Understanding Interpersonal Function in Psychiatric Illness Through Multiplayer Economic Games

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Interpersonal factors play significant roles in the onset, maintenance, and remission of psychiatric conditions. In the current major diagnostic classification systems for psychiatric disorders, some conditions are defined by the presence of impairments in social interaction or maintaining interpersonal relationships; these include autism, social phobia, and the personality disorders. Other psychopathologies confer significant difficulties in the social domain, including major depression, posttraumatic stress disorder, and psychotic disorders. Still other mental health conditions, including substance abuse and eating disorders, seem to be exacerbated or triggered in part by the influence of social peers. For each of these and other psychiatric conditions, the extent and quality of social support is a strong determinant of outcome such that high social support predicts symptom improvement and remission. Despite the central role of interpersonal factors in psychiatric illness, the neurobiology of social impairments remains largely unexplored, in part due to difficulties eliciting and quantifying interpersonal processes in a parametric manner. Recent advances in functional neuroimaging, combined with multiplayer exchange games drawn from behavioral economics, and computational/quantitative approaches more generally, provide a fitting paradigm within which to study interpersonal function and dysfunction in psychiatric conditions. In this review, we outline the importance of interpersonal factors in psychiatric illness and discuss ways in which neuroeconomics provides a tractable framework within which to examine the neurobiology of social dysfunction.

Key Words: Decision making, interpersonal function, multi-agent games, neuroeconomics, psychiatric illness, social neuroscience

At least three prominent psychiatric conditions are characterized by difficulties in interpersonal functioning: borderline personality disorder (BPD; and the personality disorders more generally), autism, and social phobia. Individuals with BPD have unstable and intense social relationships (1) and exhibit social problem-solving deficits (2,3), and "frantic efforts to avoid abandonment" is the DSM-IV criterion for BPD with the highest specificity and positive predictive power (4). Social impairments are also included in the imperative criterion of autism spectrum disorder (ASD) (1), and individuals with autism display minimal social reciprocity and exhibit limited interest in social interactions (5,6). In social phobia, individuals experience debilitating fear of judgment or embarrassment in interpersonal situations that contributes to avoidance of social interactions (1,7,8). This is by no means an exhaustive list, and several other psychiatric conditions are defined in part by interpersonal difficulties (e.g., paranoid schizophrenia [1], psychopathy characterized by patterns of manipulating others' emotions and lack of empathy and, in children, conduct and oppositional defiant disorder characterized by aggression and defiance toward others; for review, see Blair *et al.* [9]).

In other psychiatric conditions, interpersonal dysfunction is not an imperative criterion but rather a debilitating sequela of illness. For example, individuals with major depressive disorder report greater distress from interpersonal difficulties (10), more negative interactions with partners (11), fewer social supports (12), and impaired family functioning (13) relative to control groups. In comparison, those with posttraumatic stress disorder (PTSD) exhibit anger and interpersonal aggression as complicating factors in social relationships and critical barriers to effective treatment (for meta-analysis, see Orth and Wieland [14]). Anger and aggression affect the therapeutic process, particularly among those with combat-related PTSD (15–17), and damage interpersonal relationships that are essential to the social support necessary for recovery of functioning (18–27).

As an essential first step, the foregoing data provide excellent descriptive accounts of critical domains of interpersonal dysfunction in psychopathology, from social withdrawal in major depression to an impaired ability to make social inferences in autism. Equally apparent from this work, however, is the conspicuous absence of a unifying framework within which to programmatically examine the interpersonal difficulties seen in psychiatric illness. Neuroeconomics, and quantitative/computational approaches to social behavior more generally, provides a conceptual framework that facilitates explanatory insights into the interpersonal phenomena and associated neurobiology that accompany psychiatric illness.

Multiplayer Games and Learning Models Facilitate a Computational Neuroscience of Social Behavior

In many ways, the late arrival of interpersonal anomalies to a biological understanding of psychiatric illness is not surprising—social signals are a vast and difficult domain to quantify and parameterize. However, converging interest from a variety of fields—from behavioral economics to machine learning to psychology and neuroscience—is bringing a powerful set of tools to bear on the understanding of basic neural computations of social interaction and, by extension, pathologies of social behavior (see also Hasler [28] and our related discussion in Kishida *et al.* [29]). Here we outline advances in two areas, behavioral economics and machine learning, that provide traction for understanding social behavior and the neuroscience of how it breaks down in psychiatric illness.

Behavioral Economic Approaches to Social Behavior

For more than half a century, mathematicians and economists have studied how humans make decisions with, about, and among one another (30). These decisions are often studied as utility-maxi-

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mizing choices made within structured economic settings, and the underlying phenomena have been of common interest to social psychologists and behavioral economists alike: prosocial behavior, social influence, social biases, norm violations, interpersonal relations, and group dynamics. Two features of behavioral economics recommend it to the study of social behavior and its pathologies. First, behavioral economics offers a rich set of well-characterized paradigms with which to evaluate social interactions (31). An even greater contribution, however, lies in the quantitative performance benchmarks for behavior that accompany these paradigms. That is, economics offers mathematical depictions of interpersonal dynamics, and in doing so suggests mechanistic accounts of normative social behavior against which pathological dynamics and neural function can be verified or dismissed. This contribution is critical, as mathematical models of social behavior represent an intermediate level of description that has the potential to link social phenomenology to neurobiological mechanisms, not unlike the role that psychophysical models in vision science have played in explaining visual illusions in terms of their underlying neurophysiology (e.g., apparent motion illusion in terms of adaptation of receptive fields) (32).

Behavioral economic methods for examining social behavior typically extend from game theoretic principles. Game theoretic paradigms or "games" consist of a set of participants ("players" or "agents," each with "preferences"), a set of behavioral options ("strategies") available to those players, a formalized structure including "order of moves," a specification of outcomes ("payoffs") for each combination of strategies, and task instructions ("information") that provide participants with payoff-relevant variables. By varying the strategies, payoffs, and structural features of these interactions, seemingly simple exchange games can be adapted to elicit and evaluate an assortment of social phenomena—from discrimination to prosocial behavior, and intergroup dynamics to high order social cognition (33–36). A variety of multiagent economic games have received attention for their utility in parsing the behavioral dynamics associated with social preferences (e.g., fairness instincts in ultimatum, dictator games) and strategic cooperation and competition (e.g., prisoner's dilemma, stag's hunt, trust games). Social interactions elicited in the context of these games can be modeled and then related to measures of neural activity, using tools such as positron emission tomography (37), functional magnetic resonance imaging (38), near infrared spectroscopy (39), and electroencephalography (40).

For example, in neurotypical participants, much progress in understanding neural signals critical to trust and cooperation has been made using variants of a simple trust game (41,42). In a trust game, an individual has the opportunity to entrust a valued resource (often money) in a social partner, with the hope that the partner will repay that trust with a return on their investment. Trust can thus be operationalized as the amount of resources invested, and trust or cooperation between individuals develops and is maintained when trust is repaid. When trust is broken, cooperation falters. This basic paradigm was used in one of the first functional neuroimaging studies in which interacting participants were scanned simultaneously and identified neural responses that predicted intention to trust and reputation formation (38). The trust game has now been used in neuroimaging studies as a sensitive and parameterized assay of many aspects of trust and cooperative exchange (43–48).

Machine Learning Approaches to Social Behavior

Machine learning approaches, particularly reinforcement learning, have been increasingly applied to multiagent games to describe the mechanisms by which humans learn, navigate, and make choices in social environments (for review, see Behrens *et al.* [49]). In basic reinforcement learning, individuals have expectations about the values associated with potential actions, and ongoing differences between predicted and obtained outcomes ("prediction errors") dynamically update action-value pairings and influence subsequent decisions ([50–56]; for discussion of the utility of reinforcement learning models for understanding psychiatric illness, see Montague *et al.* [57] and Maia and Frank [58]). Social actions are similarly drawn from a behavioral repertoire (e.g., share, cooperate, defect) and have intended effects and associated outcomes that change over time and social context. Reinforcement learning approaches can thus be applied to multiagent settings to test specific variables that contribute to interpersonal dysfunction (e.g., value of one's own social decisions, value of a partner's actions, learning social action-value pairings, updating social expectations, etc.).

Using this approach, Behrens *et al.* (59) as well as Burke *et al.* (60) found that learning from personal experience and learning from social partners combine to influence decisions through separable neural learning signals reflected in hemodynamic activity in ventral striatum and prefrontal cortex (PFC). Learning in social environments can also incorporate rich scenarios that take into account the mental states of others. For example, when an employer decides to check (or not) the work of an employee, a value calculation is made: it is costly to take the time to check the work, but checking may induce the employee to do better work in the future if s/he thinks the employer will keep checking. In this way, the value of checking depends, in part, on how the employer believes the action will influence the future choices of the employee. Computational models have begun to delineate neural signals that track beliefs about the mental states of others in diverse social settings, including this "work or shirk" dilemma (61), games of cooperation (62,63), bargaining (64), and competitive learning (65). As outlined below, these models applied to multiplayer games are relevant for examining the role of social inference and its underlying neurobehavioral mechanisms in interpersonal impairments associated with psychopathology.

Multiplayer Economic Games Quantify the Behavioral Dynamics and Neurobiology of Social Difficulties in Psychiatric Illness

Neural signals measured in real-time interpersonal interactions combined with formal computational models of social dynamics, provide powerful tools with which to explore normative and abnormal social behavior. The framework is ostensibly simple: to understand the neurobiology of social dysfunction, one must measure neural activity as participants engage in social interaction or make social decisions. However, social interaction and psychiatric illness are each uniquely difficult to assess because the state space of social behaviors is vast, and there are few external indicators of psychopathology beyond self-report and symptoms ascertained through clinical interviews or behavioral observation to aid in objective psychiatric diagnosis.

Multiplayer economic games provide one tool to evoke, monitor, and measure the degree and type of social impairment in distinct psychiatric illnesses. As noted earlier, one significant contribution of behavioral economics is quantitative performance benchmarks for social behavior. Specifically, measurements from individual subjects can be compared against these metrics, and these benchmarks can be used to design realistic social partners. Although the preferred players for basic behavioral economics par-