Social Medicine and Health Management (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/socmhm.2025.060205
ISSN 2616-2210 Vol. 6 Num. 2

Study of Interbrain Synchronization in Different Status

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Keywords: Brain Synchronization; Identity Status; Social Interaction

Abstract: This study investigates the brain synchronization patterns and underlying mechanisms of social interaction among individuals with different social statuses, revealing how social hierarchy influences interpersonal neural coordination. The findings provide theoretical support for understanding the relationship between social status and interpersonal interactions in social cognitive neuroscience, while advancing the research framework on how social hierarchy affects group collaboration through neural mechanisms.

1. Introduction

With the rapid advancement of neuroscience and brain research, researchers have increasingly shifted their focus from isolated brain activities to the coordinated patterns of multiple brain activities during social interactions, making inter-brain synchronization [1,2] (IBS) a prominent research focus. This synchronization refers to the coupling phenomenon of brain activities between two or more individuals during social interactions, typically measured using techniques such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), or functional near-infrared spectroscopy (fNIRS) [3,4]. Notably, social interactions do not occur in a vacuum. Individuals' identity status—including core dimensions like social class affiliation, power dynamics, and group role positioning—exert profound shaping effects on both the dynamic processes and final outcomes of social interactions [5]. Research has demonstrated that individuals occupying different social statuses exhibit distinct cognitive processing biases, emotional arousal patterns, and behavioral decision-making tendencies in specific social contexts. These differentiated manifestations likely stem from specific neural and physiological characteristics, particularly in functional connectivity or interbrain synchronization between brain regions [6]. Understanding how social status modulates neural connectivity holds crucial significance for unraveling the neural mechanisms underlying how social hierarchies influence interpersonal coordination, group cohesion, and even social inequality.

2. Brain synchronization between different identities and statuses

2.1 Brain Interconnectivity

Brain synchronization refers to the phenomenon where neural activities in two or more individuals' brains coordinate in time during social interactions. Its core mechanisms involve mirror neuron activation, phase-locking of neural oscillations, and coordination of higher-order cognitive regions[1-3]. Measurement-dependent hyper-scan techniques, where functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG) have become mainstream tools due to their high temporal resolution and flexible experimental environments, are employed. fNIRS monitors hemodynamic changes in the cerebral cortex to reflect neural activity, making it suitable for studying natural conversations or collaborative tasks. EEG directly captures synchronized neural oscillations, demonstrating millisecond-level neural coupling sensitivity.

2.2 Theoretical Basis

2.2.1 Social hierarchy

Social hierarchy refers to the relative positional differences formed among individuals within social networks based on dimensions such as power, status, and authority. These differences significantly influence the behavioral patterns and psychological processes of both interacting parties. Social hierarchy embodies fundamental organizational principles in human social interactions, characterized by elements like power asymmetry, status disparities, and authority structures [7]. By regulating cognitive strategies, emotional responses, and social behavioral patterns, social hierarchy ultimately affects neural synchronization characteristics during interactions [8].

2.2.2 Social Cognitive Neuroscience: The "Hierarchical Processing Theory"

The "Hierarchical Processing Theory" posits that differences in interbrain synchronization during social interactions stem from automated judgments of others 'social status and subsequent differential allocation of neural resources. First, individuals automatically prioritize hierarchical judgments of others' status during interactions, a process dependent on activation of the "social hierarchy perception network" [9]. Craik and Lockhart's 1972 framework proposing that processing depth determines cognitive outcomes laid the foundation for this theory[10]. When status differences are perceived, the brain activates a "resource allocation bias mechanism," showing significant variations in neural resource distribution between high-status and low-status individuals. Through brain imaging techniques, Bush et al. discovered that the prefrontal cortex and amygdala form a "threat monitoring and emotional regulation pathway." Low-status individuals exhibit significantly enhanced activation of this pathway due to perceived interaction risks, aligning with their cognitive biases of "behavioral compliance" and "threat avoidance." The dorsolateral prefrontal cortex, as the core decision-control region, shows markedly stronger activation in high-status individuals during decision-making compared to low-status groups, confirming their resource allocation tendency to prioritize "decision control" and "power maintenance" information. This differential allocation leads to divergent cognitive and emotional processing goals between parties[11]. Such neural resource allocation differences ultimately result in reduced interbrain synchronization. von Stein et al. noted that intercortical synchronization depends on the consistency of processing goals. In hierarchical decision-making interactions, high-status individuals rely on the dorsolateral prefrontal cortex for decision processing, while low-status individuals depend on the amygdala for threat monitoring. The functional divergence in neural activity between these regions disrupts the synchronization foundation of the prefrontal-amygdala pathway, resulting in significantly lower synchronization levels compared to peer groups. This neuro-synchronization mechanism provides direct evidence for the theoretical framework [12].

2.2.3 The "Empathy-Apathy Model" in Affective Neuroscience

The Empathy-Apathy Model examines how emotional sharing pathways are modulated, proposing that status differences alter the balance between emotional and cognitive empathy, thereby influencing brain synchronization patterns [13,14].

In scenarios where both parties interact on equal footing, the dual activation of "emotional empathy" and "cognitive empathy" drives intense synchronization between the brains. Schwartz et al. utilized EEG hyperscanning technology to discover that during emotional sharing tasks, individuals in equal status exhibit synchronized activation of two networks: the "emotional empathy network" formed by the amygdala and anterior insula, and the "cognitive empathy network" composed of the medial prefrontal cortex and temporoparietal junction. This synchronization significantly elevates alpha and beta wave synchronization between brain regions. The dual coupling pattern of "emotional resonance + intentional understanding" achieves high-intensity synchronization between the limbic system and default network, which is the key reason for the higher brain synchronization observed in groups with equal status[15].

When status disparities exist, individuals in higher social positions actively suppress emotional empathy to maintain "decision objectivity" and "authoritative image," resulting in reduced synchronization of the limbic system. Only in specific scenarios does the synchronization of cognition-related brain regions briefly increase. Falcon et al.'s study on emotional sharing tasks among SES-differentiated groups revealed that high-status individuals showed only 60% of the pre-insular cortex activation intensity compared to SES-matched groups, with 45% lower synchronization with low-status individuals, directly demonstrating the "emotional alienation" mechanism. Meanwhile, cognition-related brain regions (such as the dorsolateral prefrontal cortex) only briefly synchronize during "behavioral coordination needs," validating the core hypothesis of "synchronous dynamic regulation" in the model and explaining the emotional processing-level causes of reduced brain synchronization in status-differentiated groups [16].

The balanced regulation of the empathic network serves as the core driver of interbrain synchronization. Abu-Akel and Shamay-Tsoory systematically analyzed the neuroanatomical foundations of emotional empathy (amygdala, prefrontal cortex) and cognitive empathy (medial prefrontal cortex, temporoparietal junction), demonstrating that the coordinated or antagonistic modulation of these two empathy pathways directly impacts interbrain information transfer efficiency. Status disparities disrupt this balance by reducing synchronization in the limbic system while selectively enhancing synchronization in cognitive brain regions, thereby providing neural mechanistic support for the "empathy-detachment model" [17].

2.2.4 Social Psychology: The Identity Theory

The Identity Theory, from the perspective of group belonging, proposes that an individual's perception of identity consistency serves as a key mediating variable in neural synchronization, thereby influencing interbrain synchronization.

When interacting parties belong to the same identity group, activation of the "in-group identity network" enhances interbrain synchronization. Hinvest et al. used EEG hyperscanning technology to discover in natural conversation scenarios that when individuals perceive "identity congruence" with their interaction partner (such as peers or SES neighbors), the "in-group identity network" formed by the medial prefrontal cortex and posterior cingulate gyrus becomes significantly activated, generating a strong sense of "we" belonging. This sense of belonging drives "cognitive and emotional alignment" between both parties, ultimately leading to significant enhancement of prefrontal cortex synchronization, directly demonstrating the promoting effect of the same identity group on interbrain synchronization [18].

When significant identity disparities exist between individuals, this triggers "out-group categorization" that intensifies "self-other distinction" processing, leading to reduced brain synchronization. A 2025 study by Professor Li Xianchun's team on cross-SES (socio-economic status) community collaboration tasks revealed that, without identity intervention, participants' identification scores with "the other party belonging to a different social class" showed a significant negative correlation with prefrontal cortex synchronization ($r = -0.58$). However, when participants' identities were reconstructed as "community members" through intervention, their in-group identification scores increased by 30%, accompanied by a 25% rise in prefrontal cortex synchronization. These findings confirm that identity differences-induced "out-group categorization" enhances "self-other distinction" processing in the temporoparietal junction, reduces cognitive and emotional engagement with "out-groups," and ultimately results in decreased synchronization [19].

An individual's perception of "identity consistency" between self and others requires mediation through identity recognition to transform into interbrain synchronization changes. When interacting parties form "in-group" identity recognition, the brain enhances processing of "self-other cognitive alignment" in regions like the medial prefrontal cortex, promoting cognitive-emotional coordination. Conversely, when identity recognition manifests as "out-group" categorization, this processing is inhibited, thereby reducing interbrain synchronization. Cikara synthesized fMRI and EEG studies on group identity and neural processing, explicitly demonstrating a significant positive correlation between medial prefrontal cortex activation intensity and subjective ratings of in-group belongingness. This brain region indirectly influences interpersonal neural synchronization by regulating the depth of "self-other cognitive alignment" processing[20].

3. Research Methods

3.1 Natural Interaction Paradigm

In 2023, Ma Yina's research team employed super-resolution scanning technology to record neural activity in core brain regions including the prefrontal cortex (PFC) and temporal-parietal junction (TPJ) [21]. The study divided 120 participants into 40 groups, randomly assigning each group one leader (high-status) and two followers (low-status). Two intervention groups were established: the "team-building intervention group" (which engaged in 10-minute "name chain" activities before interactions) and the "non-intervention group." Brain activity during communication was monitored using fNIRS. Results showed that the dorsolateral prefrontal cortex (rDLPFC) synchronization between leaders and followers in the intervention group was significantly higher than in the non-intervention group. Notably, leaders' rDLPFC activity preceded followers 'by 1-6 seconds, a time difference linked to strong functional connectivity between rDLPFC and TPJ in leaders' brains. This indicates that high-status individuals enhance neural synchronization by actively predicting followers 'mental states. Additionally, leader-follower pairs demonstrated significantly higher synchronization than follower-follower pairs, with synchronization intensity positively correlating with communication quality (rather than frequency), confirming the critical role of high-status individuals' interaction strategies in neural coordination.

Jiang et al. employed a "natural emergence" approach to identity status manipulation, organizing 84 participants into 28 pre-set leader-free trios. These groups freely discussed the theme of "community activity planning." Through post-event questionnaire surveys and video-based behavioral coding, the most influential individuals within each group were identified as "natural leaders" (high status), while others were classified as "followers" (low status). EEG hyperscanning results revealed that the brain synchronization (INS) between natural leaders and followers was significantly higher than that among followers themselves. Moreover, synchronization intensity showed strong correlations with leadership communication skills such as "response accuracy" and "topic guidance ability," but not with speech frequency. This further validated the core conclusion of the natural interaction paradigm: "status differences trigger synchronization variations, and synchronization quality depends on high-status individuals' interactive capabilities" [22].

Kreinreich et al. expanded the identity status typology in the natural interaction paradigm by studying romantic partners (high social connection, implicit equality status) and strangers (low social connection, no explicit status). Through EEG recordings of brain synchronization during natural social interactions [23], the results showed that the partner group exhibited significantly higher gamma rhythm synchronization in the TPJ compared to the stranger group. This synchronization was anchored to moments of social gaze and positive emotions, independent of verbal content. These findings suggest that "social connection intensity" modulates synchronization among individuals with equal status in natural interactions, providing a complementary approach for applying the natural interaction paradigm in non-hierarchical status research.

3.2 Intergroup Interaction Paradigm

In their study, Yang et al. recruited 546 participants to form 81 "three-on-three" competitive groups. Each group was randomly assigned a leader (high-status) and two members (low-status). They established two groups: the "In-group Reinforcement Group" (informed before the competition that "group performance depends on collective cooperation and members should prioritize supporting each other") and the "No Reinforcement Group," with the competition task being a "knowledge quiz" [24]. Results showed that in the In-group Reinforcement Group, the synchronization of the inferior frontal gyrus (IFG, a core region of the observation-execution system) between leaders and members was significantly higher than in the No Reinforcement Group. This synchronization level positively correlated with behavioral indicators such as "leaders allocating more resources to members" and "members being willing to sacrifice personal interests for the group." However, while In-group Reinforcement enhanced cross-status synchronization within the group, it also intensified behavioral differentiation between the in-group and out-group. Members of the out-group showed significantly lower IFG synchronization compared to the in-group, confirming the dual effect of "in-group bonding enhancing cross-status synchronization but potentially exacerbating intergroup barriers" in intergroup contexts.

Reinero et al. 's study further validated the connection between synchronization and collective performance in the intergroup interaction paradigm. Using EEG fMRI recordings, the research monitored brain activity in four-person teams during both collaborative and individual work scenarios, while controlling for task interface consistency to eliminate stimulus interference [25]. The findings revealed that during team collaboration, intragroup members with different status positions exhibited significantly higher whole-brain intrinsic connectivity (INS) than individuals in solo work. Importantly, INS's predictive power for collective performance remained independent of in-group identification, demonstrating that "status-based role division" and "group belonging" act as dual moderating variables in the intergroup paradigm. These factors collectively shape the neural mechanisms underlying group collaboration.

Research on specific intergroup contexts (such as the Israeli-Palestinian conflict) [26] provides complementary evidence for this paradigm. Using fNIRS to examine brain synchronization between in-group (same ethnic group) and out-group (different ethnic group) individuals, the study found that high-status (community leaders) and low-status (ordinary residents) members within the in-group exhibited significantly higher behavioral synchronization and intergroup brain synchronization (IBS) in the inferior frontal gyrus (IFG) compared to their out-group counterparts of equivalent status. This confirms the synchronizing moderating mechanism in the intergroup interaction paradigm where "group identity takes precedence over individual status," offering valuable insights for cross-cultural identity-status synchronization research.

3.3 Task Collaboration Paradigm

The teacher-student interaction study published by Pan Yafeng's research group exemplifies the paradigm's application [27]. This study involved 34 pairs of teachers (high-status knowledge leaders) and students (low-status knowledge executors), implementing two task types: "scaffolding instruction" (where teachers guided students in solving math problems, with teachers as dominant figures and students as passive executors) and "independent problem-solving tasks." Brain activity in the prefrontal-temporal-parietal network was recorded using fNIRS. Results showed that during scaffolding instruction, the interbolus synchronization (IBS) between teachers and students 'prefrontal-temporal-parietal networks was significantly higher than in independent problem-solving tasks. This synchronization exhibited both "simultaneity" (instant alignment between teacher explanations and student comprehension) and "temporal lag" (time difference in teacher's waiting for student feedback). Further analysis revealed that teaching strategies like "detailed feedback" and "gradual guidance" significantly enhanced cross-status synchronization, while passive knowledge absorption by students reduced synchronization quality. The synchronization intensity showed a strong positive correlation with student academic performance, confirming the core conclusion of the task collaboration paradigm: "high-status individuals' active guidance enhances cross-status synchronization, which is strongly associated with task performance."

The Mother-Child Study: A Comparative Analysis of Stranger Collaboration [28] expanded the paradigm's identity status framework by examining 34 mother-child pairs (high intimacy + implicit status difference: mothers as dominant actors (high status) and children as executors (low status)) and strangers with children. Using a "synchronized puzzle task" recorded through fNIRS-ECG, the results showed that brain synchronization (INS) was higher in both cooperative and competitive scenarios compared to baseline levels. Notably, the mother-child group exhibited significantly greater INS than the stranger-child group. Autonomic nervous system synchronization showed positive correlation with neural synchronization during competition but no correlation during cooperation, indicating that the interaction between "social attributes and status-based division of labor" in collaborative tasks influences neural synchronization independently of physiological arousal.

Dumas et al.'s hand imitation collaboration study further revealed the directional synchronization in task collaboration [29]. The research paired 18 participants to spontaneously engage in hand imitation cooperation (alternating roles as demonstrators/high-status and imitators/low-status), recorded through dual EEG and video. Results showed that behavioral synchronization periods were significantly correlated with cross-brain synchronization networks in the right central parietal alpha-mu wave region, and high-frequency neural synchronization exhibited asymmetry (top-down modulation from demonstrators to imitators), validating the mechanism of "identity status division driving synchronization direction" in collaborative tasks.

While these paradigms differ in design, they all share a core objective: to uncover how status differences influence brain synchronization. Their distinct strengths complement each other: the ecological validity of the natural interaction paradigm compensates for the task collaboration paradigm's scenario limitations; the intergroup interaction paradigm's collective perspective expands individual-level research in natural interaction; and the precise control of the task collaboration paradigm resolves variable confounding issues in intergroup interaction.

4. Discussion

Research on brain synchronization between individuals with different social statuses has revealed the neural mechanisms through which social hierarchies influence interpersonal interactions. Status differences shape predictive behaviors and modulate functional brain connectivity, leading to unique synchronization patterns between leaders and followers. Social connections and interaction contexts significantly modulate synchronization intensity and functional effects. Current studies utilizing fNIRS and EEG have established the core role of brain synchronization in facilitating information exchange and maintaining group stability, yet the following limitations remain [30] : (1) Most research is conducted in controlled laboratory settings, leaving the synchronization characteristics between individuals with different social statuses (e.g., workplace hierarchies, social class groups) in natural environments inadequately explored, with ecological validity requiring improvement; (2) Existing studies predominantly employ temporary role assignments (e.g., designated leaders in experiments) rather than examining long-term stable social statuses (e.g., innate social class differences), making it difficult to reflect the neural effects of authentic hierarchical structures. Future research should integrate multidisciplinary approaches and expand study scenarios and subjects to not only deepen understanding of neural mechanisms in social hierarchy interactions but also provide crucial cognitive neuroscience evidence for building more harmonious and efficient group relationships.

5. Conclusion

In conclusion, research on brain synchronization between individuals with different social statuses provides new perspectives for understanding neural mechanisms in social interactions. Existing studies indicate that status differences influence information exchange and neural coordination between individuals, with factors such as social connections, perspective selection, and self-other overlap playing significant roles. Future research should further integrate multidisciplinary approaches to explore the mechanisms by which status differences affect brain synchronization, thereby providing scientific evidence to promote harmonious social interactions.

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