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A NEXUS OF NEURAL MECHANISMS OF COOPERATION AND SOCIAL CONFORMITY: TOWARD A NEURO-CULTURAL INTERDEPENDENCE MODEL

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Нейронные механизмы сотрудничества и социальной конформности: нейрокультурная модель взаимозависимости

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Abstract

Increasing evidence links cultural influences on brain activity to various cognitive and affective processes, necessitating an integrative framework to account for the dynamic interplay between culture, behavior, and neural function. The mechanisms of cooperation and social conformity within culture exhibit variable interdependence across contexts, manifested by distinct neural patterns. To address the isolated examination of these

Резюме

Растущее число научных работ связывает культурное влияние на активность мозга с различными когнитивными и аффективными процессами, что требует интегративной концептуальной основы для учета динамического взаимодействия между культурой, поведением и нейронными функциями. Механизмы сотрудничества и социальной конформности в рамках культуры проявляют переменную взаимозависимость в различных контекстах, которая также выражается в специфических паттернах

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Публикация подготовлена в результате проведения исследования (№ 24-00-013 «Адаптивные основы культуры: к пониманию культурных ориентаций через призму компромиссов истории жизни») в рамках Программы «Научный фонд Национального исследовательского университета “Высшая школа экономики” (НИУ ВШЭ)».

mechanisms, we propose a Neuro-Cultural Interdependence Model delineating four modes (competitive interdependence, conditional interdependence, selective interdependence, communal interdependence) characterized by specific neural signatures and behavioral tendencies within cultural contexts. These modes represent varying degrees of interdependence, elucidating how individuals interact and rely upon others in their cultural milieu. The framework posits a direct linkage between cultural orientations and neural activity, offering a novel perspective on culture's internalization and manifestation at the individual level, underscoring its embeddedness within neural processes influencing cognitive, affective, and behavioral inclinations in relation to others. Crucially, our proposed model highlights an isomorphic relationship between cultural orientations and their corresponding neural structures. It demonstrates that the mechanisms of cooperation and social conformity function concurrently at both the cultural and neural levels, revealing a direct parallel in how these elements operate. We conclude by providing recommendations for future elaboration and empirical validation of our model to be conducted using advanced neuroimaging techniques.

Keywords: cultural neuroscience; cultural orientations; neural correlates; cooperation; social conformity; interdependence.

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нейронной активности. Чтобы преодолеть изолированное рассмотрение этих механизмов, мы предлагаем нейрокультурную модель взаимозависимости, описывающую четыре режима (конкурентная взаимозависимость, условная взаимозависимость, избирательная взаимозависимость, общинная взаимозависимость), которые характеризуются специфическими нейронными коррелятами и поведенческими тенденциями в различных культурных контекстах. Эти режимы представляют различные степени взаимозависимости, проясняя, как индивиды взаимодействуют и полагаются на других в своей культурной среде. Данная модель постулирует прямую связь между культурными ориентациями и нейронной активностью, предлагая новый взгляд на интернализацию культуры и ее проявление на индивидуальном уровне, подчеркивая ее укорененность в нейронных процессах, влияющих на когнитивные, аффективные и поведенческие склонности в отношении других. Важно отметить, что предложенная нами модель подчеркивает изоморфные отношения между культурными ориентациями и соответствующими им нейронными структурами. Она демонстрирует, что механизмы сотрудничества и социальной конформности функционируют одновременно как на культурном, так и на нейронном уровнях, обнаруживая прямую параллель в том, как действуют эти элементы. В заключение мы предоставляем рекомендации для будущего развития и эмпирической проверки нашей модели с использованием передовых методов нейровизуализации.

Ключевые слова: культурная нейронаука, культурные ориентации, нейронные корреляты, сотрудничество, социальная конформность, взаимозависимость.

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Author Contributions

A. Godovanets delineated and described the specifics of various modes within the Neuro-Cultural Interdependence Model (NCIM), tabulated the model and identified neural correlates of cooperation. E. Monahhova outlined the neural correlates of social conformity and completed the full formatting of the article. E. Komyaginskaya explored how the NCIM relates to existing literature. A. Gallyamova and D. Grigoryev defined the research problem, shaped the framework of the NCIM, detailed the content of modes and proposed their labels.

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Вклад авторов

А. Годованец описала особенности различных режимов нейрокультурной модели взаимозависимости (NCIM), свела модель в таблицу и определила нейронные корреляты сотрудничества. Э. Монахова определила нейронные корреляты социальной конформности и отформатировала статью. Е. Комягинская описала, как NCIM соотносится с существующей литературой. А. Галлямова и Д. Григорьев сформулировали проблему исследования и структуру NCIM, а также детализировали содержание режимов и предложили их названия.

The intriguing question of why people act differently across cultures is thoroughly investigated in psychology. Our paper is the attempt to address the neurobiological underpinnings of cultural differences in cognition, emotion, and behavior, advancing the understanding that culture is not merely an external social influence, but embodied and reflected in individual neurophysiological processes that help humans form and maintain complex institutions. Cultural environments deeply intertwine with brain function, suggesting cultural values and practices are embedded within cognitive functions and behavioral processes (Han & Ma, 2015; Shkurko, 2020). The concept of gene-culture coevolution likely demonstrates our brains are shaped by both biological inheritance and cultural context, affecting not only functional organization, but also anatomical structure (Danilkina, 2020).

Cultural neuroscience, though a relatively nascent field, provides insights into how cultural beliefs and practices fundamentally influence social interactions, including individual experiences and perceptions. Yet, existing models do not fully capture neuronal variability across cultures. We propose our **Neuro-Cultural Interdependence Model**, based on the premise that most social interactions reflect human mechanisms for *cooperation* and *social conformity* (see Table 1 for definitions of the terminology used). Mechanisms that promote cooperation and social conformity operate at both cultural and neural levels (Gallyamova & Grigoryev,

Table 1

Glossary

Term	Definition
Culture	refers to collective adaptation to a specific ecology, shaping how people live in a particular society and encompassing values, attitudes, practices, and symbols that maintain societal functionality.
Cooperation	refers to an individual's tendency to interact with others to achieve mutual benefits to facilitate coordination and communication.
Social Conformity	refers to an individual's tendency to align their actions with those of others to facilitate coordination and achieve collective goals.
Interdependence	refers to the extent and manner in which individuals rely on each other to achieve personal and collective goals.
Mode	refers to a particular way or approach in which something occurs or is experienced, expressed, or done. In various contexts, it describes specific cultural forms or variations of behavior, interaction, or operation.
Competitive Interdependence	refers to a mode in which individuals prioritize personal goals over collective objectives, demonstrating strong autonomy and self-sufficiency. This is characterized by low levels of both cooperation and social conformity.
Conditional Interdependence	refers to a mode in which individuals' competitive behaviors and perceived status within a hierarchical social structure shape their interactions. This is characterized by low cooperation and high social conformity, where actions are moderated according to established social norms.
Selective Interdependence	refers to a mode in which individuals choose cooperative activities that align with their personal values and situational context, balancing personal autonomy with collaborative engagement. This is characterized by high cooperation and low social conformity.
Communal Interdependence	refers to a mode in which individuals highly value their roles within the collective, often placing group needs above personal desires. This is characterized by high levels of both cooperation and social conformity, fostering a deep commitment to collective goals.

2024). This dual presence enables a direct link between culture and the brain, suggesting that cultural orientations are isomorphic with similar structures and processes at these levels.

Different combinations of these mechanisms shape four modes of neuronal activities, behavioral tendencies, and cognitive functions. These modes demonstrate various forms of interdependence, which aid individuals in adapting to particular social environments. Although all modes may be activated in each individual, their prevalence varies across cultures due to local social influences. This framework establishes a direct interrelationship between cultural orientations and neural processes, offering insight into how culture is internalized and manifested at the individual level.

Neural Bases of Cultural Differences

Research demonstrates significant cultural variation accompanied by specific brain activity, particularly in how individuals process social information such as self-reflection and empathy. During social cognitive tasks East Asians typically show higher activity in the dorsal medial prefrontal cortex (dmPFC), lateral prefrontal cortex (lPFC), and temporo-parietal junction (TPJ), while Westerners exhibit stronger responses in the anterior cingulate cortex (ACC), ventral medial prefrontal cortex (vmPFC), and the insula (Han & Ma, 2015).

The model of cultural views of self differentiates between the *'independent self'* prevalent in individualistic cultures and the *'interdependent self'* that is predominant in collectivistic societies (Kitayama & Park, 2010). Each self-construal is linked to distinct patterns of brain activity: those with independent self-view show increased activity in the mPFC during self-reflective tasks and in the ACC when their freedoms are threatened, while those with interdependent self-view exhibit more activity in the TPJ when considering others' perspectives and in the ACC when conforming to a group (Han & Ma, 2015; Shkurko, 2020).

The approach to linking distinct neural activity to different self-construals offers valuable insights yet has limitations. Markus and Kitayama (1991) originally proposed that individuals possess both independent and interdependent selves, with the prominence of each varying according to the social context. This is supported by studies showing neural activity changes with experimental priming on the same task (Han & Ma, 2015; Knyazev et al., 2018), suggesting both long-term cultural experiences and short-term encounters influence brain mechanisms behind cognitive functions.

The concept of self-construals, as defined by Kitayama and Park (2010), links them to stable social elements such as values and goals. However, this poses a contradiction since many studies indicate that self-construals are highly flexible and context-dependent. This flexibility aligns with the idea of neuroplasticity, which emphasizes the brain's capacity to adapt quickly to various situations. Therefore, the current approach to studying neural differences based on static self-construals may require reevaluation. Developing a framework that recognizes the dynamic and fluid nature of neural responses to social environments could enhance our understanding significantly.

Additionally, equating independent/interdependent self-construals with individualism/collectivism can overlook the cultural nuances, as this has primarily been applied in Western and East Asian settings. However, Latin American cultures display collectivist values alongside a sense of individual self-perception (Krys et al., 2022). This variation is influenced by factors such as social ecology, resource allocation, ethnic diversity, and historical-religious contexts (Gallyamova & Grigoryev, 2023). Furthermore, within cultures classified as interdependent, there are distinctions between the *relational self*, which is linked to close personal relationships, and the *collective self*, which relates to a broader group identity. The relational self exhibits more pronounced activity in mPFC (Zheng et al., 2018).

The assumption that societies with high collectivism primarily focus on social cues lacks evolutionary evidence. Across cultures, individuals must interpret complex social cues, challenging the individualism vs. collectivism dichotomy. Even in independent cultures, decoding social information is vital for interpersonal strategies in competitive environments (Shkurko, 2020). These observations highlight the shortcomings of viewing culture through a single-dimensional lens. A more nuanced, multidimensional approach to interdependence would provide a clearer understanding of the relationship between culture and the brain.

Bridging Cultural Contexts and Brain Function

This perspective is informed by research from Tomasello et al. (2012) and Claessens et al. (2020), which highlight human cooperation and social conformity as essential to our evolutionary success (Gallyamova & Grigoryev, 2024). Humans have evolved to be ultrasocial, thriving in large groups – a trait vital for survival in varied and challenging environments. Social cohesion within these groups is maintained through mechanisms of social conformity, including strong group identity, adherence to group norms, and the enforcement of these norms by penalizing nonconformists. These processes are adaptive, changing to meet the demands of different physical and social environments. By examining these fundamental mechanisms, we can gain a deeper understanding of how the brain adapts to social life in diverse cultural settings. Therefore, we suggest that a focus on cooperation and social conformity is crucial for analyzing neural activities across different cultural contexts.

Adherence to social norms engages the dorsal posterior medial frontal cortex (pMFC), anterior insula (AI), anterior cingulate cortex (ACC), TPJ, and mPFC (Klucharev et al., 2009; Sanfey et al., 2003; Wu et al., 2016). These regions exhibit distinct patterns during norm violations, reflecting conflict detection, theory of mind, and emotional processing. Intriguingly, these structures are also associated with the self-construals suggesting a link between social conformity and neural activities reflective of self-construal (Kitayama & Park, 2010). This alignment supports the idea that the spectrum of independent to interdependent self-identities corresponds to an individual's capacity for social conformity.

However, social conformity alone does not fully capture the breadth of social interactions or the variety of neural responses seen in different contexts.

Cooperation is another complex social behavior involving mutual or coordinated efforts among individuals or groups to achieve a common goal or benefit. When engaging in cooperative tasks and social interactions, like the dorsolateral prefrontal cortex (dlPFC), ACC, precuneus, TPJ, and mPFC are activated (Emonds et al., 2012; Pisauro et al., 2022). These areas are essential for cognitive control, strategic thinking, collaborative problem-solving, and predicting cooperative-competitive shifts.

Cooperation and social conformity, while both rooted in evolved psychological predispositions for social interaction, differ in their focus. Cooperation focuses on achieving mutual goals through joint action planning and reward processing (Balconi et al., 2017). Conformity involves assessing social norms and the emotional impact of aligning with or deviating from group expectations, activating brain regions involved in evaluating normative behavior and processing emotions related to belonging (Cialdini & Goldstein, 2004). This suggests a complex interconnection between different facets of social interaction and neural activity.

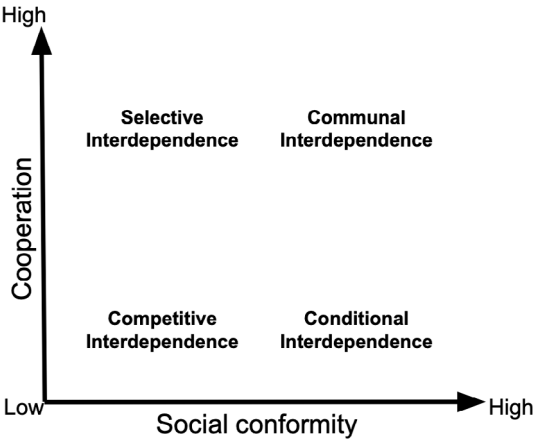
A Neuro-Cultural Interdependence Model

Our preliminary model, labeled the ***Neuro-Cultural Interdependence Model***, is deeply rooted in a new framework by Gallyamova and Grigoryev (2024) that examines cultural orientations through the lens of human behavioral ecology. This model posits that understanding the development and functionality of cultures requires recognizing the essential roles of the combination of cooperation and social conformity. It proposes an approach to categorize cultural orientations based on the prevalence of high and low levels of cooperation and social conformity. Further, our model contends that if culture serves as a collective adaptation to ecological conditions, then individual brains should have neural traits that enhance personal fitness. These traits support the maintenance of this collective adaptation and optimize functioning within its social influences. Consequently, different behaviors become more adaptive in different cultural contexts, each associated with specific patterns of brain activity. Crucially, our approach maintains that while individuals are capable of displaying each mode, the dominant social environment determines which mode is most effectively adapted to that specific context.

NCIM delineates four specific modes based on high and low levels of cooperation and social conformity across cultures: (1) *competitive interdependence* (low cooperation and low social conformity), (2) *conditional interdependence* (low cooperation and high social conformity), (3) *selective interdependence* (high cooperation and low social conformity), (4) *communal interdependence* (high cooperation and high social conformity), see Figure 1. Each mode represents how individuals differently engage with their cultural context, emphasizing cultural orientation diversity across societies and enhancing our understanding of implications for social behavior and neural mechanisms. The following descriptions focus on the key behavioral aspects associated with varying levels of cooperation, social conformity, and their interdependence. Key brain regions and functions are detailed in Appendix A. However, it is crucial to acknowledge the complexity of the neural

Figure 1

Neuro-Cultural Interdependence Model



processes involved in social behaviors. Our aim in this paper is to identify and categorize the brain regions potentially involved in each mode. By organizing existing research on neural activities related to cooperation and social conformity, we set the groundwork for further exploration of how the mechanisms of human cooperation and social conformity mutually unfold each other within cultural contexts and specific brain mechanisms.

Competitive Interdependence (Low Cooperation + Low Conformity)

This mode is characterized by individuals prioritizing personal goals over collective objectives. Social conformity may be reduced due to a stronger orientation towards autonomy and self-sufficiency. However, even in competitive settings, interdependence can still exist, particularly in achievement-focused task-groups requiring task specialization and strategic interactions. While interactions may emphasize individual advancement over mutual benefit, cooperation and interdependence are not entirely absent. The level of cooperation and social conformity to group norms is relatively lower than other modes but can vary based on context and task demands.

This mode is theorized to activate brain regions involved in mentalizing, competition, and self-conceptualization, such as the inferior parietal cortex, mPFC, and left precuneus. These areas are essential for interpreting opponents' intentions and navigating competitive interactions by balancing first-person and third-person perspectives, emphasizing their involvement in strategic thinking and managing competitive environments (Decety et al., 2004; Frith & Frith, 2003; Wang et al., 2023).

Regions like the ACC, AI, and pMFC are known to be activated during conflicts between personal motivations and external social norms or expectations. The ACC and AI focus on the emotional and cognitive challenges during social discord

(Nee et al., 2007; Palminteri et al., 2012), while the pMFC aids in decision-making and adapting behaviors in response to social conflicts and 'prediction errors,' serving as teaching signals in the reinforcement learning process (Klucharev et al., 2009; Shestakova et al., 2013). However, some studies suggest increased pMFC activity is associated with changing opinions or judgments to align with others, indicating a role in social conformity rather than conflict (Berns et al., 2010; Campbell-Meiklejohn et al., 2010).

Emotional and stress responses are significant, involving the vmPFC, dlPFC, nucleus accumbens (NACC), and amygdala. Research shows that negative emotions like guilt can impact decision-making, leading to increased neural activity in these areas when personal gain is at stake (Chang et al., 2011). Additionally, the amygdala plays a critical role in navigating social disagreements, with heightened activity aiding adaptation to contentious interactions (Klucharev et al., 2009).

Conditional Interdependence (Low Cooperation + High Conformity)

In the conditional mode of interdependence, one's perceived status or position within the hierarchical social structure is theorized to shape how competitive behaviors are expressed and moderated according to established social norms. Individuals are thought to strategically align their interactions and norm adherence as a means to effectively navigate these social landscapes and potentially secure competitive advantages relative to their social standing.

This mode involves the PFC, especially the lPFC, along with the vmPFC. These regions are critical for assessing social hierarchies and modulating emotional responses during competitive interactions, impacting societal perceptions and self-concept (Balconi & Vanutelli, 2016). The vmPFC and ventral striatum (VS) mediate reward recognition as individuals adjust behaviors to meet societal standards and expectations, demanding enhanced mentalizing abilities to predict others' mental states (Decety et al., 2004; Frith & Frith, 2003).

Adherence to social norms engages a complex network of brain regions integrating cognitive and emotional components of social conformity, aligning individual behaviors with broader societal expectations (Sanfey et al., 2003; Wu et al., 2016). The pMFC, crucial for cognitive control and decision-making, modulates susceptibility to social influence, while the insula and lPFC manage anxiety related to ostracism and behavioral adjustments for norm alignment (Berns et al., 2010; Campbell-Meiklejohn et al., 2010). ACC activation varies based on self-construal, increasing in individuals with an independent self-view when personal desires clash with social norms and in those with an interdependent view when social conformity is needed, underlining a neural foundation for prioritizing collective goals over personal ones (Shkurko, 2020).

Selective Interdependence (High Cooperation + Low Conformity)

In this selective interdependence mode, individuals balance personal autonomy with collaborative engagement, choosing cooperative activities aligning with personal

values and context. This allows engagement in collective actions harmonizing with individual ethical convictions and goals while maintaining autonomous decision-making capacity, diverging from mere group norm adherence.

Central to this mode is conditional cooperation, where a complex network of brain regions assesses the value and reliability of social information to align cooperative actions with both personal and societal goals. The vmPFC, frontopolar cortex, and VS are key in this evaluation process, while the AI and ACC foster emotional connections and social bonding, enhancing empathy and social affiliations that drive cooperative behaviors (Hein et al., 2010; Singer et al., 2004). Oxytocin modulates these neural responses, promoting trust and cooperation (Bartz et al., 2010; De Dreu et al., 2010). A sophisticated reward-based learning mechanism involving the VS and vmPFC processes reward prediction errors from cooperative acts, crucial for adjusting behaviors to maximize cooperative benefits. The caudate nucleus (CN) plays a pivotal role in adjusting actions based on fairness and reciprocity (Rilling et al., 2004).

Conversely, personal autonomy involves distinct activations during social conflicts or deviations from norms. The ACC, AI, and pMFC become particularly active when individuals' actions contradict group expectations, highlighting the neural underpinnings of conflict, cognitive dissonance, and cognitive control in autonomous decision-making (Berns et al., 2010; Izuma et al., 2010). The rostral ACC processes errors and conflicts, supporting autonomy against collective pressures, while the dlPFC is prominent in competitive and strategic scenarios, facilitating autonomous decision-making. Additionally, the amygdala manages stress from interpersonal disagreements, with increased activity during contentious interactions (Klucharev et al., 2009).

Communal Interdependence (High Cooperation + High Conformity)

In communal interdependence contexts, notable neural activation is theorized in areas related to empathy, reward processing, social cognition, and collective decision-making, reflecting an orientation towards community goals and norms. This hypothesized neural configuration enhances responsiveness to social stimuli, supporting behaviors prioritizing group objectives over individual ambitions, and fostering strong community bonds.

Individuals in this mode highly value their roles within the collective, often placing group needs above personal desires. This is supported by neural circuits within the reward processing network (VS, NACC, CN, ventromedial and orbitofrontal cortex, rostral ACC), facilitating altruistic behaviors and enhancing social cohesion by making cooperative interactions rewarding (Rilling et al., 2002; Tsoi et al., 2016). Dopamine plays a crucial role in this configuration, especially within the VS, aligning individual decisions with group norms and promoting social conformity (Wu et al., 2016; Schultz, 2015). Pharmacological studies show that dopamine modulation can impact social behaviors (Campbell-Meiklejohn et al., 2012).

For social cognition, the TPJ, superior temporal sulcus (STS), and inferior parietal lobule (IPL) are critical. TPJ is essential for theory of mind, crucial for understanding others' perspectives and predicting social outcomes in cooperative and competitive

settings (Decety & Grèzes, 2006). Neural substrates for empathy, guilt, and reputation management (ACC, insula, lPFC, and supplementary motor area [SMA]) play roles in emotional connection with others and adhering to expectations. Neuroimaging studies demonstrate that empathetic responses vary based on social ties, with differential activity in the insula and ACC depending on whether interactions involve ingroup or outgroup members (Hein et al., 2010; Singer et al., 2006). Anticipated guilt can activate these regions, steering behaviors towards greater social conformity (Chang et al., 2011; Emonds et al., 2012). Additionally, the pMFC engages when individuals change their opinions to align with the group's, suggesting its role in facilitating group opinion change (Campbell-Meiklejohn et al., 2010; Berns et al., 2010).

Connectives with Other Frameworks

The importance of cooperation and social conformity, along with their interaction, is widely recognized across various social science disciplines. In the study of cultural orientations, models often differentiate based on interaction forms for common goal achievement and self-construal (e.g., Triandis, 1996). From human behavioral ecology perspective, Gallyamova and Grigoryev (2024) suggest that four combinations of cooperation and social conformity lead to four distinct cultural orientations. This idea echoes anthropological research, such as relational models theory (Fiske, 1991), which proposes four elementary models organizing social interactions across societies, encapsulating varying cooperation and social conformity levels and associated morals (Rai & Fiske, 2011). Douglas's plural rationality theory (1978) delineates on the degree of social conformity (*group*) and the rules of cooperation within groups (*grid*). These combinations of social dimensions help to explain how resources are distributed in different relational models (Favre & Sornette, 2016) and enhance our understanding of neuroscience, particularly through the lens of Damasio's somatic marker hypothesis (Verweij et al., 2015).

In intergroup relations, these constructs are reflected through the universal *horizontal* and *vertical* dimensions, essential for effective social navigation (Fiske et al., 2007). The Dual Foundations Theory distinguishes between *threat-driven conformity vs. individualism* and *empathy-driven cooperation vs. competition* trade-offs that shape social worldviews and political ideologies, stemming from them (Claessens et al., 2020). In organizational psychology, *cooperativeness* and *assertiveness* present primary conflict resolution styles that mainly vary in the extent to which an individual seeks to satisfy their own or others' interests (Thomas, 2008). By focusing on cooperation and social conformity, this approach facilitates exploration of interconnections across various disciplines, as illustrated in Table 2, which outlines theoretical intersections.

Conclusion

The proposed NCIM captures fundamental types of social interaction by integrating cultural contexts, behavioral patterns, and brain functions. It classifies cultural

Table 2

Connectives of the Other Frameworks with NCIM

		Social conformity	
		Low	High
Cooperation	High	**Selective Interdependence** *Culture Orientation:* Horizontal Individualism *Relational Model:* Equality Matching *Moral:* Equality *Cultural Bias:* Low Group + Low Grid (Individualists) *Conflict-Handling Style:* Collaborating/Compromising	**Communal Interdependence** *Culture Orientation:* Horizontal Collectivism *Relational Model:* Communal Sharing *Moral:* Unity *Cultural Bias:* High Group + Low Grid (Enclaves) *Conflict-Handling Style:* Accommodating/Cooperating
	Low	**Competitive Interdependence** *Culture Orientation:* Vertical Individualism *Relational Model:* Market Pricing *Moral:* Proportionality *Cultural Bias:* Low Group + High Grid (Isolates) *Conflict-Handling Style:* Competing/Avoiding	**Conditional Interdependence** *Culture Orientation:* Vertical Collectivism *Relational Model:* Authority Ranking *Moral:* Hierarchy *Cultural Bias:* High Group + High Grid (Hierarchies) *Conflict-Handling Style:* Compromising/Competing

orientations into distinct modes, each characterized by specific neural activities and behavioral tendencies, focusing primarily on two key mechanisms: cooperation and social conformity. We have developed a framework that merges these mechanisms, outlining their behavioral expressions and identifying potential brain regions that are involved at the intersection of these mechanisms across different forms of interdependence. In formulating the model, we concentrated on associations between regions-of-interest (ROI) and functions, as the existing literature predominantly highlights specific brain areas and cognitive processes relevant to how our model conceptualizes these interactions.

Moving forward, the next step in refining NCIM involves clarifying the specifics of activation and deactivation within each mode and detailing the structural and functional connectivity of the described ROIs in the human brain to develop a comprehensive understanding of the relationship between brain activity and behavior. As an example of this approach's effectiveness, we can refer to the work of Firat (2021), who describes the anatomical and functional connections of the prefrontal cortex to elucidate behavioral responses. Functional neuroimaging was used to show how values operate through explicit processes in the dlPFC and implicit processes in the vmPFC, through describing the connections of vmPFC with sensory cortices and limbic structures, highlighting its role in cognitive and behavioral processes, while also detailing the role of dlPFC in executive functions and cognitive control. This dual perspective effectively links brain regions with specific behavioral outcomes, providing valuable insights into behavioral mechanisms. We aim to employ a similar approach for further refinement of NCIM.

By linking neural signatures to specific modes of interdependence, our model elucidates the dynamic brain-culture interplay guiding individuals' cognitive, affective, and behavioral inclinations during social interactions. This highlights the plasticity of neural circuitry's interaction with cultural orientations, suggesting social mechanisms such as cooperation and social conformity are shaped both culturally and biologically. By creating this isomorphic framework, our approach

enhances cultural neuroscience by exploring how social interaction mechanisms are manifested across different cultural contexts and neurobiological systems. This integration of insights from several fields highlights the significance of NCIM for future empirical research.

To validate and enhance our model, we suggest using advanced neuroimaging techniques, such as fMRI and fNIRS hyperscanning. These methods allow for real-time, simultaneous observation of brain activation patterns across individuals in various experimental settings, ranging from cooperative to competitive scenarios. The foundational research by Balconi and Vanutelli (2017) and Wang et al. (2023) provides a strong methodological base for further studies to examine how neural responses correlate with our predictions, deepening our understanding of the neurobiological basis of culturally modulated behaviors in different sociocultural contexts and modes of interdependence.

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Appendix A

Brain Regions, Behavioral Aspects, and Cognitive Processes Associated with the proposed NCIM

Brain regions \ Mode	Competitive Interdependence (Low Cooperation + Low Conformity)	Conditional Interdependence (Low Cooperation + High Conformity)	Selective Interdependence (High Cooperation + Low Conformity)	Communal Interdependence (High Cooperation + High Conformity)
anterior cingulate cortex (ACC)	**SOCIAL CONFLICT, DISAGREEMENT WITH THE GROUP:** (Emonds et al., 2012) (Klucharev et al., 2009) **CONFLICT AND PUNISHMENT PROCESSING:** (Shenhav et al., 2016)	**ADHERING TO SOCIAL NORMS:** (Wu et al., 2016; Sanfey et al., 2003) **INDIVIDUAL'S SELF-CONSTRUAL:** (Shkurko, 2020)	**EMPATHY:** (Singer et al., 2004; Singer et al., 2006). **RECIPROCAL COOPERATION:** (Emonds et al., 2012) **PERSONAL AUTONOMY:** (Klucharev et al., 2009)	**REWARD PROCESSING, ALTRUISTIC BEHAVIOUR:** (Rilling et al., 2002; Tsoi et al., 2016). **EMPATHY:** (Singer et al., 2004; Singer et al., 2006). **RECIPROCAL COOPERATION:** (Emonds et al., 2012) **MEETING THE EXPECTATION OF OTHERS, GUILT, SOCIAL PAIN:** (Chang et al., 2011)
lateral prefrontal cortex (lPFC)	**TRUST ABUSE AND GAIN MAXIMIZATION:** (Chang et al., 2011)	**EVALUATION OF SOCIAL STATUS AND HIERARCHIES:** (Balconi & Vanutelli, 2016) **REPUTATION MANAGEMENT:** (Campbell-Meiklejohn et al., 2010)	**STRATEGIC PROCESSES:** (Stallen & Sanfey, 2013)	**REPUTATION MANAGEMENT:** (Campbell-Meiklejohn et al., 2010) **MEETING THE EXPECTATION OF OTHERS, GUILT, SOCIAL PAIN:** (Chang et al., 2011)
insula	**CONFLICT AND PUNISHMENT PROCESSING:** (Nee et al., 2007; Palminteri et al.,2012)	**ADHERING TO SOCIAL NORMS:** (Wu et al., 2016; Sanfey et al., 2003) **ANXIETY AND FEELINGS OF OSTRACISM:** (Berns et al., 2010)	**EMPATHY:** (Singer et al., 2004; Singer et al., 2006). **PERSONAL AUTONOMY:** (Berns et al., 2010)	**EMPATHY:** (Singer et al., 2004; Singer et al., 2006) **IN-GROUP AND OUT-GROUP MEMBERS, SOCIAL PAIN:** (Hein et al., 2010) **ANXIETY AND FEELINGS OF OSTRACISM:** (Berns et al., 2010) **MEETING THE EXPECTATION OF OTHERS, GUILT, SOCIAL PAIN:** (Chang et al., 2011)
medial prefrontal cortex (mPFC)	**ADHERING TO SOCIAL NORMS:** (Wu et al., 2016; Sanfey et al., 2003)	**COMPETITION:** (Decety et al., 2004; Balconi et al., 2017) **MENTALIZING:** (Frith & Frith, 2003; Decety et al., 2004) **ADHERING TO SOCIAL NORMS:** (Wu et al., 2016; Sanfey et al., 2003; Van Overwalle, 2009) **SOCIAL INFLUENCE AND CONFORMITY:** (Klucharev et al., 2011)	**ASSESMENT OF SOCIAL INFORMATION RELIABILITY:** (Klucharev et al., 2011) **REWARD PROCESSING:** (Rilling et al., 2002; Stallen & Sanfey, 2013)	**REWARD PROCESSING, ALTRUISTIC BEHAVIOUR:** (Rilling et al., 2002; Tsoi et al., 2016)
ventral striatum (VS)	**TRUST ABUSE AND GAIN MAXIMIZATION:** (Chang et al., 2011)	**SOCIAL REWARD PROCESSING:** (Klucharev et al., 2009)	**ENCODING REWARD PREDICTION ERRORS:** (Schultz, 2015)	**REWARD PROCESSING, ALTRUISTIC BEHAVIOUR:** (Rilling et al., 2002; Tsoi et al., 2016) **SOCIAL CONFLICT RESOLUTION:** (Wu et al., 2016) **ENCODING REWARD PREDICTION ERRORS:** (Schultz, 2015)
temporoparietal junction (TPJ)	**SOCIAL CONFLICT, DISAGREEMENT WITH THE GROUP:** (Emonds et al.,2012)	**ADHERING TO SOCIAL NORMS:** (Wu et al., 2016; Sanfey et al., 2003)	**SELF-RELATED COGNITIONS:** (Decety & Grızes, 2006)	**SOCIAL COGNITION (THEORY OF MIND):** (Decety & Grızes, 2006) **SELF-RELATED COGNITIONS:** (Decety & Grızes, 2006) **MONITORING DECISIONS OF OTHERS:** (Campbell-Meiklejohn et al., 2010) **MEETING THE EXPECTATION OF OTHERS, GUILT, SOCIAL PAIN:** (Chang et al., 2011)
posterior medial frontal cortex (pMFC)	**SOCIAL CONFLICT, DISAGREEMENT WITH THE GROUP, REINFORCEMENT LEARNING:** (Shestakova et al., 2013; Klucharev et al., 2009) **REWARD PROCESSING, AUTONOMOUS BEHAVIOR:** (Klucharev et al., 2009)	**COGNITIVE CONTROL AND DECISION-MAKING:** (Berns et al., 2010)	**COGNITIVE CONTROL AND DECISION-MAKING:** (Berns et al., 2010) **COGNITIVE DISSONANCE:** (Izuma et al., 2010)	**ADHERING TO GROUP OPINION, ADVICES AND OPINIONS:** (Campbell-Meiklejohn et al., 2010; Berns et al., 2010)
amygdala	**SOCIAL DISAGREEMENT STRESS:** (Klucharev et al., 2009)	**ADHERING TO SOCIAL NORMS:** (Adolphs, 2003)	**SOCIAL DISAGREEMENT STRESS:** (Klucharev et al., 2009)	