Neural mechanisms tracking popularity in real-world social networks

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Contributed by Peter S. Bearman, October 16, 2015 (sent for review August 31, 2015; reviewed by Emily B. Falk, Matthew D. Lieberman, and Alexander Todorov)

Differences in popularity are a key aspect of status in virtually all human groups and shape social interactions within them. Little is known, however, about how we track and neurally represent others' popularity. We addressed this question in two real-world social networks using sociometric methods to quantify popularity. Each group member (perceiver) viewed faces of every other group member (target) while whole-brain functional MRI data were collected. Independent functional localizer tasks were used to identify brain systems supporting affective valuation (ventromedial prefrontal cortex, ventral striatum, amygdala) and social cognition (dorsomedial prefrontal cortex, precuneus, temporoparietal junction), respectively. During the face-viewing task, activity in both types of neural systems tracked targets' sociometric popularity, even when controlling for potential confounds. The target popularity–social cognition system relationship was mediated by valuation system activity, suggesting that observing popular individuals elicits value signals that facilitate understanding their mental states. The target popularity–valuation system relationship was strongest for popular perceivers, suggesting enhanced sensitivity to differences among other group members' popularity. Popular group members also demonstrated greater interpersonal sensitivity by more accurately predicting how their own personalities were perceived by other individuals in the social network. These data offer insights into the mechanisms by which status guides social behavior.

social status | fMRI | social network | popularity | social cognition

Humans are a fundamentally social species, and the social networks in which we are embedded significantly determine our physical and psychological well-being (1). Effectively navigating interactions within these networks requires efficient mechanisms for processing social information about network members. This ability is so important that it may be among the foremost computational challenges that influenced primate evolution, particularly the dramatic development of our "social brains" (2, 3).

Differences in popularity reflect status inequalities that shape social interaction within virtually all human groups across an enormous array of contexts, from classrooms to military barracks to voluntary associations and beyond (4–8). For decades, social scientists have used sociometric assessment and social network analysis (SNA) to measure the organization of groups and individuals' positions within them. Using these techniques, the extent to which each group member is collectively liked by group members—termed sociometric popularity—can be quantified (5, 9, 10). Highly likeable individuals attract group members and elicit their affiliation with warmth, altruism, and related traits like agreeableness (5, 10–12). Sociometric popularity disparities arising from asymmetries in group members' liking ties are present in virtually all human groups and constitute a fundamental basis for status differentiation (4, 5).

The fact that differences in popularity have important behavioral consequences raises the question of how we recognize these differences in the first place. Consider, for example, that in our everyday social networks, we recognize that certain group members are collectively liked more than others, even when this consensus preference differs from our own. Adults and even children can perceive other group members' asymmetric liking ties, detect differences in their relative popularity, and accordingly orient attention and affiliative behavior toward popular individuals (5–8). Achieving such acute sociometric awareness and attunement to popular group members might feel like second nature to us, yet little is known about the underlying neural mechanisms. Here, we combined functional MRI (fMRI) and SNA to investigate how the human brain tracks the popularity of members of real-world social networks.

To provide new insights into the neural mechanisms that undergird navigation of our complex social worlds, we addressed three interrelated questions. First, which brain systems track real-world popularity? Second, what is the functional organization of those systems? And third, does one's own status predict more or less neural attunement to others' status? Although no prior human research has investigated these questions, the extant literature suggests that two distinct types of brain systems may be involved in tracking popularity.

The first is comprised of the ventromedial prefrontal cortex (vmPFC), ventral striatum (VS), and amygdala. These densely interconnected regions (13), henceforth referred to collectively as the "valuation system," are consistently implicated in processing the affective value and motivational significance of various stimuli, including other people (13–18). Although human neuroscience research has yet to investigate sociometric popularity, nonhuman primate researchers have found that neurons in these regions signal group members' dominance rank (19–21) and proposed that the vmPFC, VS, and amygdala interact to encode, monitor, and signal other individuals' social value (22). If tracking group members' popularity depends on the motivational significance

Significance

In virtually all human groups, differences in popularity induce social status and shape interactions. How do we recognize that certain individuals are popular—highly liked by the group—even when this collective preference differs from our own? Our results suggest that group members' popularity is tracked by activity in neural valuation systems, which in turn engage social cognition systems that facilitate understanding others' mental states. Popular participants' valuation systems demonstrated enhanced sensitivity to differences among other group members' popularity. These neural data offer insights into how status guides social behavior and reinforces social network structures, and why the affective valuation and social cognition systems are critical for navigating these networks and achieving high status within them.

Author contributions: N.Z., P.S.B., and K.N.O. designed research; N.Z. performed research; N.Z., P.S.B., J.W., and K.N.O. analyzed data; and N.Z., P.S.B., J.W., and K.N.O. wrote the paper.

Reviewers: E.B.F., University of Pennsylvania; M.D.L., University of California, Los Angeles; and A.T., Princeton University.

The authors declare no conflict of interest.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1511477112/-/DCSupplemental.

and social value attributed to them, then valuation system activity should track targets' sociometric popularity.

The second network is comprised of the dorsomedial prefrontal cortex (dmPFC), temporoparietal junction (TPJ), and precuneus. These interconnected regions, henceforth referred to collectively as the "social cognition system," are consistently activated in neuroimaging studies involving judgments about others' psychological characteristics, mental states, and intentions (14, 18, 23), or the passive viewing of social stimuli—such as familiar faces—for which we might spontaneously make such attributions (24). Although no neuroscience work has asked how these systems might track sociometric popularity, behavioral research shows that people are particularly concerned with understanding high-status individuals' mental states (especially how they are viewed by them) and predicting their intentions (25–28). If perceivers are preferentially motivated to understand popular (relative to unpopular) group members' mental states, then social cognition system activity should scale with targets' popularity.

Based on these findings, both the valuation and social cognition systems are candidate neural networks for tracking group members' popularity. Our primary objective was to test these possibilities, recognizing that they are not mutually exclusive. Indeed, the two systems are functionally distinct but their interactions are often critical for diverse social behaviors (14).

To address these questions, two different groups of well-acquainted participants were recruited from two voluntary student organizations with equivalent size and affiliation network structures (*Methods*, Fig. 1, and Table S1). Specifically, sociometric popularity was indexed by individuals' degree prestige within the directed liking network, standardized by group. This measure of popularity aggregates liking ratings received by each group member and thus intuitively reflects how much individuals are collectively liked by their fellow group members (9) (see *SI Text* for alternative conceptualizations of popularity).

To model everyday social encounters within face-to-face social networks, we developed a round-robin neuroimaging paradigm in which group members were both the target stimuli presented during the scan and the perceivers that viewed them. A cover task (29) guided perceivers to make simple judgments about briefly presented photographs of target faces.

To provide a strong test of our hypotheses about the neural systems tracking targets' sociometric popularity, our primary analyses were based on independently identified valuation and social cognition networks that were localized using two additional tasks that participants completed in the same scanning session (*Methods* and *SI Text*). We then used combinations of multilevel regression and mediation analyses to ask how activity within each network tracked targets' sociometric popularity during this face-viewing task, how activity in these systems interacted, and how perceivers' own popularity impacted their sensitivity to differences in target popularity.

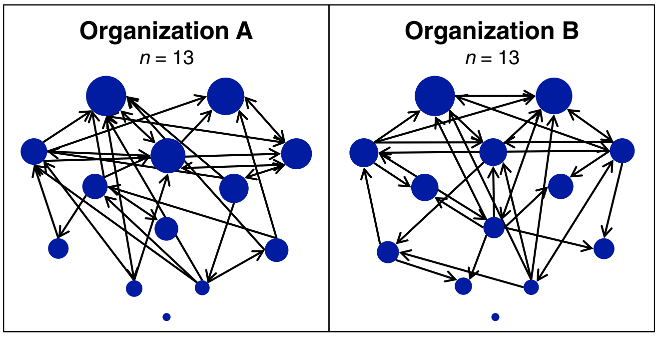

Fig. 1. Social network structure of study participants ($n = 26$) in two voluntary student organizations (clubs; participant information detailed in *Methods*, Table S1, and *SI Text*). Each network was comprised of 13 well-acquainted members. Each node represents one person. Directional arrows represent group members' directed liking relations (for visual clarity, only ties in the upper quartile are displayed). Node size reflects sociometric popularity: the extent to which the group collectively likes that person. Sociometric popularity was indexed by degree prestige, which we then standardized by group (*Methods*). Calculated by simply summing the weights of all liking ties received by an individual, this SNA metric represents an intuitive and straightforward index of popularity (9).

Results

Target Popularity Analyses.

ROI approach. For our primary analysis, we first needed to independently localize regions-of-interest (ROIs) related to affective valuation and social cognition. Following the established analytic approach of previous neuroimaging studies, the monetary incentive delay (MID) task (30) was used to independently localize regions active during anticipation and receipt of monetary rewards (31, 32). The social cognition system localizer was a well-validated person judgment task (33) commonly used to identify regions involved in thinking about others' mental states and traits, here adapted such that perceivers made judgments about target group members and predicted targets' judgments of them. [As noted earlier, these are precisely the kinds of judgments that people are preferentially motivated to make about high-status (relative to low-status) targets.] For each functional localizer task we then defined 8-mm radius spherical ROIs surrounding activation peaks that fell within our a priori ROIs (*Methods* and *SI Text*). From the MID task we obtained anatomically constrained functional ROIs in the vmPFC, VS, and amygdala (Fig. 2*A*). The person judgment task revealed clusters with peaks in the dmPFC, precuneus, and bilateral TPJ (Fig. 2*B*). The activation peaks we found are consistent with previous neuroimaging studies using the MID (30–32, 34) and person judgment tasks (see ref. 23 for review).

We then asked whether activation within these independently localized valuation and social cognition ROIs scaled with the popularity of targets presented in the face-viewing task. To answer this question we used multilevel models regressing activation parameter estimates (βs) extracted from each ROI against target popularity, controlling for each perceiver's liking of targets to ensure that analyses reflect neural sensitivity to how much target group members are collectively liked by the group and not merely individually liked by the perceiver. These analyses (*SI Text*) revealed that target popularity was positively associated with activity in ROIs independently identified by the valuation (Fig. 2*C*) (vmPFC, amygdala, VS) and social cognition (Fig. 2*D*) [dmPFC, precuneus, left (l) TPJ] localizer tasks ($Ps < 0.05$). The only ROI in which activity did not track target popularity was the right (r) TPJ ($P > 0.5$), and was therefore not included in the subsequent analyses. To rule out alternative explanations, we conducted additional regression analyses controlling for perceiver–target relational characteristics (e.g., relationship duration, subjective interpersonal closeness) and target attributes (e.g., sex, facial attractiveness). The positive association between target popularity and βs from each ROI remained significant even when/after controlling for these potential confounds ($Ps < 0.05$), and did not differ between groups ($Ps > 0.2$) (see *SI Text* and Tables S2 and S3 for full list of potential confounds tested and regression results). Activity in valuation and social cognition systems was predicted by target popularity, whether or not perceiver's own liking of target was partialled out ($Ps < 0.01$) (*SI Text*).

Whole-brain approach. To validate these results and complement our hypothesis-driven ROI analyses with a data-driven analytic approach, we also conducted a random-effects, parametric whole-brain regression analysis at the group level. This analysis replicated the ROI-based analysis: the same core valuation (vmPFC, amygdala, VS) and social cognition (dmPFC, precuneus, lTPJ) regions tracked significantly with target popularity, even when controlling for the aforementioned potential confounds (*SI Text*, Fig. S1, and Table S4). It is worth noting that the whole-brain analysis used a two-tailed hypothesis to allow for testing of brain regions in which activity tracked negatively with target popularity; however, no such regions were found. (See Fig. S2 for comparison of the distinct neural correlates of target popularity and liking.)

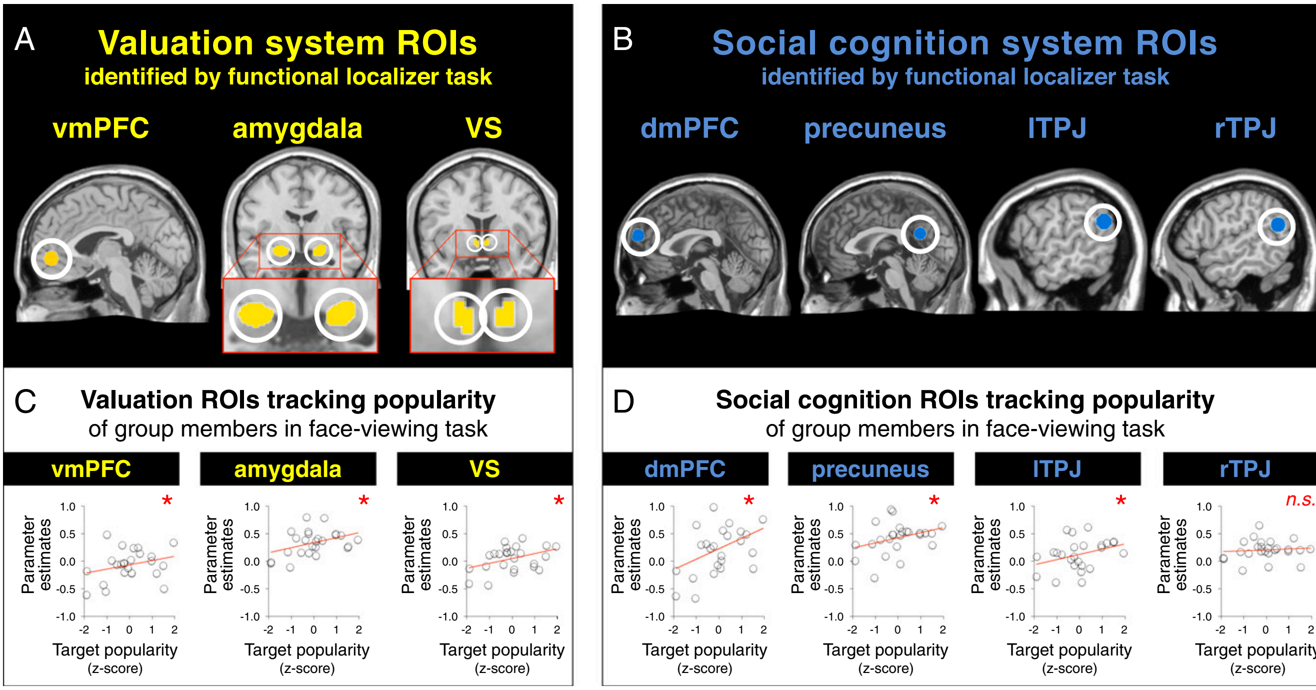

Fig. 2. Popularity of targets (group members presented as stimuli during the face-viewing task) predicted activity in each of the valuation and social cognition ROIs (all *P*s < 0.05, as indicated by asterisks) except rTPJ (*P* > 0.5), even when controlling for perceivers' own liking of target and other potential confounds (*Results*, *SI Text*, and Tables S2 and S3). Core brain regions underlying (*A*) valuation and (*B*) social cognition—and corresponding ROIs—were identified using two independent functional localizer tasks (*Methods* and *SI Text*). Each task identified a set of commonly coactivated and strongly interconnected regions that are referred to collectively as the valuation and social cognition systems, respectively. Illustrations of the parametric relationship between target popularity and βs extracted from (*C*) valuation system ROIs and (*D*) social cognition system ROIs. Note that activity is averaged across perceivers for visual clarity.

Mediation Analyses. The observed correlations between target popularity and activity in valuation and social cognition regions confirmed our primary hypotheses, which led to our second question: Do the two systems track popularity in parallel (independently) or serially, with one system assuming a primary role that mediates the popularity–activity relationship for the other? We predicted the valuation system would function as mediator based on the aforementioned literatures in social psychology [i.e., it is high-status individuals' social importance that motivates others to predict their mental states (25–28)] and nonhuman primate neurophysiology [i.e., neurons in valuation regions encode social value and signal presence of high-status group members (19–22)]. To test this prediction, we performed multilevel mediation analyses, assessing whether valuation system activity explains the observed relationship between target popularity and social cognition system activity. (βs extracted from the vmPFC, amygdala, and VS—ROIs that had been independently localized by the MID task—were averaged together to compute a composite measure of valuation system activity during the face-viewing task; likewise, βs extracted from the dmPFC, precuneus, and lTPJ—ROIs that had been independently localized by the person judgment task—were aggregated for a composite measure of social cognition activity.) We found that valuation activity did in fact significantly mediate this relationship ($P < 0.01$) (Fig. 3 and *SI Text*). [Moreover, additional analyses indicated this model had greater strength of evidence than did the sum total of (*i*) the alternative serial organization in which social cognition system activity operated as the mediator, and (*ii*) the parallel organization in which the two systems' activity independently tracked target popularity (*SI Text*).] These results suggest that (*i*) a primary representation of sociometric popularity is value-based or motivational in nature, and (*ii*) social cognitive systems may be engaged in the presence of popular group members to the extent that valuation systems signal their motivational significance. In such cases, social cognition systems may ready perceivers for effective interaction by supporting retrieval of knowledge about what target individuals are like and how they view us (precisely the two kinds of judgments elicited by the social cognition functional localizer task). This knowledge is useful for predicting high-status individuals' behavior and deciding how to act accordingly (25–28).

Perceiver Popularity Analyses. The finding that valuation system activity directly tracked target popularity led to our third question: Does the strength of this relationship (i.e., attunement to group members' popularity differences) relate to one's own popularity?

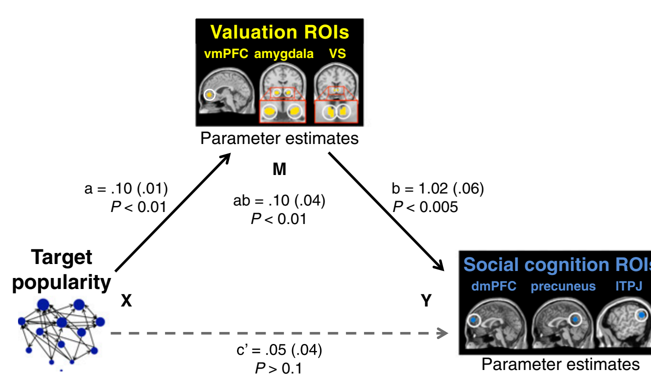

Fig. 3. Activity in the valuation system (vmPFC, amygdala, and VS ROIs independently localized by the MID task) mediated the observed relationship between target popularity and social cognition system activity (dmPFC, precuneus, and lTPJ ROIs independently localized by the person judgment task), with 64.6% of the total effect mediated ($P < 0.01$). See *Methods*, Fig. 2, and *SI Text* for details on how these systems were defined and independently localized. Further analyses confirmed that the data supported this mediation model over both (*i*) the alternative serial organization in which social cognition system activity operated as the mediator, and (*ii*) the parallel organization in which the two systems' activity independently tracked target popularity (*Results* and *SI Text*).

In studies both of adults and children, popular individuals have more accurate perceptions of the affiliative social network structure that underlies differences in popularity (7, 35, 36). In addition, human and nonhuman primate experiments have shown that although low-status individuals pay attention to group members of any status, high-status group members attend selectively to one another (6, 37). Therefore, we hypothesized that (*i*) perceiver popularity would amplify the effect of target popularity on valuation system activity, [i.e., that valuation system activity of popular (relative to unpopular) perceivers would be more sensitive to status differences among group members], and (*ii*) this effect would be driven by popular perceivers' attenuated responses to less popular targets.

We tested this prediction with a multilevel model regressing valuation system βs against target popularity, perceiver popularity, and their interaction term (as well as additional models with the aforementioned covariates) (*SI Text*). We found that in addition to the main effect of target popularity (parameter estimate ± SE: 0.100 ± 0.037, $P < 0.01$), there was also an interaction such that the effect of target popularity on valuation activity was amplified for more popular perceivers (Fig. 4 and *SI Text*) (0.077 ± 0.037, $P < 0.05$). In other words, the valuation systems of popular perceivers were better calibrated to detecting the status differences among group members. This result is not an artifact of popular perceivers liking more popular targets. Consistent with our hypothesis and the aforementioned human and nonhuman primate findings (6, 37), the interaction effect was largely driven by an attenuation of responses to less-popular targets in popular, but not unpopular, perceivers (Fig. 4). Moreover, the main effect of perceiver popularity showed a nonsignificant trend in the opposite (i.e., negative) direction (0.122 ± 0.078, $P = 0.13$). Considered in tandem, these results suggest that popular individuals demonstrate enhanced interpersonal sensitivity (i.e., attunement to group members' status differences), whereas unpopular individuals show more generalized interpersonal responsiveness (i.e., elevated valuation responses to all group members regardless of status). In support of the inference that popular perceivers have heightened interpersonal sensitivity (7, 35, 36), we also found that they were more accurate in predicting how each of the other group members perceived them across various personality attributes (*SI Text* and Fig. S3).

Discussion

Taken together, the present results provide, to our knowledge, the first examination of neural mechanisms tracking popularity. Using a naturalistic face-viewing task, we identified two kinds of neural systems activated during encounters with members of real-world social networks. Affective valuation regions may assign motivational significance to group members based on their sociometric popularity and, in turn, may mediate engagement of social cognition regions that support understanding their mental states.

This neural mechanism presents adaptive features for navigating interactions within complex social networks. Tracking group members' status serves vital functions supported by valuation regions, such as assigning motivational importance to particular individuals, monitoring and detecting their presence, and signaling they deserve privileged status in attention and decision-making (17, 19–22). In an experimental demonstration of this principle, rhesus macaques were willing to sacrifice fruit juice to view faces of high-status group members, while requiring overpayment of juice to view low-status monkeys' faces (38). Given the valuation system's critical role in reward processing and reinforcement learning (13), this mechanism may also provide intrinsically rewarding reinforcement that motivates proximity and preferential attention to popular individuals as well as incentivizing interactions with them (5, 6, 8, 12, 22). At the group-level, this neural mechanism may help stabilize social networks over time, thereby contributing to the self-reinforcing nature of social status and hence the reproduction of social structure (39).

The mediation analysis suggests that the valuation system translates group members' popularity into motivational value signals that mediate activation of social cognition systems critical for explicit

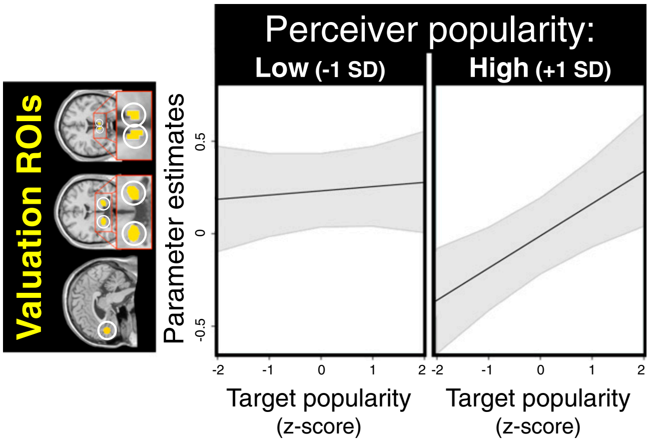

Fig. 4. Interaction plot depicting popular (+1 SD, relative to −1 SD unpopular) perceivers' enhanced attunement to group members' status differences (shaded area represents 95% confidence interval). The main effect of target popularity on valuation activity ($P < 0.01$) was amplified for more popular perceivers ($P < 0.05$), suggesting their valuation systems were more sensitively calibrated to detecting status differences among group members. In contrast, there was a nonsignificant main effect trend of perceiver popularity in the opposite (i.e., negative) direction ($P = 0.13$), suggesting the valuation systems of unpopular individuals demonstrate greater generalized interpersonal responsiveness (i.e., elevated responses to all group members regardless of status). Additional details provided in *Results* and *SI Text*.

attributions about group members' psychological states and characteristics. Given our motivation to understand high-status individuals' mental states and predict their behavior (25–28), this neural mechanism may be both adaptive and socially advantageous: upon observing popular group members, it could proactively set in motion social-cognitive processes that facilitate social interaction.

The social advantage of this neural mechanism is further suggested by the results of our individual-differences analysis showing that perceivers' own popularity correlated with how strongly their valuation systems tracked network members' popularity. These intriguing findings are consistent with two views of how perceivers' own status relates to their perceptions of others. One view comes from the social psychological literature on power, which suggests that having low power or subordinate status imbues other people with heightened relevance that motivates more careful attention to them and their perspectives (25, 40, 41). Our data suggest that differences in popularity may function in a similar way: as illustrated in Fig. 4, unpopular perceivers (Fig. 4, *Left*) demonstrated elevated valuation responses to all group members regardless of their status; by contrast, popular individuals (Fig. 4, *Right*) demonstrated valuation responses that scaled with targets' status. These results dovetail with evidence that although low-ranking monkeys and unpopular humans pay attention to group members of any status, their high-status counterparts attend selectively to one another (6, 37). Another view consistent with our data is that popular individuals achieve their status because they are particularly skilled social perceivers. At the behavioral level, heightened interpersonal acuity has been linked to popularity in social networks of children (7) and adults (35, 36), and we likewise found that popular individuals more accurately predicted how individual group members viewed them (Fig. S3). The findings in Fig. 4 could thus be interpreted as evidence at the neural level of popular individuals' enhanced social attunement (i.e., that their valuation systems were better calibrated to the social structure). On this view, perceivers' valuation responses to others might not reflect a consequence of perceivers' own status, but rather a determinant of how much status they ultimately achieve.

Consistent with this account, which causally prioritizes valuation regions' functioning as influencing status, primate and rodent studies have shown that lesions to the orbital PFC and amygdala resulted in disrupted social behavior and loss of status, and manipulation of serotonergic neurotransmission and synaptic efficacy in the mPFC influenced social skills, affiliative behavior, and changes in status (42). Although such experimental manipulations cannot be conducted in human research, the paradigm advanced here could be implemented longitudinally to investigate whether individual differences in the valuation system's social sensitivity are important determinants or consequences of one's ability and motivation to affiliate with group members and achieve status. Understanding the causal mechanisms underlying such individual differences in humans could have implications for clinical conditions such as depression and developmental disorders such as autism spectrum disorders, in which diminished interpersonal sensitivity, affiliative motivation, and social interaction have been linked to atypical valuation system structure and function (43, 44).

More broadly, our findings are consistent with prior research showing that other aspects of network membership may also relate to the structure and function of valuation and social cognition systems. Recent studies (reviewed in ref. 3) have reported that individuals' social network size and complexity correlated with gray matter in the vmPFC (45, 46), amygdala (47, 48), and lTPJ (45). Moreover, individual macaques' gray matter in the mPFC and regions approximating human TPJ covary with both social network size (which was experimentally assigned) and social status (49, 50). These findings support the proposition that affective valuation and social cognition systems are critical for navigating complex social networks and achieving high status within them.

Here it is important to note that prior neuroimaging studies examining processing of another dimension of social status—dominance—have not consistently implicated the valuation and social cognition systems observed here, but rather regions of the lateral PFC and inferior parietal lobe (51). These differing findings could reflect the possibility that the relative dominance and sociometric popularity of group members are represented by different types of brain systems. However, they could also reflect differences in methodology. Whereas our stimuli depicted members of participants' real-world groups to study naturally occurring variability in social status, other human neuroimaging studies focusing on dominance have tended to experimentally manipulate social status with less naturalistic stimuli (see ref. 51 for review). [Note that the nonhuman primate studies in which valuation regions were found to track group members' status (19–21) also used similarly naturalistic stimuli (i.e., faces of group members).] Our expectation is that for voluntary identity groups of comparable scale (ranging from 8–79), where similar structural dynamics are observed, the findings reported here should be robust (4, 52). As the scale increases, mutual observation becomes impossible. Consequently the structuring dynamics of networks change (53). Similarly, in groups with strong formal hierarchies, different dynamics may be observed. Future work could address these and other questions about the neural mechanisms that track popularity, specifically, and other kinds of social status in a wide range of social networks more generally.

In conclusion, this study advances an experimental paradigm that models group members' everyday encounters using a naturalistic task and personalized stimuli. In so doing, we provide an interdisciplinary framework that integrates theories and methods from social psychology, neuroscience (fMRI), and sociology (SNA) to enable research on the brain mechanisms underlying person perception and social cognition processes in real-world, status-laden social networks.

Methods

Participants. Participants were 26 healthy young adults (12 male, 14 female; mean age = 28.7 y, SD = 2.3) recruited from two different voluntary student club organizations with equivalent size and affiliation network structures (13 members from each) (Fig. 1 and Table S1) at a large university in the United States. Initial recruitment yielded 100% member response rate in both organizations, however not all met the inclusion criteria (detailed in *SI Text*) to participate in each of the study phases. Of 28 total individuals comprising both groups, 26 (93%) were eligible, willing, and able to participate in the study; among the 26 participants, all 26 (100%) completed the initial session in which the social network instruments were administered, 25 (96%) were photographed and incorporated as targets (face stimuli) in the subsequent fMRI face-viewing task, and 21 (81%) constituted perceivers who completed the fMRI scanning session (Table S1).

Beyond these core participants, 40 additional participants were recruited via Mechanical Turk to provide normative ratings of stimuli used in the fMRI face-viewing task (*SI Text*). All participants received monetary compensation and provided informed consent following the standards of the Columbia University Institutional Review Board. Additional recruitment and participant information is provided in *SI Text*.

Procedure and Design. The study was comprised of two sessions. In a preliminary session, sociometric instruments and self-report questionnaires were administered, and photographs were taken of participants' faces (to be used subsequently in the fMRI face-viewing task). In a second session, participants underwent fMRI scanning while completing several tasks described below. For all computerized tasks in both sessions, stimulus presentation and behavioral data acquisition were controlled using E-Prime 2.0 (Psychology Software Tools). For tasks completed in the fMRI scanning session, visual stimuli were displayed on a projection screen using a LCD projector and viewed via a rear-projecting mirror.

Sociometric Assessment and SNA. Sociometric assessments of group members' affiliative relations and resulting network structure were collected from participants during the first session. These assessments were conducted via a computerized peer-rating paradigm in which participants rated how much they liked each group member (presented in randomized order) on a sliding visual analog scale anchored by the labels "not very" and "very" on opposite ends. This sociometric instrument provided a continuous measure of personal liking (i.e., affiliation tie strength) between group members that was used as a covariate in analyses (*Results* and *SI Text*) and also to compute each group member's popularity. Specifically, sociometric popularity was indexed by individuals' degree prestige (alternatively referred to as "indegree centrality") within the directed liking network (9), which we then standardized by group. In other words, liking ratings received by each group member were summed for that individual and then standardized to *z*-scores within group. Using these sociometric assessments and network analyses thus generated a popularity index that reflects how much individuals are collectively liked by their fellow group members.

Round-Robin fMRI Face-Viewing Task. Stimuli for the fMRI face-viewing task were prepared from photographs of participants. During the preliminary session, participants' faces were photographed with affectively neutral facial expression and gaze directed straight at the camera. These photographs were cropped and converted to grayscale images with equal luminance. In addition, a "ghost face" stimulus image representing the superimposition of all group members' faces was prepared for each group following methods used in prior face perception research (29). The face-viewing task implemented a rapid event-related design that included 10 repetitions of each stimulus face presented in pseudorandomized order. Faces were presented for 1,000 ms and interstimulus intervals (ISIs) consisting of white fixation cross on black background were jittered between 1,500 ms and 11,500 ms (mean duration of ISI = 3,500 ms). Perceivers viewed faces of targets while performing a simple cover task (29) to maintain their alertness throughout. Specifically, participants were instructed to press a button with their pointer (second) finger each time a group member's face was presented and a different button with their ring (fourth) finger each time a "ghost face" was presented (∼9% of total presentations).

Independent Functional Localizer Tasks for Valuation and Social Cognition Systems. Two functional localizer tasks were completed at the end of the scanning session (methods detailed in *SI Text*). Participants completed the MID task (30) to independently identify valuation regions active during the anticipation and receipt of monetary rewards (31, 32). Trials in which participants won monetary rewards were contrasted with those in which they could not (win trials > neutral trials), encompassing both the anticipation and feedback phases of each trial. This analysis (thresholded at $P < 0.05$, corrected) revealed activation peaks consistent with previous studies using the MID task (30–32, 34) in regions of a priori interest: the vmPFC (−3, 48, −6), VS (0, 9, −3), and amygdala (−21, −6, −12 and 18, −3, −12). We then defined spherical ROIs with a radius of 8 mm around these peaks (31, 32) (Fig. 2*A*) [for the VS and amygdala, spherical ROIs were then anatomically constrained using structural masks obtained from FSL (*SI Text*)].

We used a well-validated person judgment task adapted from ref. 33 as an independent functional localizer to identify social cognition regions supporting two kinds of judgments relevant in interactions with group members: evaluating target group members' mental states and traits [e.g., "to what extent is (target) helpful?"] and predicting how targets perceive them [e.g., "to what extent does (target) see me as lonely?"]. Specifically, we conducted a whole-brain conjunction analysis (thresholded at $P < 0.05$, corrected) to localize activation present in both you-about-other and other-about-you trials relative to active baseline curved line trials. This analysis revealed clusters with activation peaks in regions of a priori interest that were consistent with previous neuroimaging studies using similar social cognitive tasks (see ref. 23 for review): dmPFC (0, 60, 21), precuneus (−3, −57, 21), and left (−60, −60, 24) and right TPJ (54, −60, 21). As with the valuation localizer, we defined spherical ROIs with a radius of 8 mm around the observed activation peaks (Fig. 2*B* and *SI Text*).

Imaging Acquisition and Analysis. Whole-brain fMRI data were acquired on a 1.5 Tesla GE system. High-resolution anatomical images with 1-mm × 1-mm × 1-mm resolution were acquired with a T1-sensitive SPGR sequence at the end of the scan session. Functional images were acquired with a T2*-sensitive EPI blood oxygenation-level dependent sequence. Scanning parameters and further details are included in *SI Text*.

ACKNOWLEDGMENTS. We thank the participants in this study; K. Tsvetkova, L. Bennett, Y. Jun, A. Radin for data collection assistance; and N. Bolger and K. Makovi for helpful advice and assistance with multilevel mediation and social network analyses, respectively. This work was supported by a Columbia University Interdisciplinary Center for Innovative Theory and Empirics seed grant (to P.S.B. and K.N.O.); National Institute of Child Health and Human Development Grant R01-HD069178 (to K.N.O.); and National Institute on Aging Grant R01-AG043463 (to K.N.O.).

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