

Review

The Neural Mechanism Underlying Differentiated In-Group Versus Out-Group Face Recognition and Memory, Identification, Empathy and Pro-social Behavior: Evidence from fMRI and ERP Studies

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Abstract

In the context of perceiving individuals within and outside of social groups, there are distinct cognitive processes and mechanisms in the brain. Extensive research in recent years has delved into the neural mechanisms that underlie differences in how we perceive individuals from different social groups. To gain a deeper understanding of these neural mechanisms, we present a comprehensive review from the perspectives of facial recognition and memory, intergroup identification, empathy, and pro-social behavior. Specifically, we focus on studies that utilize functional magnetic resonance imaging (fMRI) and event-related potential (ERP) techniques to explore the relationship between brain regions and behavior. Findings from fMRI studies reveal that the brain regions associated with intergroup differentiation in perception and behavior do not operate independently but instead exhibit dynamic interactions. Similarly, ERP studies indicate that the amplitude of neural responses shows various combinations in relation to perception and behavior.

Keywords: facial recognition and memory; intergroup identification; empathy; pro-social behavior; neural mechanisms

1. Introduction

Social cognition refers to the process by which animals acquire, process, analyze, and take relevant actions based on social information [1]. It encompasses various aspects, including the recognition of social attributes of others, understanding of relationships with others, emotional responses and reactions to others, analysis of social environments, and adaptive behaviors [2]. Social recognition is often used to describe an individual's ability to distinguish familiar and unfamiliar conspecifics [3]. It is this ability to differentiate that leads individuals to recognize and identify members within and outside of social groups. This perceptual differentiation forms the basis of the different cognitive processes underlying in-group and out-group memory, emotions, and decision-making [4]. In recent years, more emphasis has been put on exploring the neural mechanism underlining this differentiated perception. In the field of neuroscience research, the study of in-group and out-group perceptual differentiation mainly focuses on aspects of facial recognition and memory, intergroup identification, empathy, and pro-social behavior.

Facial recognition and memory are closely related. Facial memory refers to the ability to maintain a representation of a face in long-term memory [4]. Facial recognition relies on facial memory and allows individuals to differentiate between faces. When processing faces, individuals will categorize and process them differently, such that they often show better facial memory for faces within their own

social group [5]. Intergroup identification is built upon social identification, which refers to the enhanced ability to identify individuals within their own social group, integrating their group identity with their sense of self, and enhancing their sense of belonging [6,7]. The inclination towards affiliation likely leads individuals to engage in personalized recognition of in-group members and categorization of out-group members, resulting in the development of intergroup identification [8–10]. In terms of empathy and pro-social behavior, empathy refers to the emotional state that arises and resonates with another person's emotional state, such as pain. However, this emotional state is influenced by intergroup dynamics, which in turn impacts decision-making regarding pro-social behavior (altruistic behavior) [11,12].

These four aspects, encompass facial recognition and memory, intergroup identification, empathy, and pro-social behavior, are not independent of each other and may have a hierarchical relationship. Facial recognition and memory, as well as intergroup identification, serve at the level of differentiated perception, which in turn influences an individual's empathy and pro-social behavior at the behavioral level. But what are the neural mechanisms underlying this differentiated perception and behavior?

With advancements in neuroscience technology, we are better equipped to investigate the neural mechanisms of social behavior. Studies using functional magnetic resonance imaging (fMRI) suggest that multiple brain regions are involved in the formation of intergroup perceptual bias,



including the fusiform face area (FFA), anterior cingulate cortex (ACC), amygdala, and prefrontal cortex (PFC) (Fig. 1).

Research investigating the FFA shows that this area is activated when participants recognize faces of different ethnicity, and that participants are better at recognizing faces of the same ethnicity [13]. The ACC, as a central hub of cognitive and affective networks, is involved in the perception of stereotypes among intergroups [14]. The amygdala is responsible for perceiving and evaluating potentially threatening stimuli. Accordingly, amygdala activation appears to be elicited by negative emotions brought on by the presence of stereotypes when engaging in intergroup identification, and amygdala activation is more pronounced when individuals face out-group members [15]. There is also research suggesting that amygdala subregions are also involved in altruistic behavior. The PFC is mainly involved in the perception of intergroup prejudice and decision-making regarding pro-social behavior [16]. The activity of the PFC is affected by social factors such as stereotypes and prior experience. However, these perceptual biases are not deeply ingrained. Studies have shown that perceived prejudice among groups is malleable, such that intergroup prejudice can be reduced through specific interventions [17]. In addition to the aforementioned four brain regions, there are other brain regions involved in intergroup differentiated perception. For example, the anterior insula (AI) is involved in empathy, while the bed nucleus of the stria terminalis (BNST) and the right temporo-parietal junction (rTPJ) are associated with pro-social behavior [18–20]. Furthermore, based on event-related potentials (ERPs), studies found that amplitude N170 mainly relates to facial recognition, and amplitude P300 can reflect pro-social behavior and altruistic behavior [21,22]. Therefore, in this article, we provide a comprehensive review of the involvement of the four major brain regions and ERPs in facial recognition and memory, intergroup identification, empathy, and pro-social behavior.

2. Facial Recognition and Facial Memory

2.1 fMRI Studies

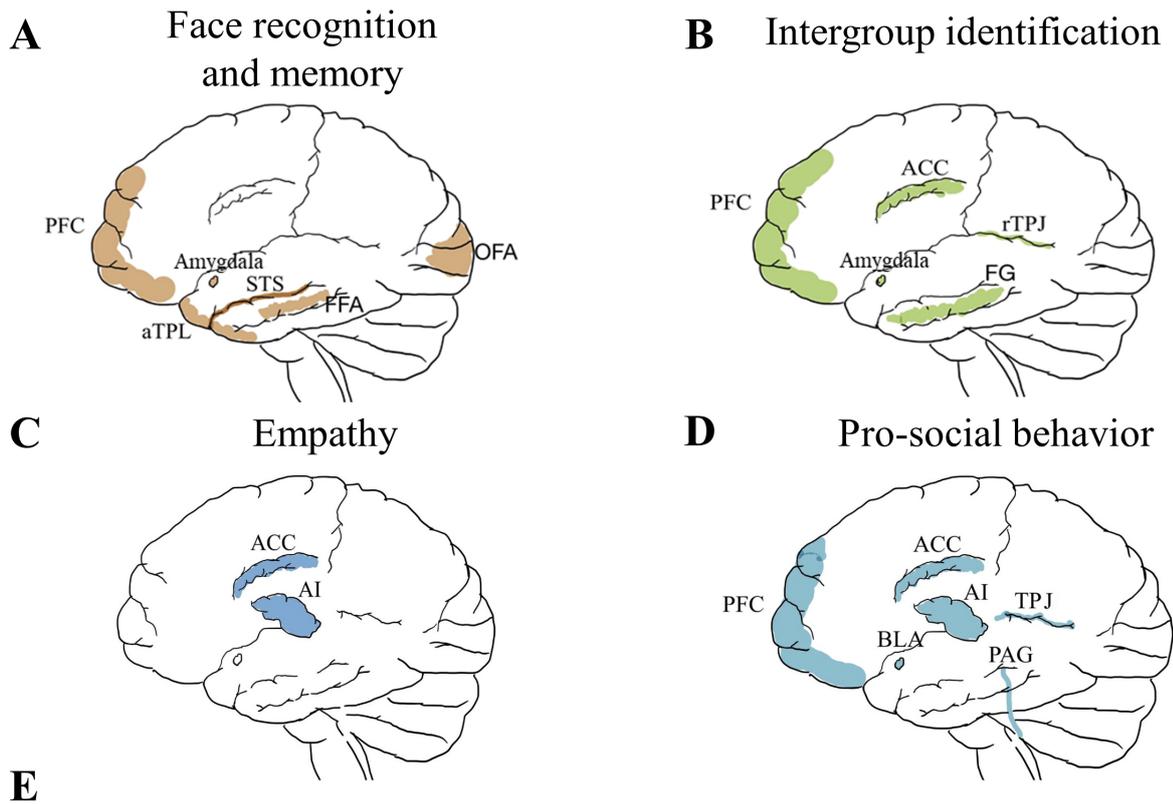
2.1.1 Fusiform Face Area

One of the breakthroughs in cognitive neuroscience is the discovery of an area of the brain that preferentially responds to human faces, known as the FFA [23,24]. The FFA is thought to be responsible for extracting the physical information of different faces and is therefore considered the core brain area involved in facial recognition [25–29]. When individuals view faces of others that are either the same or different ethnicity, they tend to recognize faces of other ethnicities faster than those of the same ethnicity, and they are more accurate at recognizing faces of their own ethnicity than other ethnic targets which indicated that the recognition of same or other ethnicities may depend on different processes [30,31]. To address this issue, the researchers conducted a classification task to examine

whether there were differences in levels of activation within different brain regions when Chinese participants classified faces of the same ethnicity and other ethnicities. The study revealed that the right FFA (rFFA) exhibited higher activation during the recognition of same-ethnicity faces compared to other-ethnicity faces [32–34]. In addition, although participants recognize faces of other ethnicity faster, they can more accurately recognize faces of their own ethnicity than other ethnicity [35,36]. This phenomenon is known as the other-ethnicity effect [37]. One explanation for this effect is that people conduct a more holistic analysis of faces of the same ethnicity. The rFFA was active when individuals performed an integrated analysis of their own ethnicity face, but not other ethnicities [34]. This differential response within the FFA to facial recognition of the same ethnicity and other ethnicities is more pronounced with increasing age [38]. These findings suggest that the rFFA plays a large role in the processing of faces of similar ethnicity than faces of other ethnicities.

Further investigation into the role of the FFA revealed its involvement in personalized processing of faces. Through the use of fMRI, researchers found that the specificity of FFA neural responses depended on the need for individualization. Specifically, when Korean participants performed tasks involving individualization, ethnicity categorization, and gender categorization, it was observed that the FFA exhibited activity specifically during individual face recognition and was inactive during the classification of common characteristics, such as ethnicity or gender [39]. This shows that the differential response of the FFA to faces of members of the same ethnicity and other ethnicity does not originate from its classification of faces of different group members, but from differentiated processing at the individual level [35,40,41]. Behavioral research has shown that recognition at the individual level and racial classification are two steps, and there is a trade-off between these two, which is an important sign of face-specific processing [42]. Another study involved having participants from China identify and classify faces of the same and other ethnicities. Specifically, they were presented with full-color face photos of 64 Caucasian and 64 Chinese young adults. The neural responses of the FFA and the occipital face area (OFA) were measured using fMRI. The study found that for faces of other ethnicities, both the FFA and OFA responded more to individual recognition than to classification, while for faces of the same ethnicity, the two brain areas were more sensitive to recognition and classification. The right superior temporal sulcus (STS) response was opposite to that of the FFA and OFA.

In addition, the individualized recognition process strengthened the functional connection between the FFA and the STS, while classification strengthened the functional connection between the OFA and the STS. The moderating effect of these two groups of functional connections was negatively correlated. That is, the recognition process



	PFC	Amygdala	FFA	OFA	aTPL	STS	AI	TPJ	ACC	PAG
Face recognition and memory	■	■	■	■	■	■				
Intergroup identification	■	■	■					■	■	
Empathy							■		■	
Pro-social behavior	■	■					■	■	■	■

Fig. 1. Brain regions involved in different aspects of intergroup perception. (A) The main brain regions involved in facial recognition and facial memory: prefrontal Cortex (PFC), amygdala, fusiform face area (FFA), occipital face area (OFA), anterior temporal pole region (aTPL), and superior temporal sulcus (STS). (B) The main brain regions involved in intergroup identification: PFC, amygdala, FFA, temporoparietal junction (TPJ), and anterior cingulate cortex (ACC). (C) The main brain regions involved in empathy: Anterior insula (AI) and ACC. (D) The main brain regions involved in pro-social behavior: PFC, amygdala, AI, TPJ, ACC, and periaqueductal gray (PAG). (E) Summary of behavior and related brain regions, color blocks represent brain regions that are associated with behavior; gray color represents regions that are not related.

attenuated the brain activity associated with the classification process, and vice versa. The results showed that in the core face-processing network, although the recognition and classification of faces of the same ethnicity and other ethnicities may activate the same neural network, the activation and functional connectivity of brain regions involved in different processing are affected by the type of face ethnicity and the situation [13,43].

Human facial recognition is a dynamic process, and the connection between the core area and the extended area of the face system is key to facial recognition.

Numerous white matter connections exist between the occipitotemporal-facial area, superior temporal sulcus, and the insula, suggesting that there may be direct anatomical connections from face-specific areas to frontal nodes which may be responsible for emotions associated with familiar faces, and the processing of the information provides the basis of the processing of emotional information associated to familiar faces. [44]. For example, an individual's affective attitude affects the FFA. A positive attitude modulates blood oxygenation level-dependent signal (BOLD) in the right fusiform gyrus and the left inferior occipital gyrus

when individuals process faces of the same and other ethnicities. When confronted with out-group members, individuals' positive attitudes and experiences directly modulate the neural processing of out-group members [45,46].

In summary, the FFA is mainly involved in the differential recognition process of faces of the same ethnicity and faces of other ethnicities. People are better at identifying the faces of members of their own ethnicity. This is mainly reflected in the fact that compared with individuals of different ethnicities, people can perform better-integrated analysis and reidentification processes for an individual face of their own ethnicity. At the same time, the FFA is dynamically connected to other brain regions during face processing, and therefore, intergroup face recognition could be affected by personal attitudes and prior experience.

2.1.2 Amygdala

The literature suggests that the amygdala strongly influences the function of the fusiform gyrus during face perception and that this influence is determined by an individual's experience and the salience of face stimuli [47]. In healthy participants, increased activation of the amygdala has been associated with the other-ethnicity effect. For instance, when Caucasian adults are presented with faces of African Americans, there is an increase in amygdala activity. [48]. Clinical studies have also found enhanced amygdala responses to facial stimuli (four different gender faces) in individuals with asperger syndrome (AS) following oxytocin treatment [49]. Additionally, increased bilateral amygdala responses have been observed in Asian and Black/African American participants compared to Caucasian participants when exposed to Caucasian face stimuli, both in healthy participants and participants with major depressive disorder [50]. The amygdala also plays a crucial role in the recognition of emotion. In a classical facial emotion perception task, the right amygdala is thought to be involved in the autonomic arousal associated with facial emotion generation, while the left amygdala may be involved in decoding or evaluating facial expressions during early perceptual emotion processing [51]. Furthermore, as a component of facial information, age may influence the neural networks connected to the amygdala during the processing of faces with different ages (accompanied by emotional expressions) in participants of different age groups [52]. In face and house contrast experiments, strong bilateral activation of the amygdala and lateral activation of the fusiform gyrus have been observed, indicating that the role of the amygdala may include processing stimuli of neutral emotional faces in relation to social factors [53]. Moreover, increased bilateral activation of the amygdala is associated with delayed memory performance, therefore amygdala activity also seems to be related to facial memory [54].

2.2 Event-Related Potential Studies

Visual and social factors have been found to affect facial perception and memory in ERPs studies. When individuals detect face-like stimuli or resembling faces, the amplitude of N170 changes and N170 is generally thought to reflect processes prior to individual face recognition [21,55]. By measuring event-related potentials in the brain, neural correlates of structural face encoding (as evidenced by the N170 inversion effects) can be modulated by both visual (ethnic factors) and non-visual (social factors) stimuli. This suggests that the classification of individuals as either within-group or out-group members influences the perception process of same-ethnicity and other-ethnicity faces [56].

In the domain of visual perception, individuals exhibit a greater ability to accurately remember faces belonging to the same racial group. Enhanced memory for faces belonging to the same racial group can potentially be attributed to the presence of other race bias (ORB). In one study, the researchers investigated the relationship between ERPs and ORB by assessing the recognition of Asian and European faces. Asian and European participants were presented with stimuli comprised of 120 unfamiliar Caucasian faces and 120 unfamiliar Asian faces. The findings revealed a significant ORB effect in both groups, with a negative N170 amplitude observed in response to other-race faces [57]. Facial recognition is generally considered to be a continuous process, with the identification of individual identities prior to perceptual processing [58]. Ethnicity-related bias was accompanied by larger N170 responses to faces of other ethnicities, which may reflect different perceptual processing of these faces [59].

There are multiple mechanisms that could impact memory for faces of other ethnicities. Results of facial recognition experiments have shown that when attention allocation or holistic processing is reduced, the influence on memory will decline, and studies have demonstrated that increased holistic processing during memory encoding contributes to other ethnicity effects on facial memory [60]. The ERPs generated during memory retrieval and recall are often referred to as the parietal old/new effect. In subjective memory tasks, ERPs are associated with memory and familiarity. The results showed that the old/new effect might have had a significant effect on the recognition of the faces of members of the same ethnicity but not on the faces of other ethnicities. These results suggest that the other ethnicity effect is a phenomenon based on memory encoding and recognition, illustrating that memories might support recognition of same ethnicity faces and lead to more detailed memory retrieval [61]. In daily life, people automatically form impressions of others based on subtle facial features, such as thick and close eyebrows distorted or squashed noses, that convey a sense of trust. Therefore, researchers used event-related potentials to study how the perceived credibility of faces can influence long-term

memory, as these face-based judgements influence current and future social interactions [62]. The results showed that a more persistent memory for untrusted faces, which may be based on face familiarity [63]. Besides memory, the ERPs studies showed that social factors could also influence intergroup face procession. It was found that improvement in personal social influence will increase discrimination against low social status groups [64]. A neural index of visual face processing (the N170 component of the ERPs) revealed that social status influences the encoding of in-group white faces and out-group black faces and that it can influence implicit biases and stereotypes, as well as early processing of in-group and out-group faces [65]. In summary, people will automatically form impressions of others based on their ability to visually observe subtle facial features. Meanwhile, the perception and memory of faces are also affected by social factors.

3. Intergroup Identification

Society is composed of diverse groups, and due to individuals' inclination towards group affiliation, they tend to engage in personalized recognition of in-group members and categorization of out-group members [8–10]. The brain engages distinct neural dynamics to sort faces into different racial categories [66].

3.1 FMRI Studies

3.1.1 Anterior Cingulate Cortex

The ACC is an important brain region involved in social cognition [67]. When people engage in social activities, the first impression is facial recognition. By testing individuals' perception of disgusting faces, it was found that the insula-ACC neural circuit was largely involved in racially biased perception of disgust [68]. Disgust perception suggests that individuals are emotionally biased towards members of the "in-group" and biased against those of the out-group [68]. When participants made choices about their own team, brain regions such as the ACC, inferior frontal gyrus, and dorsolateral prefrontal cortex (DLPFC) were commonly recruited. These brain regions are known for their roles in cognitive control and social perception [69]. Research has shown that reversal learning of threatening or safe stereotypes through behavioral experiments involving fear conditioning can alter individuals' prejudice against other group members, and corresponding activity in ACC [70]. This suggests that perceived bias can be reshaped by the social environment [71].

During social interaction, individuals extract multiple pieces of social information, such as ethnicity, gender, and behavioral habits, that influence their specific emotional responses. It was found that when Caucasian Americans see African Americans faces, it can trigger a negative emotional experience [72]. This is an example of intergroup stereotypes. Additionally, the study found that the ACC showed increased activity when social information contradicted the

emotional information it carried, indicating that the ACC is sensitive to social information and stereotype inconsistency. The response of the ACC is plastic, and this plasticity could be diminished by increasing the exposure of the participant to another other social groups [14]. Furthermore, the dorsal ACC was activated when participants felt excluded from their racial group [73]. In addition, when individuals face potential threats from others of the same or different ethnicities, the brain responds differently [74]. The ACC showed increased activity when participants were faced with same-ethnicity members who did not pose potential threats [75]. In summary, in the process of social classification identification, the ACC is involved in the stereotyping of specific social groups, particularly when the stereotype of the group conflicts with the image of a single individual. This is consistent with the conflict detection function of the ACC [76].

3.1.2 Amygdala

The amygdala is vital for fear conditioning and fear memory retrieval [77]. It is also responsible for the detection and evaluation of potentially threatening stimuli [78,79]. The primary role of the amygdala is coordinating cortical networks in response to emotional facial expressions [80]. When Caucasian Americans are confronted with unfamiliar African or Caucasian faces displaying negative emotions, the amygdala displays a heightened response [15]. However, although the activation of the amygdala in the perception of in-group members and out-group members is differentiated but, whether it is more active to faces of in-group members or out-group members remains controversial [81,82]. In a study that examined 3T magnetic resonance imaging (MRI) scans of 20 participants of African descent and 22 participants of European descent while viewing the faces of African descent and European descent individuals, both groups demonstrated greater right amygdala activation, and the African ethnicity group had greater right amygdala activation for white faces [83]. In addition, a multi-voxel pattern analysis found that the implicit evaluation level of Japanese participants toward Korean participants could be predicted by the response of the left amygdala [84]. This indicated that the response of the amygdala may be related to more complex social and cultural background information. A study found that when participants were randomly assigned to a new group, they exhibited a range of perceptual, emotional, and behavioral in-group biases. When participants were assigned to a mixed-ethnicity team, the amygdala, fusiform gyrus, preorbital cortex, and dorsal striatum were more active when participants saw the new in-group member faces than when they saw the faces of new out-group members [85].

One explanation for the above findings is that cultural factors influence the neural basis of facial emotion perception [86]. The moderating effects of cultural factors on bilateral amygdala neural responses depend on in-group bias

and collectivist values. Indeed, studies suggest that cultural factors can influence individuals' perceptions of the facial emotions of in-group members [87]. Other studies have also shown that the amygdala is activated bilaterally by individuals' perception of emotional expressions on faces of others of a different ethnicity, and this differential perception is influenced by cultural context [88]. Therefore, the amygdala responds to stereotypes or prejudices of out-group members, and the conditions under which the amygdala is activated depend on the subject's social cognition regarding the target [89].

Another consideration is the differences in amygdala activity from the perspective of threats, such as the cultural context association between black males and potential threats involved in subjects' identification of black males [90]. Using conditioning paradigms, researchers investigated neural activity underlying the development of aversive learning bias in European-decent participants when confronted with in-group (Caucasian) and out-group (Black) members. The study revealed that the amygdala and ACC played a crucial role in differentiating between Caucasian and Black faces during the acquisition and extinction of fear [91]. In addition, the role of the amygdala in group recognition also showed high plasticity. Amygdala sensitivity to ethnicity does not exist in childhood but emerges during adolescence [17]. Studies have shown that exposure to more members of out-of-ethnic groups during childhood is associated with reductions in amygdala responses to familiar black faces in adulthood [92]. This further demonstrates its strong relation to social factors.

Taken together, when engaging in intergroup identification, amygdala activation appears to be elicited by negative affect derived from the identification of social information. This differentiated emotional response is often related to social and cultural factors, such as stereotypes of members of other ethnic groups.

3.1.3 Prefrontal Cortex

The PFC plays a key role in social cognition, with its' various subregions having different functions. In the process of racial categorization, different faces of in-group and out-group members influence how individuals process emotions at the behavioral and neural level. Researchers found that the in-group member can exert a more powerful influence on social events (such as earthquake aftermath, attending a funeral, being in the hospital, etc.)-related emotional reactions than out-group members and during which the subregions of the PFC (e.g., ventromedial prefrontal cortex [VMPFC], dorsomedial prefrontal cortex [DMPFC], medial prefrontal cortex [MPFC]) were involved [16]. In children's perception of different facial emotions (neutral, happy, angry), the MPFC exhibits a greater activation for happy faces [93]. In a facial recognition task using 3D digital face models, the dorsolateral prefrontal cortex (DLPFC) showed increased activity when emotional information con-

flicted with social stereotyping [14]. A multi-voxel pattern analysis revealed that the occipital neural networks might represent ethnicity in a fixed situation when making judgements about group membership. The early sensory perception of ethnicity was treated in a fixed manner, but the following-up integrated analysis was complex and depended on the decision-making context. In friendship judgements, the orbitofrontal cortex (OFC) preferentially encode ethnicity, while in personal trait judgements, the ventromedial prefrontal cortex (VMPFC) preferentially represents ethnicity [94].

Group bias is not only seen in racial recognition but also other types of social identification. Researchers found that individual's cognition of yea-sayers (those with a lenient criterion) modulates several brain regions, including the caudate nucleus, DLPFC, and hippocampus. The caudate nucleus and DLPFC play a key role in personal cognition through repetitive feedback (receiving feedback multiple times about one's actions or performance within a task, thereby aiding individuals in gradually adjusting and improving their behaviors, decisions, or cognitive biases) [95]. In addition, it was also found that right dorsolateral prefrontal cortex (rDLPFC) and right temporoparietal junction (rTPJ) neural synchronization among in-group members could be a candidate mechanism responsible for hostility between groups. Intragroup binding (in this study, "Intragroup binding" refers to the process of bringing individuals together through grouping) decreased rDLPFC activity and increased functional connectivity between the rDLPFC and rTPJ, while intragroup rDLPFC synchrony was positively correlated with inter-group hostility [96].

In summary, the PFC plays a key role in the process of ethnic classification, which could be influenced by the in-group members. And when identifying ethnicity within or outside the group, each subregion of the PFC assumes different roles.

3.2 Event-Related Potential Studies

Event-related potential studies have shown that individuals are better at recognizing the members of the same ethnicity when they identify the same ethnicity and other ethnicity [97]. To investigate whether there is racial dominance in attention allocation, one study asked participants to look for human faces of different ethnicities among animal faces and record time-dependent potential pairs N2-posterior-contralateral, N170, and N250. The results showed that the N2pc waves appeared earlier when participants looked for faces of the same ethnicity, which demonstrated that same-ethnicity faces attracted more attention than faces of other ethnicities [98]. Through repetition suppression (RS), which refers to the decrease in neural activity in stimulus-sensitive areas when stimuli are repeated [99,100], researchers employed a specialized quantification of RS. They found that participants (Chinese) exhibited stronger RS to same-ethnicity faces compared to

other-ethnicity faces (different racial backgrounds), as observed in the face-sensitive N170 component. This neurophysiological modulation in RS suggests efficient identity coding for same-ethnicity faces [66]. Other studies related to RS effects have discovered that neural activity in the FFA can differentiate between different faces when the facial stimuli belong to the observer's own-ethnicity group (Caucasian), while the face-selective cortex does not differentiate individuals from other ethnicities [101].

4. Empathy

4.1 FMRI Studies

4.1.1 Anterior Cingulate Cortex and Anterior Insular Cortex

Empathy enables humans to understand and share each other's emotional experiences, creating emotional resonance between individuals and others, which is essential for successful social interactions [102,103]. Observing others in pain activates corresponding pain pathways in the observer [11]. Research investigating the ACC and AI has shown that both brain regions play a crucial role in processing empathy [104]. In studies investigating pain empathy, when participants observed pain in the faces of chronic pain patients, the activation levels of the bilateral anterior insula, left anterior cingulate cortex, and left inferior parietal lobule in their brains were correlated with their estimations of the observed pain intensity [105].

When experiencing pain, altruists (a person who cares about others and helps them despite not gaining anything by doing this) generate spontaneous empathic responses in the AI, anterior/middle cingulate cortex, and supplementary motor areas [106]. However, empathic perceptions of pain may be modulated by implicit racial bias [9]. One study asked subjects to rate the pain of in-group/out-group members in a minimal group paradigm experiment. They found that Chinese participants had stronger ACC responses when they rated the pain of Chinese participants than Western participants (Caucasian). The activity of the ACC was modulated by implicit racial biases while the right anterior insula (rAI) was modulated by an in-group bias. Furthermore, it was found that the activity of the ACC was modulated by the activity of the rAI (in-group bias) under painful conditions, whereas the activity of the rAI was modulated by the activity of the ACC (racial bias) under painless conditioned stimuli [107]. When the activity of the AAC and AI regions were induced to respond to painful face stimuli, the empathic neural responses of the ACC were significantly reduced if subjects observed faces of other ethnicities that were in pain [108].

Other studies have found that individuals have greater activity in the ACC and the left anterior insula when observing members of the same ethnicity receiving painful stimulation [74]. In perception of personal pain, the participants' perception of pain expressions by out-group members could also increase ACC-AI activity [109]. Subsequent studies

have shown that increasing the subjects' social interaction with members of other ethnicities significantly increases the response of the ACC to painful stimuli from members of other ethnicities [110]. This shows that the ACC is involved in the process of empathy processing, with a difference between in-group and out-group members, and it also shows that this socially biased ACC activity can be modulated through repeated exposure to out-group members.

Moreover, auditory perception can also induce empathy. The human voice is one of the main channels for social and emotional communication. Recent neuroimaging studies have shown that brain regions responding to the painful cry of others are similar to regions activated in the empathic processing of visual stimuli. Pain-related exclamations elicited increased activation in the superior and middle temporal gyri, left insula, secondary somatosensory cortices, thalamus, and right cerebellum, as well as reduced activity in the ACC. It should be noted that the emotional background used in the experiment may have contributed to this phenomenon [111].

In addition, social and contextual factors can also modulate empathic neural responses to the pain of others [112]. Research has shown that empathic responses to others' pain are mediated by a variety of situational and individual factors as well as by social hierarchies. The researchers found that painful stimulation applied to inferior-status (In this study, participants were ranked through recognition tests, and those who ranked lower were referred to as having an "inferior-status") targets induced greater activation in the AI and anterior medial cingulate cortex (amCC). Conversely, these empathic brain activations were significantly attenuated in response to superior-status targets' pain. These results revealed that sharing painful emotions with others was influenced by the relative position of the individual in the social hierarchy and that the empathic neural responses were biased towards lower-status individuals compared to higher-status individuals [113].

In summary, the perception of pain in others is one measure of empathy. Observing the pain responses of others activates sensory and emotional areas of the brain which are believed to be neural markers of empathy. Individuals have higher empathic reactions to in-group members than out-group members, and this difference can be attenuated by increasing social interaction with out-group members. Whether within groups or between groups, empathy activates the brain regions of the ACC and AI, indicating a functional connection between the ACC and AI during empathy, where they mutually coordinate and regulate the empathic process.

4.1.2 Mirror Neuron System

Research in the field of cognitive neuroscience has identified the mirror neuron system (MNS), located in the posterior region of the inferior frontal gyrus (IFG) and the anterior region of the inferior parietal lobule (IPL), as a po-

tentially crucial neural substrate for empathy. The generation and perception of actions activate the same neural circuits, which is defined as mirror neuron activity [114]. Individuals are highly influenced by the emotions of others, and the most typical example is the experience of empathy towards pain. When observing an injury on someone else, the cingulate cortex and AI are activated [115]. Conversely, the ACC and AI are also activated when experiencing empathy towards others [109]. Currently, there is limited research on inter-group empathy within the MNS. In a study investigating inter-group empathy, researchers tested 178 participants who were presented with emotional and neutral facial expressions of both in-group and out-group members. The results indicated that in the MNS, participants exhibited higher activation in the left insula when viewing in-group members compared to out-group members. This suggests greater neural resonance (mirroring) for in-group facial emotional expressions [116].

However, it should be noted that while there may be some overlap between the neural networks of the MNS and empathy, they cannot be considered identical. A meta-analysis of studies investigating the involvement of the MNS in empathy and imitation found that the superior parietal lobule, inferior parietal lobule (IPL), dorsal premotor cortex, and frontal lobe were activated during empathy and imitation. However, the inferior frontal gyrus (IFG), which is a major component of the MNS, did not show activation [117]. Other studies have indicated a moderate correlation between empathy and activity within the MNS [118]. In summary, the aforementioned literature may indicate from an alternative perspective that in human-centered research, the design of behavioral experiments has limitations and may not accurately reflect the correspondence between behavior and brain regions. Therefore, the role of the MNS in empathy requires further investigation. However, there is a significant scarcity of research on the involvement of the mirror neuron system in pro-social behavior. These gaps need to be filled by researchers.

4.2 Event-Related Potential Studies

ERPs studies have found that empathy is influenced by inter-group racial bias. For example, when participants viewed painful facial expressions of members of different ethnicities, the P2 wave amplitude response was greater than when viewing a painful facial expression of those of another ethnicity [119]. Furthermore, researchers have found that the physical environment can influence inter-group bias. In one study, ERPs were recorded for subjects observing painful or neutral faces of individuals of the same or different ethnicity when holding a cold or warm package. Activity in frontal/central regions N2 (200–340 ms) and P3 (400–600 ms) time windows were positively affected by viewing expressions of pain. The sensory experience of being cold can strengthen the emotional resonance of individuals of the same ethnicity. Under cold conditions, the

N2/P3 empathic neural responses of the same ethnicity are significantly greater than those of other ethnicities, but not in warm conditions [120]. Other studies have also found that physical sensations of warmth can increase pro-social responses to out-group members during authentic interactions [121].

5. Pro-social Behavior (Altruism Behavior)

5.1 FMRI Studies

5.1.1 Anterior Cingulate Cortex and Anterior Insular Cortex

In pro-social behavior, rewarding in-group members increases activation in the ventral striatum and left medial orbitofrontal cortex [122]. In a study including both Chinese and American participants, participants were asked to complete a pro-social decision-making task, voluntarily giving their own money to others without expecting compensation. Researchers found increased activation of the ventral striatum in all participants and this was associated with donation within the group. Participants with a strong sense of group identity and Chinese participants showed higher activity in brain regions related to self-control (ventrolateral prefrontal cortex and ACC) and cognition (dorsomedial prefrontal cortex and TPJ) when contributing outside the group [123].

In summary, empathy is the main driving force for individuals to engage in pro-social behavior. Compared with out-group members, ACC-related reward circuit is more active when individuals help in-group members.

In studies investigating the differentiation of pro-social behaviors between groups, there is a relative scarcity of reports regarding the AI. In studies examining within group dynamics, it was found that the rAI plays a significant role in promoting altruism and pro-social behavior [124]. Other studies have revealed that activation of empathy-related brain regions, such as the AI and MPFC, is linked to increased pro-social behavior towards “victims” (in this study, the term “victim” refers to individuals who have experienced social exclusion). These findings suggest that neural responses associated with empathy during social experiences may foster spontaneous pro-social treatment of individuals in need [125]. Furthermore, in a study of reciprocity, the insula and ACC were positively correlated with reciprocity behavior [126].

In conclusion, the ACC and AI contain crucial networks for empathy and play a role in driving pro-social behavior. However, there is currently limited research on the differentiation of pro-social behaviors between groups in relation to these two brain regions. The differences in empathy between in-group and out-group members may explain the variations in pro-social behavior exhibited by individuals towards these different groups. This also partly accounts for the strong correlation between the brain regions involved in empathy and pro-social behavioral regulation. Research should focus on this aspect in future stud-

ies, as it holds significant importance in gaining a deeper understanding of the relationship between empathy and pro-social behavior. Furthermore, as mentioned in the section on empathy, the mirror neuron system is involved in the regulation of empathy.

5.1.2 Amygdala

Neural processing associated with empathy is strongly influenced by social identity. Human emotion plays an important role in decision-making [127]. Individuals feel more empathy for in-group members because the shared neural circuits that generate and perceive facial expressions, including the temporal pole region, the amygdala, left insula, left inferior frontal gyrus, inferior and middle temporal gyrus, right hippocampus, and para-hippocampus, showed higher activity when participants view other in-group members [128]. Moreover, recent research implicates that the amygdala is involved in costly altruism (donating a kidney to a stranger) [129]. In other studies, participants were asked to donate real money or hypothetical money. Real donation behavior is associated with increased activation of the amygdala, caudate nucleus, and rACC, during which the amygdala shows higher activity than hypothetical donation [130].

In addition, in the presence of vulnerable in-group members or other pain signal stimuli, coordinated transmission of information occurs from the amygdala to subcortical regions (including the striatum, bed nucleus of stria terminalis, hypothalamus, and periaqueductal grey), through which the amygdala can rapidly encode nonverbal pain signals that support the development of caring behaviors [131–133]. There is also research showing activity and functional connectivity of the amygdala and periaqueductal grey in response to care-evoking situations by examining rare altruists (such as organ donation). Furthermore, altruists were found to have increased sensitivity to pain and increased amygdala activity [134]. In summary, the amygdala seems to respond to modulate the feeling of empathy and, therefore, modulate altruistic behavior through connects to other brain regions.

5.1.3 Prefrontal Cortex

Activation of the PFC influences pro-social behavioral choices, and in real moral decision-making, different subregions of the PFC determine whether subjects make selfish or pro-social moral choices [135]. In subregions of the PFC, pro-social behavior preferentially recruits the VMPFC and DLPFC. The results of functional connectivity analyses have suggested that the VMPFC and DLPFC may be involved in the assessment of pro-social behaviors and determining whether to engage in related behaviors, respectively [136]. Researchers employed an unsupervised dictator game to test subjects' pro-social tendencies, using continuous theta burst stimulation (cTBS) to interfere with the DLPFC and dorsomedial prefrontal cortex (DMPFC)

function of two prefrontal regions, and the results suggest a predominant tendency in humans to be pro-social when cognitive control is diminished [137].

The effects of the PFC on pro-social behavior could be modified. Compassion training can increase altruistic behavior associated with altered activation in brain regions involved in social cognition and emotion regulation, including the sub-parietal cortex, the DLPFC, and the connectivity of the DLPFC to the nucleus accumbens. Therefore, empathy can be cultivated through training, and strong altruistic behavior may result from the alteration of neurological regulation of understanding the suffering of others, executive and emotional control, and reward processes [138]. Interestingly, brain activity in the dorsal ACC and bilateral insula in response to pain was significantly reduced after individuals engaged in altruistic behavior. The decrease in pain-induced activation of the right insula was mediated by neural activity in the VMPFC. These results suggest that helping others could reduce the perception of unpleasantness [139].

In conclusion, the PFC activity affects decision-making in pro-social behavior. Through manipulation of the PFC, pro-social behavior can be increased or decreased. However, there are relatively few studies on the role of the PFC in pro-social behavior among groups. It seems that the plasticity of PFC responses for in-groups may also apply to members of out-groups. The neural mechanism underlying the difference in pro-social behavior among groups needs to be further explored.

5.2 Event-Related Potential Studies

In addition, ERP studies have found that when people consider pro-social behavior, a larger P300 amplitude can indicate intuitive pro-social motivation, and subsequent pro-social behavior can be predicted by the P300 amplitude [22]. Also, when individuals determined whether others needed help, the P300 increased significantly [140]. Implicit pro-social attitudes can affect pro-social behaviors. Using the implicit association test to detect pro-social attitudes, researchers have found an increase of N2 and P300 amplitudes, which predict subsequent pro-social behaviors [141]. However, there are currently few studies utilizing ERPs to investigate inter-group pro-social behavior, with the majority of research relying on fMRI. In future studies, it is crucial to emphasize and explore the use of ERPs in investigating inter-group pro-social behavior. This will help bridge the existing gaps in research and provide a more comprehensive understanding.

6. Conclusions

Individuals use facial recognition and memory to identify in-group members, or to classify out-group members [1,9,10]. This is then used to drive behavior during interactions with in-group or out-group members [12,80,108]. At present, research on the neural mechanisms

Table 1. Active brain regions related to intergroup social behavior.

Social behavior	Brain area											Refs		
	IC	CC	Amygdala	Midbrain	FFA	OFA	FC	TPJ	Striatum	STS	Thalamus		VTA	Hippocampus
Face recognition and memory									★					[32]
									★					[33]
									★					[38]
									★	★			★	[42]
			★						★					[54]
									★					[50]
									★					[32]
									★					[38]
		★		★					★			★		[44]
		★	★	★					★					[50]
Intergroup identification		★	★	★										[68]
			★											[82]
		★		★					★		★			[71]
		★		★										[73]
			★											[75]
			★						★					[81]
			★											[82]
			★											[83]
			★											[84]
			★				★			★				[85]
Empathy	★		★										★	[91]
								★	★					[95]
								★	★					[96]
		★	★											[107]
		★	★						★					[108]
		★	★											[109]
Pro-social behavior									★			★		[142]
									★					[122]
		★							★	★				[123]

In the table, the asterisk (★) represents the activated brain regions. IC, insular cortex; CC, cingulate cortex; FFA, fusiform face area; OFA, occipital face area; FC, frontal cortex; TPJ, temporoparietal junction; STS, superior temporal sulcus; VTA, ventral tegmental area.

of perceptual bias between groups is predominantly based on findings from human fMRI and ERPs studies as well as behavioral experiments. We summarized the findings from these studies and observed that in fMRI-based research, the FFA and OFA brain regions are primarily involved in facial recognition and memory. The cingulate cortex, amygdala, insular cortex, FFA, and frontal cortex appear to be implicated in intergroup identification. Additionally, the insular cortex and cingulate cortex are involved in empathy. Finally, the insular cortex, cingulate cortex, frontal cortex, and temporoparietal junction are implicated in pro-social behavior. These brain regions contribute to the regulation of social identity differentiation and various behavioral manifestations to varying degrees,

such as facial recognition and memory, intergroup identification, empathy, pro-social behavior (Table 1, Ref. [32,33,38,42,44,50,54,68,71,73–75,81–85,91,95,96,107–109,113,122,123,142]). Key brain regions, such as the FFA, ACC, amygdala, and PFC, do not appear to function independently. Instead, they form a dynamic neural network. Involved in the processing of facial recognition and memory, intergroup categorization, empathy and pro-social behavior. The PFC and basolateral amygdala (BLA) are simultaneously involved in facial recognition and memory, intergroup categorization, and pro-social behavior. In ERP-based studies, when it comes to facial recognition, individuals exhibit more negative amplitudes in N170 and N250 components when perceiving faces of

Table 2. Changes of event-related potentials related to intergroup social behavior.

Social behavior	Event-related potentials								Refs
	N170	P2	200–500 ms	N2	N250	P300	P3	500–900 ms	
Face recognition and memory	▼								[56]
	▼				▼				[57]
	▼				▼				[59]
								▲	[60]
			▼						[61]
								▲	[60]
Intergroup identification	▼			▼					[66]
		▼		▼					[98]
Empathy		▲		▲					[119]
				▲			▲		[120]
Pro-social behavior									

The triangles in the table represent the change in the amplitude of ERPs between in-group members and out-group members. The symbols ‘▲’ and ‘▼’ represent ERP waveforms, indicating a decrease and an increase in amplitude, respectively. ERP, event-related potential.

out-group members, while the amplitudes in the 200–500 ms and 500–900 ms time windows show more positive responses. During inter-group identification, P2 and N2 time windows exhibit more negative amplitudes. In the context of empathy, the involved ERPs show more positive amplitudes. P2, N2, and P3 time windows are collectively involved in facial recognition and memory as well as inter-group identification. These ERPs may reflect distinct electrical potential changes associated with differentiating recognition behaviors (Table 2, Ref. [56,57,59–61,65,66,98,119,120]). To gain a deeper understanding of inter-group differences, we have compiled a summary of the experimental methods employed (Table 3, Ref. [32,33,38,39,42,44,45,47,48,50,52,56,57,59–61,65,66,68,71,73–75,81–85,87,88,91–96,98,107–109,113,119,120,122,123,142]).

It is important to understand the social and neural mechanisms underlying the formation of inter-group bias as reducing this bias through effective interventions would improve overall social welfare. From a social science perspective, in modern society, the acceptance and tolerance of group heterogeneity is one important factor determining social and economic development [143–145]. Reducing inter-group differences by increasing social accommodation can promote inter-group trust and inter-group cooperation, as well as the implementation of pro-minority policies [146,147]. In fact, inter-group recognition has been found to be highly malleable in both real-world and laboratory experiments [138]. People with more experience interacting with out-group members showed lower implicit bias and better out-group facial memory. Laboratory training, such as exposure to positive out-group paradigms, proximity to out-group members, and intentional perception of similarities between out-group members and the self, could

alter perceptions of out-group members, thereby alleviating the identification of out-group members [17,110,148].

From a clinical perspective, with the emergence of an increasing number of research findings, the development of non-invasive techniques is continuously advancing. These techniques include quantitative electroencephalogram (EEG) measurements, brain connectivity data, and clinical data combined with machine learning algorithms to establish relevant models. Additionally, imaging technology has been used to detect changes in brain structure and function at multiple levels. Such integrated approaches enable us to more accurately diagnose and evaluate the cognitive functions of individuals with psychological disorders and establish scientific evaluation criteria [149–151]. By gaining an in-depth understanding of patients’ cognitive characteristics, we can translate scientific progress into clinical practice, thus formulating more precise treatment plans. These efforts will contribute to improving treatment outcomes and promoting individual recovery [152–154].

7. Limitations and Outlook

Despite a growing body of research aimed at uncovering the neural mechanisms behind social behavior, there are still some limitations. First, there are few experimental methods to study the neural mechanism of social differentiation recognition. This is because the current research on this issue is mainly based on human subjects. Therefore, the experimental methods that can be used are relatively limited. However, social decision and social behavior require complex neural analysis. The current experiments, either a social identification experiment or facial recognition experiment, not only elicit the response of a single brain region but joint participation of various brain regions within a neural network [66]. In future research, it is recommended

Table 3. Main references related to intergroup social behavior.

Social behavior	Participants	Stimuli	Methods	Refs
Face recognition and memory	Chinese young adults	64 Caucasian and 64 Chinese young adults' faces	fMRI	[32]
	17 Caucasian adults	192 photographs of unfamiliar Black men, Black women, White men, and White women	fMRI	[33]
	European American children, adolescents and adults	European American and African American face	fMRI	[38]
	15 Korean participants	2 African-American men, 2 African American women, 2 Caucasian men, and 2 Caucasian women	fMRI	[39]
	24 Han Chinese adults	64 Caucasian and 64 Chinese young adults' full-color face photos	fMRI	[42]
	16 native Spanish speakers	Familiar faces, unfamiliar faces and houses	fMRI	[44]
	25 white ethnicities	60 white and 60 black faces	fMRI	[45]
	13 Caucasians	Mixed Black and White faces	fMRI	
	39 typically developing	Subordinate-level discrimination based on faces	fMRI	[47]
	20 White participants	8 Black faces and 8 White faces	fMRI	[48]
	30 individuals with major depression	10 faces (5 female), all Caucasian	fMRI	[50]
	23 healthy individuals Asian, Black/African American and Caucasian			
	21 younger and 22 older	Female faces (25 each), younger and older faces (25 each), and emotional expressions (50 each).	fMRI	[52]
	16 White undergraduate students	80 Black and 80 White male faces	ERP	[56]
	20 Asian and 20 Caucasian participants	120 unfamiliar Caucasian and 120 unfamiliar Asian faces	ERP	[57]
43 students with Caucasian ethnic backgrounds	200 Caucasian and 200 Asian faces.	ERP	[59]	
36 healthy, right-handed Caucasian adults	432 unfamiliar Caucasian and 432 unfamiliar Chinese faces	ERP	[60]	
22 Caucasian undergraduates	240 Caucasian and 240 faces.	ERP	[61]	
118 White undergraduate students	Black or White face	ERP	[65]	
Intergroup identification	30 healthy right-handed Chinese students	Chinese facial pictures and African American facial pictures	fMRI	[68]
	20 White participants	Black and White faces	fMRI	
	21 healthy adult White and Asian volunteers	Black and White faces	fMRI	
	24 Caucasian males	All participants were first allocated to red and blue teams	fMRI	[71]
	14 Caucasian	Same- and other-ethnicity faces were randomly selected	fMRI	[73]
	17 right-handed undergraduates	A Black or White man holding either a handgun or similarly shaped object	fMRI	[75]
	African-American and Caucasian-American participants	African-American and Caucasian-American face	fMRI	[81]
	eight healthy, right-handed, adult males and females	Male and female faces described as Black or White	fMRI	[82]
	20 individuals of black ethnicity, and 22 individuals of white British ethnicity	Faces of black and white ethnicity	fMRI	[83]
	71 right-handed Japanese university students	20 pictures each for the Japan and South Korea conditions	fMRI	[84]
	22 White participants	Black and White ethnicity	fMRI	[85]
24 JP young adults	12 Caucasian Americans faces and 12 Japanese faces	fMRI	[87]	
19 Caucasian Americans				
15 Japanese-Americans				

Table 3. Continued.

Social behavior	Participants	Stimuli	Methods	Refs
Intergroup identification	24 Asians students 24 European students	12 right-handed healthy females and 12 right-handed males	fMRI	[88]
	20 right-handed, healthy participants of European decent	two White and two Black American male faces	fMRI	[91]
	47 White American	Black or White male face	fMRI	[92]
	88 3-year-old children	Eastern Asian, White, and Black face	fNIRS	[93]
	20 White participants	80 photographs each of White and Black faces, and 40 photographs of Asian faces.	fMRI	[94]
	16 participants	Three faces with neutral facial	fMRI	[95]
	558 participants, 252 males	Ingroup and out-group (Each group of 6 people)	fMRI	[96]
	Chinese participants	4 Chinese faces and 4 Black faces	ERP	[98]
Empathy	57 Chinese students	Three sets (Asian, black and white) of faces with neutral expressions	ERP	[66]
	37 Chinese students	16 faces divided into two groups (in-group members and out-group members)	fMRI	[107]
	17 Chinese and 16 Caucasian healthy college students	48 video clips showing faces of six Chinese (3 males) and six Caucasian models (3 males).	fMRI	[108]
	21 Chinese college students	16 Asian (8 females) and 16 Caucasian faces (8 females)	fMRI	[109]
	22 individuals (11 females)	64 color photographs	fMRI	[113]
	48 Chinese college students	Digital photographs of 16 Chinese models and 16 Caucasian models	ERP /fMRI	[119]
Pro-social behavior	40 Chinese male adults aged 18–28 years participated	16 Asian models and 16 Caucasian models	ERP	[120]
	20 Caucasian-Australian participants	Participants divided into two groups and observing video clips	fMRI	[74]
	19 participants	Pain vs. Gain (PvG) task	fMRI	[142]
	48 healthy students (24 females)	Participants were randomly allocated to either the red (24 participants) or green (24 participants) team	fMRI	[122]
	13 American and 13 Chinese	Photos of in-group and out-group	fMRI	[123]

Participants in the main literature of Table 3 encompass individuals of different ethnicities, ethnicities, skin colors, genders, and more. The Stimuli primarily focus on facial recognition, group atmosphere, and similar factors. The Methods employed primarily involve fMRI and ERPs. fMRI, functional magnetic resonance imaging; ERP, event-related potential.

to combine multiple experimental techniques, such as the use of multimodal imaging measures, the combination of fMRI and EEG or fMRI and transcranial magnetic stimulation (TMS), to improve the accuracy of experiments and obtain behaviorally relevant information from multiple perspectives [141,155–157]. Therefore, methods for recording neural activity more accurately in time and space are needed.

Second, the techniques we primarily rely on are mainly used to detect changes in brain activity in the cortical and shallow subcortical regions. There are still limitations in studying deep brain regions. However, experimental studies using mouse models have demonstrated the significant role of many deep brain regions, such as the hippocampus, locus coeruleus, and habenula, in the regulation of social behavior [158–160]. Nevertheless, due to technological limitations, it remains challenging to directly detect activity changes in these deep brain regions in humans.

Finally, most studies provide correlational analyses rather than direct causal relationships. While techniques such as transcranial Doppler (TCD) and transcranial magnetic stimulation (TMS) can partially address this issue, their accuracy is still limited in terms of temporal precision, stimulation patterns, and depth penetration capabilities [161,162]. Furthermore, due to the complexity of neural activity patterns, such as the presence of oscillations, accurately simulating such intricate dynamics remains challenging.

It seems that the use of animal models can partially overcome certain limitations. At present, some studies have used mice to explore the neural mechanisms of social behavior [163–165]. The availability of *in vivo* electrical recordings, *in vivo* microscopic imaging and optogenetics allows researchers to detect dynamic changes in complex neural networks and connect them to social behaviors [166,167]. The downside of these experiments is the extent to which the social behavior of animals is comparable to that of humans. However, it can still be regarded as a powerful supplement to experimental research with human subjects. Therefore, in future research, a more comprehensive understanding of the causal relationship between brain regions and social behavior may be achieved by integrating multiple approaches, including animal models, human studies, neuroimaging techniques, and behavioral experiments.

One other question that needs to be addressed in the future is understanding of the mechanisms underlying the plasticity of corresponding brain regions in response to inter-group contact. Although we know that inter-group contact leads to changes in these brain regions, the specific mechanisms involved are still not well understood and require further investigation.

Author Contributions

XZ and LT designed the study. XZ, LT, KP conducted data collection. KP prepared the figures and table. XZ and

KP wrote the initial draft. XZ, LT and KP participated in preparing the final draft. XZ and LT provided supervision and advice. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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