clips were neutral.

### 2.3.3. Emotion rating scale

The emotional state was assessed using the Self-Assessment Manikin (SAM) scale (Bradley and Lang, 1994). Participants rated their emotional valence and arousal respectively using the SAM scale on a 9-point scale (valence, 1 = very unpleasant, 9 = very pleasant; arousal, 1 = very calm, 9 = very excited).

## 2.4. Experimental procedure

The emotional senders in each dyad were required to complete a practice session the day before the formal experiment to ensure they could display these facial actions instructed by the actor correctly. Two trained experimenters judged the quality of the senders' producing these facial actions to ensure that they could perform these facial actions without conveying any emotions correctively.

Upon arrival in the lab, the sender and perceiver sat facing each other approximately 1.5 m apart, with an angle of 180 degrees between them. A computer was placed in front of the emotional sender to play the clips and to present the experimental instructions, while another computer was positioned at the right front of the emotional perceiver to display experimental instructions. During the video-viewing phase, the sender focused on the screen and was instructed to immerse themselves in the video content. Meanwhile, the perceiver could clearly observe the sender's facial expressions. Two video cameras were used to continuously record each dyad's facial expressions throughout the experiment (see Fig. 1A).

### 2.4.1. The emotional sender and perceiver's task

In each dyad, the sender was instructed to watch three types of video clips (positive, neutral, and facial movements). The senders were asked to immerse themselves in the video content when they watched video clips. If they experienced any emotions during viewing, they should express them as fully as possible through their facial expressions. At the same time, the emotional perceivers were required to carefully observe their partner's facial expressions or facial actions, and to respond with their natural expressions. The sequence of these six video clips (two positive, two neutral and two facial movements) were counterbalanced among different dyads.

After viewing each clip, both the emotional sender and the emotional perceiver rated their valence and arousal, followed by a quiet rest period with eyes closed. The combined duration of the self-rating period and rest period totaled 3 min. Then the next block began. The experiment consisted of six blocks, with two blocks for each experimental condition. Each block lasted for 6 min and 20 s.

## 2.5. fNIRS data acquisition and preprocessing

Data collection was conducted in a near-infrared laboratory using the NIRS system (ETG-7100, Hitachi Medical). Two wavelengths of near-infrared light, 695 nm and 830 nm, were employed, with a sampling rate of 10 Hz. The fNIRS data were collected using two  $3 \times 5$  optical plate, each included 22 channels (CH). Each optical plate was positioned at the frontal-temporal-parietal junction, with one placed on the left hemisphere and the other on the right (see Fig. 1D). To determine the correspondence between channels and brain regions, we applied virtual spatial registration to estimate the MNI (Montreal Neurological Institute) coordinates of each channel (Singh et al., 2005; Tsuzuki et al., 2007). The MNI coordinates of all channels are provided in the supplementary material (Table S1). Based on these coordinates, the 44 channels (22 from each hemisphere) were grouped into 24 regions of interest (ROIs), with 12 ROIs for each hemisphere. A channel was assigned to a given ROI if >70 % of its location overlapped with that anatomical region. The detailed channel-to-ROI correspondence is shown in Table S1. When multiple channels were assigned to the same

ROI, their signals were averaged to represent the activity of that region (Oni et al., 2023; Shader et al., 2021). The spatial distribution of the resulting ROIs is illustrated in Fig. 1E.

The preprocessing of fNIRS data was performed using MATLAB 2023b (The MathWorks). HbO signals were adopted as indicators of neural activity in this study. Principal component spatial filtering algorithm was applied to remove global components from the raw fNIRS data of each participant (Zhang et al., 2016). This method exploits the spatial distribution of signals across channels to differentiate global (systemic) from local (neuronal) components. Additionally, a correlation-based signal enhancement method was utilized to eliminate motion artifacts (Cui et al., 2010; Pan et al., 2018). This approach relies on the physiological principle that oxygenated (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) signals are typically strongly negatively correlated during neural activity. Head motion disrupts this correlation, often leading to spurious positive correlations. CBSI corrects for these artifacts by adjusting the oxy-Hb and deoxy-Hb signals to restore a strong negative correlation, thereby suppressing motion-induced noise. These methods have been shown to be effective in reducing global noise in fNIRS signals (Li et al., 2025; Int-Veen et al., 2025), and have been widely adopted in recent hyperscanning research.

Data from the six blocks were used for further analysis of interpersonal brain synchronization (IBS). To obtain stable data during the task phases, the initial and final 10 s of data for each task phase were removed, retaining 160 s of data for each task phase, resulting in a total of 320 s for each experimental condition. The wavelet transform coherence (WTC) was then employed to assess the relationship between the corresponding HbO time series of each pair of participants (i.e., IBS). Then, the values of interpersonal brain synchronization (IBS) were transformed using Fisher's r-to-z transformation to enhance the normality of data distribution (Simony et al., 2016).

## 2.6. Facial expression recording and preprocessing

Throughout the whole experiment, two high-definition cameras were used to record each dyad's facial expressions. After the experiment, two trained raters who were blind to our experimental purpose were recruited to independently code the video data frame by frame (per second) at a temporal resolution of one frame per second. Each frame was evaluated for the presence (1) or absence (0) of facial expressions based on predefined coding criteria. Inter-rater reliability was high, with the Cohen's Kappa coefficient between two raters was 0.981 ( $p < 0.001$ ), indicating the inter-rater reliability was satisfactory.

To ensure the time alignment between the facial expression data and the fNIRS data, the initial and final 10 s of each video (immediately following task onset and prior to task termination) were excluded from analysis. This resulted in 2 min and 40 s (i.e., 160 s or 160 frames) of valid data per experimental block. For each experimental condition, data from two blocks were merged, yielding 320 frames of each experimental condition for final analysis. In the positive expression condition, the presence of positive facial expressions (e.g., smiling, laughing) was coded as 1, and the absence of positive expressions was coded as 0. In the neutral expression and facial movement conditions, any observable facial movements - regardless of emotional valence (e.g., brow raise, lip movement, eye blink) - was coded as 1, and the absence of these movements was coded as 0. Based on each rater's coding results, we determined synchronous expression frames as follows: if both the sender and the perceiver in a dyad displayed facial expressions within a frame (1 s), then the frame was coded as 1 (synchronized facial expressions); otherwise, it was coded as 0 (non-synchronized facial expressions). This binary outcome (synchronized = 1; not synchronized = 0) formed the basis for calculating the expression synchronization rate (ESR).

The ESR scores for each experimental condition were computed as the number of synchronized frames divided by the total number of frames (320). Inter-rater reliability for the ESR scores derived from the two raters' coding was substantial (Cohen's Kappa = 0.644,  $p < 0.001$ ).

The final ESR scores for each dyad in each condition were obtained by averaging these two raters' scores respectively. To allow for comparability across experimental conditions, raw ESR scores were standardized using Z-score transformation (i.e., converting values to a distribution with a mean of 0 and a standard deviation of 1). These standardized ESR values (denoted as ESR) were used in all subsequent analyses to index the facial expressions synchronization of interactive partners.

## 2.7. Statistical analysis plan

### 2.7.1. The sender and perceiver's emotional state before the experiment

Two paired samples *t*-tests were conducted on the senders and perceivers' emotional valence and arousal rating scores prior to the formal experiment to ensure each dyad was in neutral emotional states before the formal experiment.

### 2.7.2. Self-reported emotion ratings of emotion sender and perceiver

The valence and arousal scores of emotional senders and perceivers were averaged across the two blocks within each experimental condition respectively. Then we employed linear mixed models (LMMs) using the "lme4" package in R (version 4.1.1) to analyze the data. A 3 (Condition: positive expression, facial movement, neutral expression)  $\times$  2 (Participant role: sender, perceiver) LMM analysis was conducted, with condition, participant role, and the interaction included as fixed effects, and participant group ID included as a random effect.

### 2.7.3. Facial expression synchronization rate

The expression synchronization rate (ESR) between each dyad was also analyzed using linear mixed model (LMM), with experimental condition as a fixed effect and participant group ID as a random effect.

### 2.7.4. Neural coupling analysis

Linear mixed models (LMMs) were applied with condition as a fixed factor to analyze interpersonal brain synchronization (IBS) in each of the 24  $\times$  24 regions of interest (ROIs) across the full frequency range (0.015–0.7 Hz). Frequencies above 0.7 Hz were excluded to eliminate high-frequency noise, such as cardiac activity (0.8–2.5 Hz). The LMM generated *p*-values for each frequency within the full range across all 24  $\times$  24 ROIs. All *p*-values were adjusted using the False Discovery Rate (FDR) method with a significance threshold of  $p < 0.05$ . If the *p*-values of IBS for the same channel pair at multiple frequencies were all significant after correction, for the simplicity, the IBS results at these frequencies were averaged before presentation. Post-hoc tests or simple effects analyses were Bonferroni-corrected.

### 2.7.5. Correlation analysis of emotion ratings, facial expression, and brain indicators

To reveal the multidimensional nature of emotional contagion, we examined whether neural, behavioral, and self-reported indicators of emotion contagion were interrelated. We examined whether emotional contagion was elicited at multi-modal levels, including interpersonal brain synchronization (IBS), facial expression synchronization rate (ESR), and the perceivers' self-reported emotional feelings. Therefore, a series of Pearson correlation analyses were conducted to examine the relationships among IBS, self-reported emotional ratings (perceiver's ratings, as an indicator of emotional contagion via subjective feelings), and ESR. All the *p*-values were corrected using the False Discovery Rate (FDR) method.

## 3. Results

### 3.1. The sender and perceiver's emotional state before the experiment

The emotional valence reported by the senders before the experiment was  $5.63 \pm 0.85$ , while that of the perceivers was  $5.85 \pm 0.94$ ,  $t_{(45)} = -1.14$ ,  $p = 0.26$ , Cohen's  $d = -0.242$ , indicating no significant

difference on emotional valence between emotional senders and perceivers. Similarly, there was no significant difference on emotional arousal scores between the senders ( $4.11 \pm 1.73$ ) and the perceivers ( $4.37 \pm 1.83$ ),  $t_{(45)} = -0.65$ ,  $p = 0.52$ , Cohen's  $d = -0.144$ . These results indicated that stranger dyads were in neutral emotional states.

### 3.2. The self-reported results of the emotional senders and perceivers

#### 3.2.1. Valence

The LMM results on the participants' self-reported valence scores showed a significant main effect of condition (see Fig. 2A),  $F_{(2, 230)} = 207.99$ ,  $p < 0.001$ , indicating that participants' self-evaluated valence scores were significantly more positive in the positive expression condition than in the facial movement condition ( $7.019$  vs.  $5.231$ ,  $b = 1.79$ ,  $t = 16.85$ ,  $p < 0.001$ ) and in the neutral expression condition ( $7.019$  vs.  $5.105$ ,  $b = 1.91$ ,  $t = 18.03$ ,  $p < 0.001$ ). There was no significant difference on participants' self-reported valence scores between in the facial movement and neutral expression conditions ( $5.231$  vs.  $5.105$ ,  $b = 0.13$ ,  $t = 1.18$ ,  $p > 0.05$ ). Additionally, there was a significant main effect of participant role,  $F_{(1, 230)} = 8.62$ ,  $p < 0.01$ , indicating that the senders reported more positive emotions than the perceivers ( $5.911$  vs.  $5.659$ ,  $b = 0.25$ ,  $t = 2.90$ ,  $p < 0.01$ ). The interaction effect between condition and participant role was not significant,  $F_{(2, 230)} = 2.62$ ,  $p = 0.075$ .

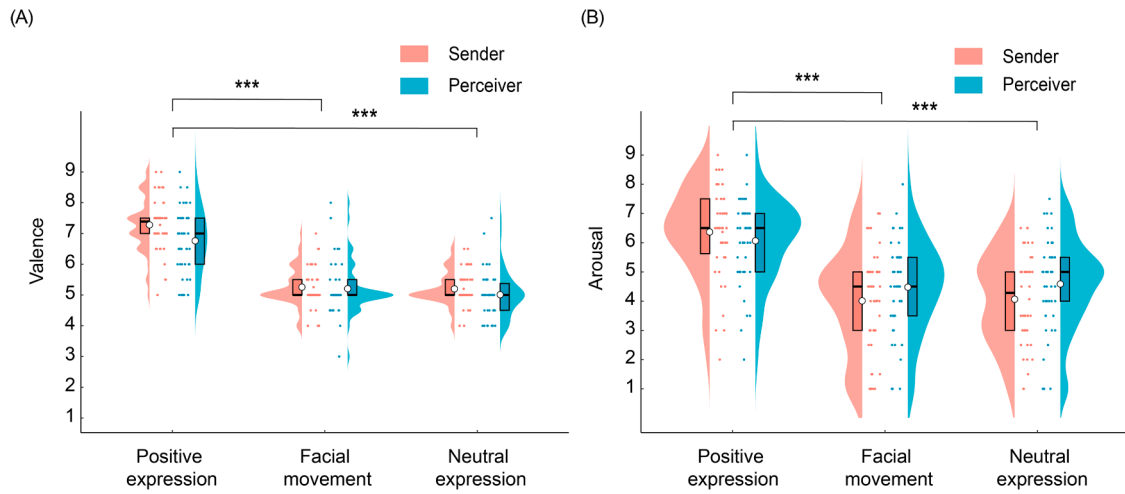
#### 3.2.2. Arousal

For emotional arousal scores rated by emotional senders and perceivers, the LMM results showed a significant main effect of condition (see Fig. 2B),  $F_{(2, 230)} = 63.26$ ,  $p < 0.001$ . Specifically, participants' self-rating arousal scores were significantly higher in the positive expression condition than in the facial movement condition ( $6.216$  vs.  $4.245$ ,  $b = 1.97$ ,  $t = 9.83$ ,  $p < 0.001$ ) and in the neutral expression condition ( $6.216$  vs.  $4.327$ ,  $b = 1.89$ ,  $t = 9.42$ ,  $p < 0.001$ ). There was no significant difference in arousal scores between in the facial movement condition and in the neutral expression condition ( $4.245$  vs.  $4.327$ ,  $b = -0.08$ ,  $t = -0.41$ ,  $p > 0.05$ ). Additionally, the main effect of participant role was not significant,  $F_{(1, 230)} = 1.99$ ,  $p > 0.05$ , with no significant difference in arousal ratings between senders and perceivers ( $4.815$  vs.  $5.043$ ,  $b = -0.23$ ,  $t = -1.40$ ,  $p > 0.05$ ). The interaction effect between conditions and participant role was not significant,  $F_{(2, 230)} = 2.69$ ,  $p = 0.070$ .

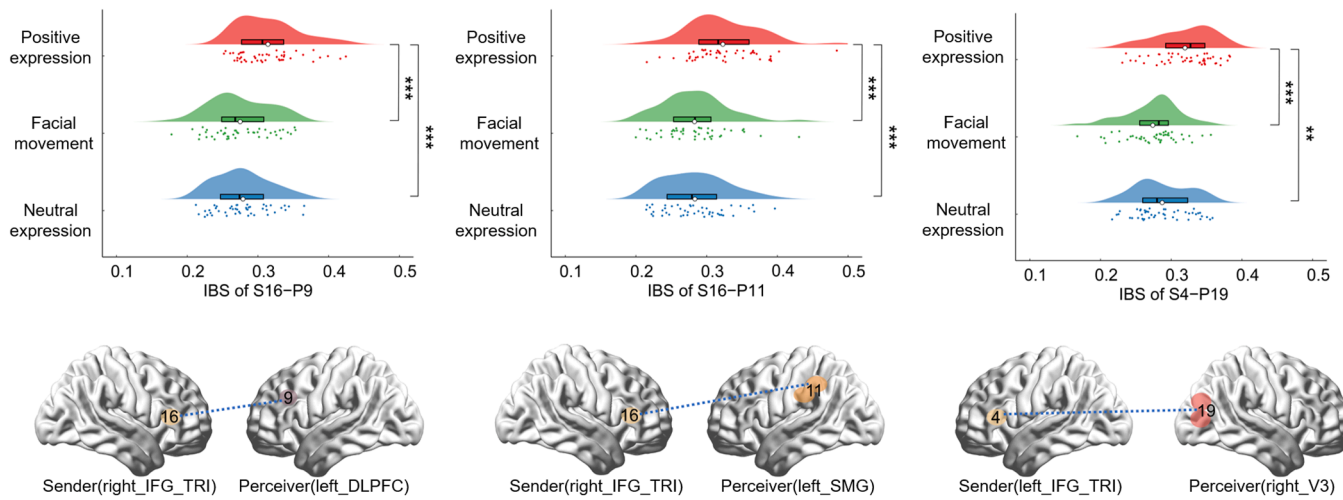
### 3.3. Interpersonal brain synchronization between the sender and the perceiver

As for the interpersonal brain synchronization (IBS), The LMM results on the IBS between the sender (right\_IFG\_TRI) and perceiver (left\_DLPFC) (IBS of S16-P9) at the frequency of 0.27HZ showed a significant main effect of condition (see Fig. 3, the left panel),  $F_{(2, 92)} = 13.51$ ,  $p < 0.001$ . Specifically, IBS of rIFG\_TRI<sub>sender</sub> - lDLPFC<sub>perceiver</sub> in the positive expression condition was significantly greater than in the facial movement condition ( $0.314$  vs.  $0.275$ ,  $b = 0.04$ ,  $t = 4.67$ ,  $p < 0.001$ ) and the neutral expression condition ( $0.314$  vs.  $0.278$ ,  $b = 0.04$ ,  $t = 4.19$ ,  $p < 0.001$ ). There was no significant difference on IBS of rIFG\_TRI<sub>sender</sub> - lDLPFC<sub>perceiver</sub> between in the facial movement condition and in the neutral condition ( $0.275$  vs.  $0.278$ ,  $b = -0.004$ ,  $t = -0.48$ ,  $p > 0.05$ ).

For the IBS of right\_IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub> (IBS of S16-P11) at the frequency of 0.27HZ, the LMM results showed a significant main effect of condition (see Fig. 3, the middle panel),  $F_{(2, 92)} = 12.80$ ,  $p < 0.001$ . Specifically, IBS of right\_IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub> in the positive condition was significantly greater than in the facial movement condition ( $0.323$  vs.  $0.283$ ,  $b = 0.04$ ,  $t = 4.36$ ,  $p < 0.001$ ) and in the neutral condition ( $0.323$  vs.  $0.283$ ,  $b = 0.04$ ,  $t = 4.30$ ,  $p < 0.001$ ). There was no significant difference on IBS of right\_IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub> between the facial movement condition and the neutral condition ( $0.283$  vs.  $0.283$ ,  $b = -0.001$ ,  $t = -0.06$ ,  $p > 0.05$ ).



**Fig. 2.** Dyad's self-reported of emotional states. (A) Self-reported of valences scores (B) Self-reported of arousal scores. Each jittered dot represents an individual participant's rating. Hollow circles indicate the group means. Violin plots depict the distribution of the data, with boxplots showing the interquartile range and the median. \*\*\* $p < 0.001$ .



**Fig. 3.** The significant IBS results of the sender and perceiver in three experimental conditions. Each jittered dot represents an individual participant's value. Hollow circles indicate the group means. The part of the graph resembling a “cloud” reflects the distribution of the data, with boxplots showing the interquartile range and the median. \*\*\* $p < 0.001$ , \*\* $p < 0.01$ . IFG\_TRI: Inferior frontal gyrus, pars triangularis; DLPFC: Dorsolateral prefrontal cortex; SMG: Supramarginal gyrus, part of Wernicke's area; V3: Visual area 3.

For the IBS of left\_IFG\_TRI<sub>sender</sub> - right V3<sub>perceiver</sub> (IBS of S4-P19) at the frequency of 0.24–0.29HZ, the LMM results showed a significant main effect of condition (see Fig. 3, the right panel),  $F(2, 92.04) = 15.27, p < 0.001$ . Specifically, IBS of left\_IFG\_TRI<sub>sender</sub> - right V3<sub>perceiver</sub> in the positive expression condition was significantly greater than that of in the facial movement condition (0.319 vs. 0.268,  $b = 0.05, t = 5.41, p < 0.001$ ) and in the neutral condition (0.319 vs. 0.287,  $b = 0.03, t = 3.39, p < 0.01$ ). There was no significant difference on IBS of these regions in the facial movement condition and in the neutral condition (0.268 vs. 0.287,  $b = -0.02, t = -2.02, p > 0.05$ ).

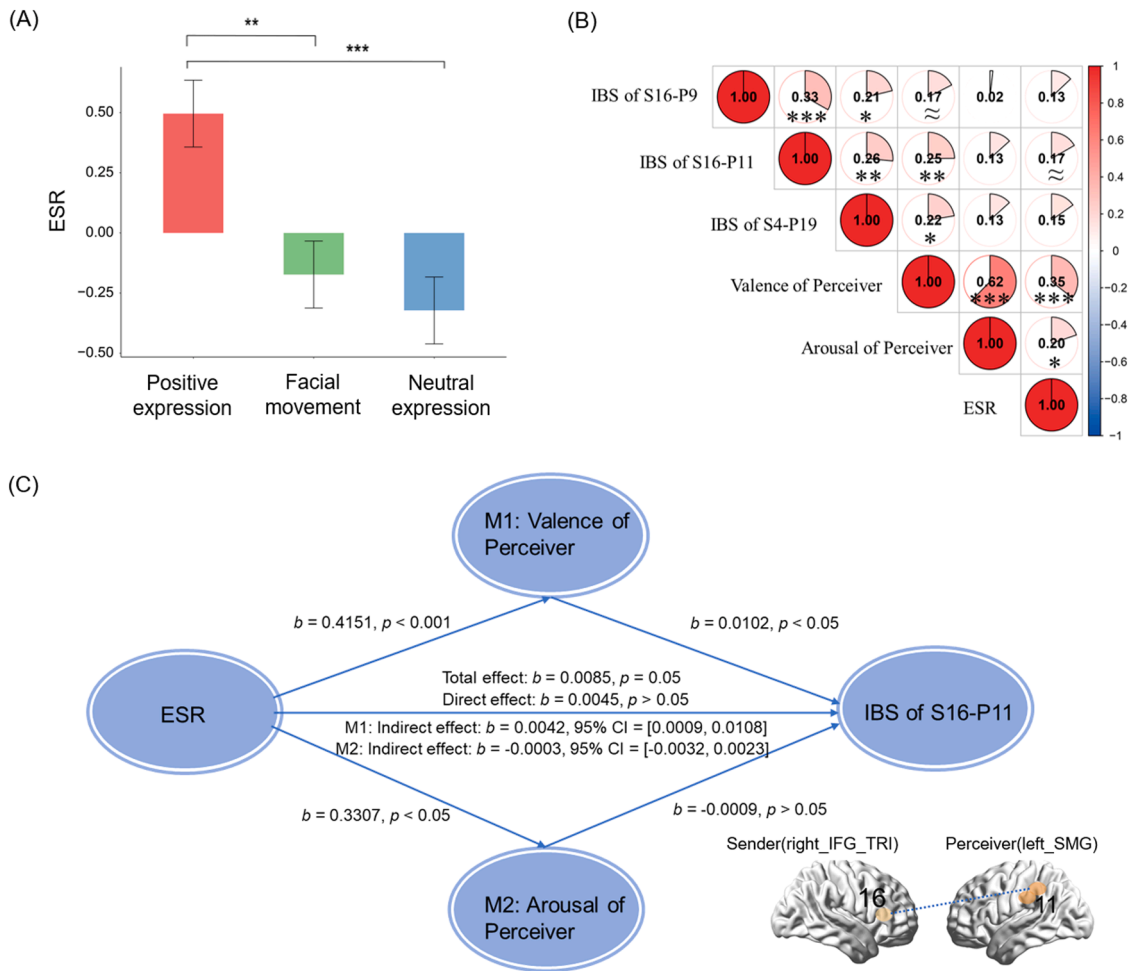
### 3.4. Expression synchronization rate (ESR) of the emotional sender and the perceiver

For the expression synchronization rate (ESR) between interactive partners, the results of the LMM showed a significant main effect of condition (Fig. 4A),  $F(2, 92) = 10.11, p < 0.001$ . Specifically, the ESR rate between the emotional sender and the perceiver in the positive expression condition was significantly higher than in the facial

movement condition (0.496 vs.  $-0.173, b = 0.67, t = 3.42, p < 0.01$ ) and in the neutral condition (0.496 vs.  $-0.322, b = 0.82, t = 4.18, p < 0.001$ ). There was no significant difference on expression synchronization rate between in the facial movement condition and in the neutral condition ( $-0.173$  vs.  $-0.322, b = 0.15, t = 0.76, p > 0.05$ ). These results indicated that facial expression synchrony between interactive partners in the positive expression condition was enhanced significantly compared to in the neutral condition and the facial movement condition. That is, in positive expression condition, emotional perceivers also exhibited facial expressions similar to emotional senders' through observing the senders' facial expressions, and hinted occurring contagion of positive emotions.

### 3.5. Positive correlations among IBS, perceiver's emotional experience, and ESR

To explore the associations among interpersonal brain synchronization (IBS), perceiver's emotional experience (valence and arousal), and emotional expression synchronization rate (ESR), A series of



**Fig. 4.** (A) The result of expression synchronization rate (ESR) in three experimental conditions,  $**p < 0.01$ ;  $***p < 0.001$ . (B) Correlational results among perceiver’s self-reporting scores, ESR and IBS. The areas and the numbers on the pie slices represent the strength of the Pearson correlation. The color bar indicates the Pearson correlation coefficient.  $*p_{fdr} < 0.05$ ;  $**p_{fdr} < 0.01$ ;  $***p_{fdr} < 0.001$ ; “~” represents marginal significance. All the  $p$ -values were FDR-corrected results. (C) Mediation analysis results of IBS, valence and arousal of perceiver, as well as the ESR. IFG\_TRI: Inferior frontal gyrus, pars triangularis; SMG: Supramarginal gyrus.

Pearson correlation analyses were conducted. The detailed correlation patterns are presented in Fig. 4B and Supplementary Table S3. These results revealed several key findings: First, the IBS patterns between the sender and perceiver (e.g., S16-P11 and S4-P19) showed a significant positive correlation with the perceiver’s valence (e.g.,  $r = 0.249$ ,  $p_{fdr} = 0.010$ ;  $r = 0.224$ ,  $p_{fdr} = 0.021$ ), suggesting that stronger inter-brain synchronizations were associated with more positive emotions of the perceivers. In contrast, IBS patterns were not significantly correlated with the perceiver’s arousal (all  $p_{fdr} > 0.11$ , FDR-corrected), indicating that interpersonal neural synchronization was more closely linked to emotional valence than to emotional arousal. Second, the correlations between IBS and ESR reached marginal significance in some pairs (e.g., S16-P11,  $r = 0.167$ ,  $p_{fdr} = 0.075$ ), suggesting a trend toward greater expression synchronization with increased IBS patterns. Third, a significant positive correlation was found between perceiver’s valence and ESR ( $r = 0.355$ ,  $p_{fdr} < 0.001$ ), indicating that perceivers who reported more positive emotions tended to exhibit more positive facial expression synchronization with the sender. Finally, the perceivers’ valence and arousal were strongly positively correlated ( $r = 0.623$ ,  $p < 0.001$ ), reflecting their interdependence as core components of emotional experience.

### 3.6. The mediating role of the perceiver’s emotional states between facial expression synchronization rate and interpersonal brain synchronization

To examine the mediational roles of perceiver’s valence and perceiver’s arousal between expression synchronization rate (ESR) and IBS of IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub>, a parallel multiple mediation model was conducted with 5000 bootstrap samples (See Fig. 4C).

The total effect of ESR on the IBS was marginally significant ( $b = 0.0085$ ,  $SE = 0.0043$ ,  $p = 0.050$ , 95 % CI [0.0000, 0.0169]). After including the two mediators, perceiver’s valence and arousal, the direct effect of ESR was no longer significant ( $b = 0.0045$ ,  $SE = 0.0045$ ,  $p = 0.318$ , 95 % CI [-0.0044, 0.0134]), suggesting a potential mediation process. Regarding the indirect effects, the total indirect effect was significant ( $b = 0.0039$ ,  $BootSE = 0.0023$ , 95 % CI [0.0011, 0.0095]). Specifically, the indirect pathway through perceiver’s valence was significant ( $b = 0.0042$ ,  $BootSE = 0.0026$ , 95 % CI [0.0009, 0.0108]), indicating that higher ESR predicted the perceiver’s more positive valence scores, which in turn was associated with increased IBS patterns. However, the indirect effect via perceiver’s arousal was not significant ( $b = -0.0003$ ,  $BootSE = 0.0013$ , 95 % CI [-0.0032, 0.0023]).

These results suggest that perceiver’s self-rated valence scores significantly mediated the relationship between ESR and IBS of IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub>, highlighting that facial expression synchronization contributes to the perceiver’s increased positive emotions, which subsequently facilitates greater IBS of IFG\_TRI<sub>sender</sub> - left\_SMG<sub>perceiver</sub>.

These results indicated that the increased facial positive expression synchronization between the emotional sender and emotional perceiver was connected to the increased valence of perceiver, and accompanied by the enhanced IBS between stranger dyads at brain regions involved in mirror neuron system.

#### 4. Discussion

The present study explored the mental and neural coupling mechanisms of the positive emotional contagion using functional near-infrared spectroscopy (fNIRS) technique. Specifically, we investigated what key characteristic of the sender (positive facial expressions vs. non-emotional facial movements) could trigger the perceiver's automatic mimicry and to reveal the possible mechanism (automatic mimicry/emotional empathy vs. cognitive control/cognitive empathy) of the positive emotional contagion tentatively. Our findings revealed that observing the sender's positive facial expressions was associated with the perceiver's automatic mimicry (indicated by facial expression synchrony), which was accompanied by the contagion of positive emotion between stranger dyads (i.e., the perceiver's emotional state was more likely to be aligned with the sender's) and the enhanced IBS patterns between interactive partners at brain regions related to the mirror neuron system/emotional empathy. The present study underscored automatic mimicry triggered by observing other's positive facial expression was closely associated with positive emotional contagion among strangers. Notably, our fNIRS findings illuminated the enhanced interpersonal brain synchronizations of brain regions related to automatic mimicry (emotional empathy) system and cognitive control (cognitive empathy) system were also associated with positive emotional contagion.

##### 4.1. Observing stranger's positive facial expressions evoked the contagion of positive emotion

Previous studies have demonstrated automatic mimicry was associated with emotional contagion (Lin et al., 2024; Paz et al., 2022). However, it remains unknown what characteristic of the sender's face could evoke the perceiver's automatic mimicry during face-to-face social interaction. In the present study, we explored the reason of the perceiver's automatic mimicry by comparing the behavioral and neural differences between two experimental conditions: observing partner's positive facial expressions and observing partner's non-emotional facial movements. These results revealed that only observing the sender's positive facial expression could trigger the perceiver's automatic mimicry accompanied with the increased facial expression synchrony compared to observing the sender's non-emotional facial actions.

These findings suggested as social animals, human would only imitate social partners' the emotional expression automatically rather than other nonsocial cues (non-emotional facial movements in this study). Moreover, we inferred that automatic mimicry might be an important mechanism of positive emotional contagion among strangers than negative emotional contagion among strangers. From the view of evolution, automatic mimicry of stranger's positive expressions (e.g., smile) was associated with a number of other positive consequences: increasing survival chances, facilitating social learning, attracting potential mates, building social bonding (e.g., liking, trust closeness to others), foster prosocial behaviors, etc. (Diana and Kret, 2025; Lakin et al., 2008; Zhou and Fredrickson, 2023), therefore, the emergence of positive emotional contagion among strangers might be especially likely to rely on an unconscious process (i.e., automatic mimicry) (Brosnan and Knapska, 2024). As the result of the enhanced facial expression synchrony, the emotional perceivers also felt more positive emotions similar to the senders' (the perceivers reported elevated emotional valence and arousal levels) when observing the sender's positive expressions relative to observing the sender's neutral expressions or non-emotional facial movements, indicating positive emotion contagion

has occurred. Our findings provided original evidence that the sender's positive emotional expression was a typical social interaction cue and could activate the perceiver's synchronous positive facial expression which was linked to positive emotion contagion (Goldenberg and Gross, 2020). However, observing other's facial movements (non-related to emotional expressions) failed to trigger emotional contagion. The present study demonstrated the adaptive function of positive expressions mimicry in interpersonal context. Positive emotional contagion might serve an adaptive function by increasing individual survival and social bond and enabling individuals to navigate their surroundings more effectively.

##### 4.2. The neural couplings mechanism of positive emotional contagion

There is no consensus in the literature that positive emotional contagion is an automatic mimicry process unconsciously or a cognitive control process consciously (e.g., social appraisal or category) (e.g., Goldenberg and Gross, 2020). The present study tried to identify the possible mental mechanism of positive emotional contagion through unveiling the interpersonal brain synchrony (IBS) patterns underlying positive emotional contagion. Our fNIRS results showed positive emotional contagion evoked higher IBS at multiple regions involved in mirror neuron system (emotional empathy) and cognitive control system (cognitive empathy) between stranger dyads ( $rIFG_{TRI\_sender} - IDLPDFC_{perceiver}$ ,  $rIFG_{TRI\_sender} - ISMG_{perceiver}$ , and  $IIFG_{TRI\_sender} - rV3_{perceiver}$ ) relative to neutral expression and facial movement conditions.

The inferior frontal gyrus (IFG) is a core region of mirror neuron system (MNS) (Paz et al., 2022; Prochazkova et al., 2018). The IFG plays a critical role in emotional understanding and emotional information processing (Schirmer and Kotz, 2006; Zhang et al., 2018). Previous studies combining with single-brain neuroimaging techniques have consistently found that mimicry of diverse emotions (e.g., happiness) activate core regions of the mirror neuron system (MNS), particularly the IFG (Likowski et al., 2012; Palagi et al., 2020; Prochazkova et al., 2018). Also, as a part region of mirror neuron system, the supramarginal gyrus (SMG) receives somatosensory, visual, and auditory inputs from the brain (Mou et al., 2024). The SMG is closely associated with empathy (Boccardo et al., 2019; Naor et al., 2020; Singer et al., 2004) and plays an important role in action representation and imitation (Esménio et al., 2019; Zhao et al., 2023). Additionally, visual area (V3) is responsible for crucial visual processing functions, especially in handling dynamic visual stimuli and motion perception (Arcaro and Kastner, 2015; Ribeiro et al., 2023), and is necessary for conscious visual perception of stimuli (Salminen-Vaparanta et al., 2019).

In a word, our fNIRS results revealed that the contagion of positive emotion increased IBS patterns of the interactive partner's multiple brain regions located in the MNS, including IFG, left SMG and right V3. The MNS is responsible for the feedback between the observation and mimicry of facial expression and neural activation associated with emotional states (Budell et al., 2015; De Waal and Preston, 2017). Automatic mimicry can be considered a gateway to emotional contagion (Palagi et al., 2020). Our findings extended the knowledge of previous studies that have demonstrated that the interpersonal brain synchronization of MNS systems were increased during joint action (Ciaramidaro et al., 2024) or coordination behavior (Lu et al., 2023). More importantly, our mediational analysis sheds new light on the interplay between behavioral, emotional, and neural synchrony during positive emotional contagion. The results revealed a significant associative pattern: greater facial expression synchrony (emotional empathy) between interactive partners was linked to more convergent positive emotional states. This shared emotional experience was positively associated with the enhancement of interpersonal brain synchronization (IBS) of stranger dyads, particularly within a brain network involving MNS systems ( $right\_IFG_{sender} - left\_SMG_{perceiver}$ ) between interactive partners. These results provided neural evidence of the two-stage model for emotional contagion (Hatfield et al., 1994). According to the

two-stage model, the first stage is automatic mimicry, and the second stage is the afferent feedback where the receiver adopts the sender's expressions. The afferent feedback is thought to elicit the activation of the perceiver's MNS system. Taken together, these findings suggest that positive facial expression synchronization of the partners might be associated with the emotional state synchrony and the interpersonal brain synchrony. These three levels of synchronization might guide social alignment (Shamay-Tsoory et al., 2019). However, it is crucial to interpret these findings with caution. All our variables were aggregated over the entire interaction block, the mediational model only revealed a statistical association among these variables, not a strict, real-time causal sequence. The observed IBS increase should be understood as a composite neural marker that reflects the intertwined nature of processes like facial mimicry and emotional sharing during the social interaction. Furthermore, our findings revealed the sender's IFG was activated in the positive expression condition. The IFG is not only sensitive to others' emotional expressions but may also play a key role in understanding positive information and producing positive expression (Hennenlotter et al., 2005; Park et al., 2023) or up-regulation of positive emotions (Scharnowski et al., 2020). Our findings underscore the importance of the sender's IFG in understanding positive stimuli, generating positive emotions and producing positive facial expressions, allowing the perceiver to resonate more strongly with the sender's positive emotional state.

Notably, it should be noted that observing other's non-emotional facial movements neither evoked the perceiver's automatic mimicry (facial expression synchrony was not significantly increased relative to the neutral condition) nor enhanced interpersonal brain synchrony between partners. Therefore, observing other's non-emotional facial movements failed in triggering emotional contagion. Our findings underscore the important role of the sender's realistic dynamic emotional expressions in provoking emotional contagion during face-to-face social interactions.

Since automatic mimicry is similar to emotional empathy (e.g., Drimalla et al., 2019; Holland et al., 2021; Paz et al., 2022), therefore, the present study suggested that automatic mimicry or emotional empathy might be closely related to the contagion of positive emotions among stranger dyads. Positive emotion contagion among human strangers is more likely to be considered as a primitive and replicative process, described as the bottom-up tendency to copy other's positive emotional states. However, the mechanism of negative emotional contagion might be more sophisticated. For instance, the sender's fear expression may cause the perceiver to feel similar fear (a replicative response), but the sender's anger expressions are likely to trigger fear, not anger (a complementary response) (Dezecache et al., 2015). In addition, whether negative emotional contagion was a replicative process also depends on the nature of interactive partner's relationship closeness, and the context of their interaction, and so on. For example, in an ingroup social context, the sender's fear expression may elicit the perceiver's similar fear expression; in an outgroup context, the sender's fear expression may be associated with the perceiver's complementary emotional response (e.g., joy or feeling of superiority).

The evolutionary benefits of positive emotional contagion adhering to an automatic mimicry process are notable. It aids in social bonds, efficient resource access, and survival by signaling beneficial opportunities (Brosnan and Knapska, 2024). In humans, the sender's positive facial expressions (laughter or smiles) served as a positive signal for the perceiver, facilitated the perceiver's identification and engagement of these positive social signals, which was crucial for fostering social bonds - a key factor in the survival of social species. The ability to positive emotional contagion among strangers rapidly provides a distinct advantage in the intricate social structures of humans, likely enhancing coordination and supporting fitness-increasing behaviors such as hunting and defense, which rely on close social bonds.

Another intriguing finding of the present study was positive emotional contagion recruited the higher IBS patterns of rIFG\_TRI<sub>sender</sub>

– IDLPDFC<sub>perceiver</sub> than facial movement condition and neutral condition. This finding suggested that positive emotional contagion also recruited the increased interpersonal brain synchronizations of the sender's mirror neuron system (rIFG) and the perceiver's cognitive control system (IDLPFC). The prominent role of the IDLPFC was related to cognitive control of emotions. The active tDCS targeting the left dorsolateral prefrontal cortex increased participants' positive emotional feelings (Palm et al., 2012; Szeremeta et al., 2023) or enhanced emotion recognition ability in healthy participants or patients with major depressive episode (Brennan, et al., 2017; Rigon et al., 2019). These findings hinted that the left dorsolateral prefrontal cortex played an important role in understanding, recognizing and executing positive emotions. Our intriguing finding of enhanced IBS patterns of rIFG\_TRI<sub>sender</sub> – IDLPDFC<sub>perceiver</sub> in the positive expression condition indicated the conscious cognitive control in a top-down manner might be also associated with positive emotional contagion. Positive emotional contagion might be involved in the perceiver's multiple mental processes related to cognitive control: emotion recognition of the sender's positive expressions, monitoring the gap between the self's emotional state and the perceiver's emotional states, up-regulating his/her own positive emotion. Since the perceivers in the present study neither performed emotion recognition task explicitly, nor reported their emotional states continuously during the whole experimental task, this speculation still needs more robust evidence in the future studies. In addition, the participants in our study were stranger dyads to eliminate the possible interfering effect of relationship closeness between partners, however, a recent study reported interpersonal closeness between the sender and the perceiver affected the extent of positive emotional contagion, suggesting social appraisal might be related to positive emotional contagion (Lin et al., 2024). These findings were accordance with previous studies on social alignment (Shamay-Tsoory et al., 2019; Shamay-Tsoory and Kanterman, 2024). However, the present study only focused on positive emotional contagion, it remains unclear whether the observed interpersonal neural coupling is specific to positive emotion contagion or would also emerge in negative emotion contagion. Future research should examine the interpersonal neural coupling mechanism of both positive and negative emotional contagion within the same interactive paradigm. This would help to clarify whether the identified neural mechanisms are valence-specific or reflect general processes related to high arousal emotional states.

#### 4.3. Limitations and future directions

Our study also has several potential limitations. First, the current study only focused on the emotion contagion of basic positive emotion (joy). The contagion of positive emotion (joy) is more likely to adhere to an automatic mimicry process: the perceivers always copied the sender's emotional states through imitating the sender's facial expressions. Future studies should explore the behavioral and neural coupling mechanism of emotional contagion of discrete emotions (e.g., pride, anger, sadness). Second, the present study only included same-gender dyads, which may limit the generalizability of our findings. Future studies should incorporate mixed-gender dyads and ensure a more balanced gender ratio to enhance ecological validity and to further investigate potential gender differences in emotional contagion. Third, future studies should explore the outcome of positive emotional contagion during social interaction (e.g., closeness, mental health, prosocial behaviors, etc.). According to positivity resonance theory (Zhou and Fredrickson, 2023), which suggests co-experience positive affect with others would build and fortify enduring social bonds (love, the relationship), it would be a very promising research field to investigate how the inter-brain dynamics that arise from shared emotional experiences affected social bonds (across two individuals or more individuals) during emotional interactions combined with hyper-scanning techniques (Felice et al., 2025). Moreover, the present study did not measure the dynamic trajectory of interactive partners' emotional states. All key

indicators-including facial expression synchrony, emotional states, and interpersonal brain synchrony-were computed over the entire task block, which limited our ability to infer the temporal or causal relationships among them. Future studies should continuously track the emotional states of both the sender and the perceiver throughout the interaction, and apply time-resolved analytic techniques (e.g., sliding window analysis, lagged cross-correlation) to explore the dynamic and potentially sequential interplay among facial expression synchrony, emotional states, and interpersonal brain synchrony. Such approaches would provide stronger evidence for hypotheses regarding the chronological order of these processes during emotional contagion. Although fNIRS provides good temporal resolution and is well-suited for ecological paradigms, its limited penetration depth restricts the measurement to superficial cortical regions, making it difficult to directly assess subcortical structures involved in emotion processing (e.g., amygdala, insula). Future studies could combine fNIRS with complementary neuroimaging techniques (e.g., fMRI, MEG) to achieve a more comprehensive understanding of the neural mechanisms underlying emotional contagion.

## 5. Conclusion

To sum up, the present study employed a real-time dyadic interaction paradigm to investigate positive emotional contagion across three interconnected levels: the sender and perceiver's subjective feelings, emotional expression synchronization (facial expression synchronization rate, ESR), and interpersonal brain synchronization (IBS). The findings of the present study firstly revealed that observing other's positive facial expressions rather than non-emotional facial movements triggered the perceiver's automatic mimicry, accompanied with facial expression synchronization between the sender and the perceiver, indicating automatic mimicry may be associated with the process of positive emotional contagion closely. Secondly, the present study revealed the increased IBS patterns of mirror neuron system and cognitive control brain system between interactive partners was associated with positive emotional contagion (the perceiver's emotional states were similar with the sender's positive emotional states). Our fNIRS results demonstrated the perceiver's automatic mimicry (emotional empathy) was closely linked to positive emotional contagion, also hinted other kinds of mental processes related to the perceiver's cognitive control (e.g., cognitive empathy) might also be associated with the positive emotional contagion. The present study encouraged more research into the still-largely unknown realm of inter-brain dynamics and contributed to a more nuanced comprehension of the dynamics of positive emotional contagion in dyadic interaction.

## Data availability

The data and code used to support the findings of this study are available from the corresponding author upon request. The data can only be used for research purposes. If the associated research is to be published, the manuscript must include the statement, "The data and code were acquired from the Shanghai Key Laboratory of Mental Health and Psychological Crisis Intervention, School of Psychology and Cognitive Science, East China Normal University."

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## CRediT authorship contribution statement

**Tongtong Zhu:** Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Jianru Bi:** Investigation, Data curation, Conceptualization. **Linzi Wang:** Investigation, Data curation. **Zimeng Xin:** Formal analysis, Data curation. **Luyao Jin:** Methodology, Investigation. **Yi Zhou:** Visualization, Validation. **Kelong Lu:** Methodology. **Xinyue Wang:** Validation, Methodology, Investigation. **Ning Hao:** Writing – review & editing, Project administration. **Yanmei Wang:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

## Declaration of competing interest

The authors declare no competing interest.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.neuroimage.2025.121462](https://doi.org/10.1016/j.neuroimage.2025.121462).

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