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Research Article

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# Social Influence Modulates the Neural Computation of Value

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## Abstract

Social influence—individuals' tendency to conform to the beliefs and attitudes of others—has interested psychologists for decades. However, it has traditionally been difficult to distinguish true modification of attitudes from mere public compliance with social norms; this study addressed this challenge using functional neuroimaging. Participants rated the attractiveness of faces and subsequently learned how their peers ostensibly rated each face. Participants were then scanned using functional MRI while they rated each face a second time. The second ratings were influenced by social norms: Participants changed their ratings to conform to those of their peers. This social influence was accompanied by modulated engagement of two brain regions associated with coding subjective value—the nucleus accumbens and orbitofrontal cortex—a finding suggesting that exposure to social norms affected participants' neural representations of value assigned to stimuli. These findings document the utility of neuroimaging to demonstrate the private acceptance of social norms.

**Keywords**

social influence, reward, nucleus accumbens, orbitofrontal cortex

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Several decades of psychological research have documented the readiness with which individuals adopt the opinions, judgments, and behavior of other people (Latane, 1981; Sherif, 1936; Turner, 1991). People follow advertisers' suggestions and government propaganda, succumb to peer pressure, and generally obey the norms established by the social groups to which they belong. In some of the best known and earliest studies of the power of social influence, Asch (1956) induced participants to make obviously incorrect perceptual judgments by merely exposing them to other people who insisted on erroneous responses. A host of subsequent studies have revealed the same tendency for individuals to conform to other people's political opinions, social attitudes, impressions of other people, and even beliefs about themselves (Turner, 1991).

Despite the ubiquity of social influence, researchers have struggled to distinguish conformity that results from true modification of beliefs and opinions (*private acceptance*) from mere acquiescence to other people's expectations (*public compliance*). On the one hand, individuals can view social norms as an important source of information about the world and therefore internalize the opinions or judgments of other people. On the other hand, individuals may change their behavior or reported opinions simply to avoid social rejection while privately continuing to hold their original attitudes (Cialdini & Goldstein, 2004). Although a number of theories view these sources of conformity as fundamentally distinct (Deutsch & Gerard, 1955; Petty & Cacioppo, 1986), it has been notoriously difficult to disentangle private acceptance from public compliance, given that changes in behavior could reflect either source of conformity.

The most common empirical strategy for distinguishing private acceptance from public compliance has been to demonstrate that new behaviors or opinions persist in the absence of the influencing group or when participants respond anonymously (Newcomb, 1967). These methods are based on the assumption that only private acceptance—not mere public compliance—will cause adherence to a norm after social motivations, such as fear of rejection or damage to one's reputation, have dissipated. However, anonymous responding is a dubious method for measuring private acceptance (Wood, 2000). In an analysis of nearly 100 studies of social influence, Bond and Smith (1996) determined that there was no difference between participants' agreement with other people's opinions when they responded publicly versus anonymously, even in variants of Asch's (1956) original paradigm, in which participants were pressured to make clearly erroneous responses that they likely did not truly accept. These results

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suggest that demonstrating behavioral signs of social influence in physical privacy does not necessarily reflect psychological acceptance of a social norm. Such findings are consistent with the idea that in daily life, many social norms are obeyed in the absence of other people. Indeed, individuals are likely motivated to conform not only to other people who are physically present but also—in Allport's (1954) famous phrase—to people who are "imagined or implied" (p. 3). Thus, despite the long history of investigating this issue in social psychology, disentangling public compliance from private acceptance remains a vexing problem.

The study reported here took a novel approach to this challenge: using neuroimaging to augment earlier strategies for studying social influence. Because neural responses are relatively immune to demand characteristics and self-report biases, neuroimaging is well suited to distinguish public compliance from private acceptance of social norms. Moreover, neuroscientists now understand a great deal about the brain basis of attitudes and subjective value, which have been a primary focus of research on social influence. For example, a considerable number of studies have demonstrated that neural activity in two brain regions—the orbitofrontal cortex and ventral striatum, especially the nucleus accumbens—represents the subjective value that animals assign to stimuli. Activity in these regions increases as the value associated with a stimulus increases, not only for primary rewards, such as food and juice, but also for secondary outcomes, such as monetary gains (Berns, McClure, Pagnoni, & Montague, 2001; Kable & Glimcher, 2007; Padoa-Schioppa & Assad, 2006; Schultz, 2002; Tom, Fox, Trepel, & Poldrack, 2007). In other words, the orbitofrontal cortex and nucleus accumbens constitute part of a network that appears to represent an individual's evaluation of events and stimuli (Montague & Berns, 2002; Rangel, Camerer, & Montague, 2008).

The role of the orbitofrontal cortex and nucleus accumbens in value computation suggests a novel method for assessing the private acceptance of social norms. To the extent that activity in these regions correlates with the subjective value individuals assign to a stimulus, activity in these brain regions should be modulated in response to social influence if individuals privately accept new group norms, but not if they merely acquiesce to social pressures. Although respondents may experience demand to explicitly report opinions that match those of their peers, there is no clear mechanism through which such demand would alter neural activity associated with subjective value. Consequently, only true acceptance of a norm should result in changes to underlying neural representations of value.

One straightforward context in which to assess this prediction is the evaluation of facial attractiveness. Earlier studies have established that engagement of the orbitofrontal cortex and nucleus accumbens correlates with the perceived physical attractiveness of faces when people view photos of members of the opposite sex. This finding is typically interpreted as demonstrating that beautiful faces are intrinsically valuable (Aharon et al., 2001; Cloutier, Heatherton, Whalen, & Kelley, 2008; O'Doherty et al., 2003). Moreover, reported ratings of attractiveness are susceptible to social influence: Individuals rate a face as being more beautiful after learning that peers rated the face as attractive and as being less beautiful after learning that peers rated the face as unattractive (Klucharev, Hytonen, Rijpkema, Smidts, & Fernandez, 2009). Here, we combined these observations to design a paradigm that allowed us to determine whether changes in the reported attractiveness of faces following social influence were accompanied by changes in the underlying neural representation of value associated with those faces, as indexed by responses in the orbitofrontal cortex and nucleus accumbens.

## Method

### Participants

Fourteen healthy, right-handed male volunteers (mean age = 21.8 years, range = 18–26) with no history of psychiatric or neurological disorders participated. Participants provided informed consent and were compensated in accordance with the regulations of the Committee on the Use of Human Subjects at Harvard University.

### Initial ratings and normative feedback

Participants were told that they were taking part in a study on facial attractiveness, and that a group of several hundred young men (ages 17 to 26 years) had already participated in this study by rating a series of female faces. Participants were then told that they would rate the attractiveness of the same faces and, in some cases, would also be shown the average rating made by the participants who had already completed the study.

Each participant then judged a series of 180 female faces drawn from a set used in earlier conformity research (Klucharev et al., 2009). On each trial, the participant viewed a computer screen showing a photograph of a female face and indicated the degree to which he perceived the face to be attractive, using a 7-point scale ranging from 1, *unattractive*, to 7, *attractive*. The participant's rating was highlighted by a blue outline on a Likert scale at the bottom of the computer screen for 4 s (see Fig. 1 for an illustration of the trial structure). On most trials (see the next paragraph), the normative rating—ostensibly, how attractive the previous group of participants had found that face—was outlined on the Likert scale in red during the final 2 s.

Although participants believed that the group ratings were the averages of ratings made by many individuals, these ratings were actually generated by a pseudorandom algorithm that resulted in four trial types. On approximately 30 trials, the normative rating was 2 or 3 points lower than the participant's own rating (*peers-lower* condition). On approximately 30 trials, the normative rating was 2 or 3 points higher than the participant's

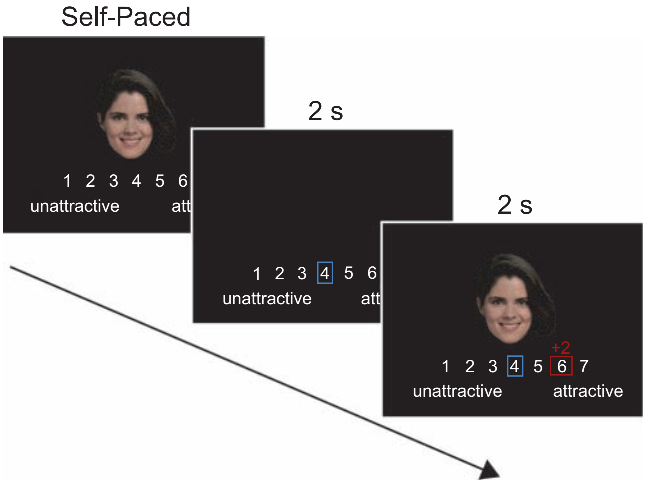

**Fig. 1.** Trial structure for the initial phase of the attractiveness-rating task. On each trial, a participant viewed a photograph of a woman and rated her physical attractiveness on a 7-point Likert scale. This part of the trial was self-paced. The participant's rating was highlighted by a blue outline on the Likert scale for 4 s. On most trials (illustrated here), the normative peer rating of the face was outlined on the Likert scale in red for the final 2 s.

own rating (*peers-higher* condition). On approximately 60 trials, the normative rating was the same as the participant's own rating (*peers-agree* condition). On approximately 60 trials, no peer data were displayed (*no-feedback* condition). Thus, although participants believed that feedback about each face represented the opinions of a peer group, different conditions in fact were created by experimentally manipulating the feedback.

Note that the feedback algorithm was constrained such that a trial could be assigned to the peers-lower condition only when the participant initially made a rating greater than or equal to 3 (allowing the supposed group rating to be at least 2 points lower), and a trial could be assigned to the peers-higher condition only when the participant initially made a rating less than or equal to 5 (because the maximum value of the scale was 7). As a result, faces initially rated by participants as more attractive were assigned to the peers-lower condition disproportionately often, whereas less attractive faces were assigned to the peers-higher condition disproportionately often. This difference resulted in higher initial attractiveness ratings for faces viewed in peers-lower trials ($M = 4.34$) than for faces viewed in peers-higher trials ($M = 2.82$). To bypass this confound, we selected for analysis a subset of faces that were matched with respect to participants' initial attractiveness ratings across conditions (all $ps > .20$). Although all faces were shown to participants in the follow-up phase of the study, only this matched subset was included in the functional MRI (fMRI) and behavioral analyses. This ruled out the possibility that findings from these analyses could be attributed to differences in the initial attractiveness of peers-higher and peers-lower faces.

## Follow-up rating task

Approximately 30 min after completing the initial ratings, participants underwent fMRI scanning while they rated all 180 faces a second time, using the same scale as before. No ostensive normative ratings were presented during the follow-up phase. Each face was presented for 4 s, and participants could rate the face at any time during that interval. Participants' ratings were then displayed in green for the remainder of the 4-s period.

Our primary behavioral analysis examined whether changes in participants' ratings of each face (i.e., follow-up rating minus initial rating) were affected by initial peer feedback. Specifically, we predicted that during the follow-up rating task, participants would rate faces initially viewed in the peers-higher condition as more attractive than those initially viewed in the peers-lower condition, thus altering their ratings to conform to social norms.

## Monetary-incentive delay task

Participants also completed the monetary-incentive delay (MID) task, developed by Knutson, Westdorp, Kaiser, and Hommer (2000), while being scanned; data from this task were used to localize brain activity related to reward in a nonsocial context. Each trial began with one of two cue symbols (a green circle or a blue circle), which was displayed for 500 ms. After a randomly determined interval (duration between 2,000 and 2,500 ms), a target stimulus (a white square) was briefly presented. The green circle indicated that the participant would win $2 if he made a button press while the target was present and would receive no reward ($0) if he responded before the onset or after the offset of the target (*reward-possible* trials). The blue circle indicated that the participant could not earn money on that trial (*neutral* trials); participants were nevertheless instructed to make a button press when they saw the target after seeing the blue circle. At the end of each trial, the participant saw the amount of money he had earned on that trial ($0 or $2) along with the total amount he had earned during the task (presented for 500 ms).

The MID task comprised 30 reward-possible trials intermixed with 15 neutral trials. The duration of the presentation of the target was varied continuously from 160 to 260 ms using an algorithm based on participants' previous performance, with the goal of creating a level of difficulty that would produce correct responses on two thirds of the reward-possible trials. This algorithm succeeded; on average, participants were rewarded on 20 of the 30 trials (range = 16–22).

## Imaging acquisition and analysis

Functional imaging data were collected on a 3-T Siemens Trio scanner (Erlangen, Germany) using a gradient-echo echoplanar pulse sequence (31 axial slices, 5 mm thick; 1-mm skip;

repetition time = 2 s; echo time = 35 ms; 3.75-mm × 3.75-mm in-plane resolution). A high-resolution T1-weighted structural scan (magnetization prepared rapid acquisition gradient echo, MP-RAGE) was collected between the facial-rating and MID tasks. Stimuli were presented on a screen at the end of the magnet bore using both the Psychophysics Toolbox (Brainard, 1997) for MATLAB (The MathWorks, Natick, MA) and PsyScope software for Mac OS X (L. Bonatti, International School of Advanced Studies, Trieste, Italy; Cohen, MacWhinney, Flatt, & Provost, 1993).

MRI data were preprocessed and analyzed using SPM2 software (Department of Cognitive Neurology, Wellcome Trust Centre for Neuroimaging, London, England). Functional data were slice-time corrected, realigned to correct for head movement, transformed into a standard anatomical space (3-mm isotropic voxels) using Brain Template 152 from the International Consortium for Brain Mapping (ICBM; template originally created by the Montreal Neurological Institute, MNI), and spatially smoothed (8 mm full width at half maximum) using a Gaussian kernel.

Statistical analyses were then performed on each subject's data using the general linear model; the event-related design was modeled using a canonical hemodynamic-response function, its temporal derivative, and additional covariates (a session mean and a linear trend) of no interest to the model. Contrast images for each participant were subsequently entered into a second-level analysis in which we treated participants as a random effect. We identified brain regions that differentiated between feedback conditions using a statistical criterion of 25 or more contiguous voxels at a voxel-wise threshold of $p < .0005$. A Monte Carlo simulation implemented in MATLAB determined that these thresholds corresponded with an overall false positive rate of less than 5% after correction for multiple comparisons (Slotnick, Moo, Segal, & Hart, 2003).

For the attractiveness-rating task, we examined neural activity when faces were presented the second time as a function of the feedback condition these faces had initially been associated with (i.e., peers higher, peers lower, peers agree, or no feedback). Although analyses were conducted on faces that were initially rated to be equally attractive, we included participants' initial ratings of each face as a covariate to guard against other potential effects of these initial ratings on the neuroimaging data. Therefore, the findings reported here represent the effects of feedback condition after removing any variance associated with initial ratings.

Our primary analysis consisted of a whole-brain, random-effects contrast of peers-higher trials and peers-lower trials (peers-higher > peers-lower contrast), which isolated brain areas that were more responsive to faces previously paired with positive peer feedback than to those previously paired with negative peer feedback. Parameter estimates for faces previously viewed in all four conditions (peers higher, peers agree, peers lower, and no feedback) were then extracted from these clusters. Additionally, to localize brain regions linked to reward in a nonsocial context, we examined blood-oxygen-level-dependent responses related to the anticipation and receipt of monetary rewards during the MID task (hit trials > neutral trials). We then defined spherical regions of interest (ROIs) in our a priori ROIs by identifying spherical regions with a radius of 8 mm surrounding reward-related peaks in the nucleus accumbens and orbitofrontal cortex from the MID contrast. Parameter estimates for these MID-related ROIs were then extracted from the attractiveness-rating data and compared across feedback conditions.

## Results

### *Behavioral evidence of social influence*

Attractiveness ratings were significantly influenced by social norms. Participants explicitly rated faces as more attractive in the peers-higher condition (mean change from the baseline rating = 0.10) than in the peers-lower condition (mean change = −0.33), paired-sample $t(13) = 2.25$, $p < .05$, $d = 0.62$ (Fig. 2), even though this analysis included only a subset of faces from the peers-higher and peers-lower conditions that participants had initially rated as equally attractive ($p > .20$). No changes in attractiveness ratings were observed for faces in the peers-agree condition or the no-feedback condition.

### *Neural correlates of social influence*

Exposure to the ostensive peer ratings also modulated reward-related brain activity when faces were viewed a second time: A whole-brain analysis revealed a significantly greater response in bilateral nucleus accumbens and orbitofrontal

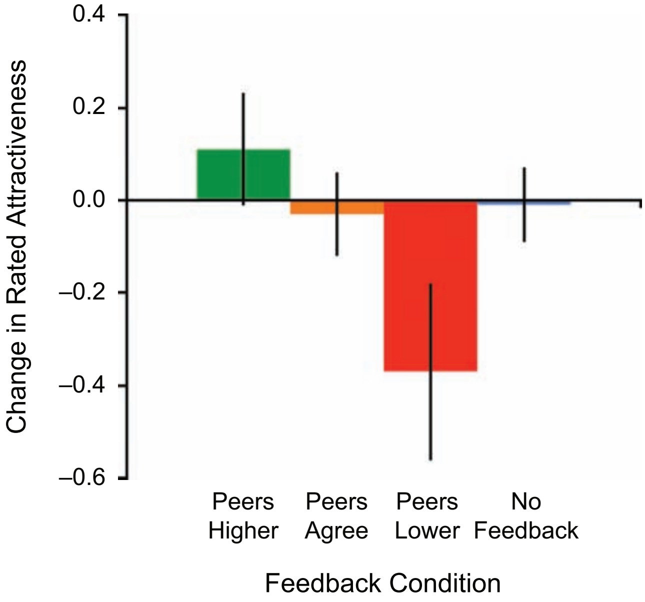

**Fig. 2.** Change in attractiveness ratings as a function of feedback condition for a subset of faces that were matched for initial attractiveness. Error bars represent standard errors of the mean for within-subjects comparisons, as described by Loftus and Masson (1994).

cortex for faces in the peers-higher condition than for faces in the peers-lower condition (Fig. 3a; also see Table S1 in the Supplemental Material available online). Because faces in the peers-lower and peers-higher conditions were matched on initial attractiveness, these differences in neural activity likely reflect changes in the value assigned to the faces as a result of social influence.

### *Overlap between social influence and monetary reward*

Replicating earlier research, we found that anticipating and winning monetary prizes during the MID task (Knutson et al., 2000) was associated with increased response in bilateral nucleus accumbens and in orbitofrontal cortex (Fig. 3b). To test whether social influence (i.e., feedback) affected activity in the clusters of nucleus accumbens and orbitofrontal cortex identified independently through the MID task, we examined the mean activity in these ROIs as a function of feedback condition. Our results were consistent with the whole-brain analysis: Faces in the peers-higher condition, compared with those in the peers-lower condition, were associated with increased response in orbitofrontal cortex, $t(13) = 2.74$, $p = .02$, $d = 0.76$, and in the right nucleus accumbens, $t(13) = 2.29$, $p = .04$, $d = 0.64$, even when these regions were defined using an independent, nonsocial-reward task. The left nucleus accumbens demonstrated a nonsignificant trend in the same direction, $t(13) = 1.47$, $p = .16$, $d = 0.41$ (Fig. 3b).

## Discussion

Although social influence has been a topic of interest in psychology for decades, researchers have struggled to distinguish public compliance with social norms from genuine, socially mediated changes in attitudes, beliefs, and perceptions. This study provides a novel approach to this challenge by demonstrating that social influence is accompanied by alterations in the neural representation of value associated with stimuli. The response of two brain regions with known roles in computing subjective value—the orbitofrontal cortex and nucleus accumbens—was higher for stimuli ostensibly rated more positively by peers than by participants themselves, as opposed to those ostensibly rated less positively by peers than by participants themselves. Additional analyses demonstrated that this modulation occurred in specific regions of the orbitofrontal cortex and nucleus accumbens that respond generally to reward (including monetary rewards). Although the orbitofrontal cortex and nucleus accumbens play dissociable roles in reward processing (Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008), these regions together constitute a system that

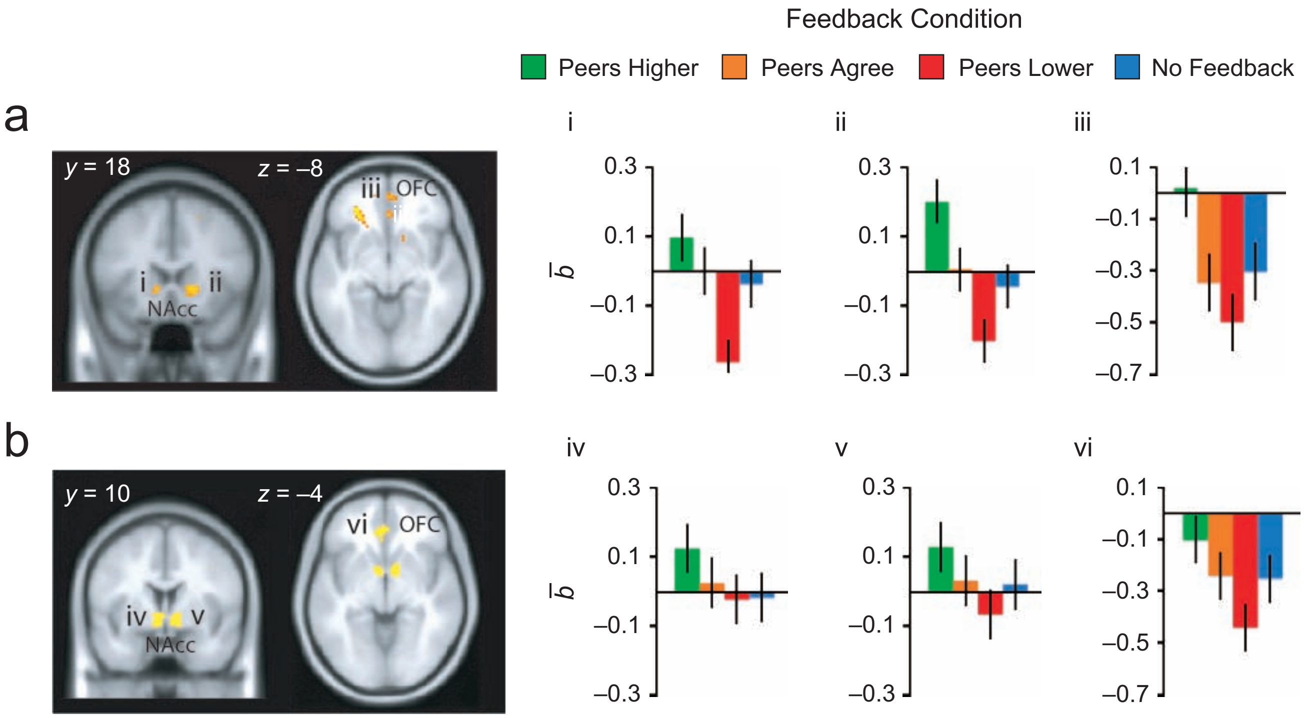

**Fig. 3.** Brain-imaging results. The images in (a) show regions identified by the peers-higher > peers-lower contrast. The images in (b) show the regions of interest identified from reward-related peaks during the monetary-incentive delay (MID) task: bilateral nucleus accumbens (NAcc; Montreal Neurological Institute coordinates: 10, 6, −4; −8, 4, −6) and orbitofrontal cortex (OFC; coordinates: −4, 40, −4). We examined activity in these regions in response to faces initially viewed in all four conditions (peers higher, peers agree, peers lower, and no feedback). The bar graphs display the mean parameter estimates for each condition in the regions of interest (identified by the roman numerals) extracted in the two analyses. Error bars represent standard errors of the mean for within-subjects comparisons, which were determined as described by Loftus and Masson (1994).

learns and encodes the value of events and stimuli. Thus, these results suggest that—at least in the context of this study—social influence is sufficient to modify the value assigned to a stimulus as reflected by underlying neural activity. These findings are consistent with recent demonstrations that other socially mediated expectancies (e.g., about the price or brand of a beverage) also modulate value-related neural activity (McClure et al., 2004; Plassmann, O'Doherty, Shiv, & Rangel, 2008).

These findings complement and expand on recent studies of the neural bases of conformity (Campbell-Meiklejohn, Bach, Roepstorff, Dolan, & Frith, 2010; Mason, Dyer, & Norton, 2009). For example, Berns, Capra, Moore, and Noussair (2010) documented neural changes associated with public—but not private—conformity. In this earlier study, adolescent participants rated their enjoyment of song clips and then learned the normative popularity of each song. Participants later rated popular songs more positively than unpopular ones, but this behavioral effect was not accompanied by modulations of activity in the orbitofrontal cortex or nucleus accumbens. Instead, conformity was associated with increased activity in the anterior cingulate cortex and insula—activity that the authors interpreted as indices of participants' anxiety about social rejection and as consistent with mere public compliance with the group norms.

It is not completely clear why this earlier research failed to demonstrate the socially influenced changes in neural representations of value that we observed in our study, but differences in the target objects (music vs. faces), participant populations (adolescents vs. adults), and task parameters (immediate vs. later conformity) may at least partially account for this divergence. Unlike song preferences, facial attractiveness is known to correlate with activity in the orbitofrontal cortex and nucleus accumbens, which makes this stimulus type especially well suited to observing socially mediated changes in these regions (Cloutier et al., 2008; O'Doherty et al., 2003). Further, adolescents may be particularly sensitive to fears of social rejection, which would increase the likelihood that they will conform publicly in the absence of private changes in evaluation. Finally, participants in the study conducted by Berns et al. (2010) made their follow-up rating of each song clip within seconds of making their initial rating and receiving peer feedback. This design draws considerable attention both to normative opinions during follow-up ratings and to any discrepancies between participants' own initial and follow-up ratings. By increasing the salience of social influence, this aspect of Berns and his colleagues' design likely made participants especially prone to engage in public compliance. In contrast, participants in our study received normative feedback about a large number of faces and made follow-up ratings much later. This stimulus quantity and the delay between initial and follow-up ratings may have attenuated explicit pressure to conform. These complementary findings serve to highlight the subtle factors that can lead to either public compliance or private acceptance and suggest the usefulness of neuroimaging as a method for disentangling these two sources of influence.

Our findings also complement those of another study (Klucharev et al., 2009) that examined neural activity at the time peers' attitudes were first presented. As in our study, participants rated the attractiveness of faces and subsequently learned whether peers agreed or disagreed with those initial ratings; unlike in our study, participants were scanned while making their initial ratings and receiving feedback as to whether their ratings agreed or disagreed with the group norms. Being in agreement with peers increased activity in the nucleus accumbens, whereas disagreeing with them decreased activity in this region. Moreover, the magnitude of this modulation in nucleus accumbens predicted conformity with peer ratings. These earlier findings suggest that individuals experience consensus with other people as intrinsically rewarding and that individuals may be actively motivated to modify their own opinions to more closely match social norms. Our study extends these observations by suggesting that social influence is accompanied by neural modifications that bring the representation of value associated with a stimulus more closely in line with the opinions of other people.

Together, these findings suggest an important—and previously unanticipated—role for neural systems involved in subjective value and reward as a core basis for conformity. More broadly, these data offer a novel way to conceptualize social influence: as a core human motive rather than a sign of individual weakness. Social psychologists have often depicted conformity as a sign that individuals lack the fortitude to resist the influence of other people (Le Bon, 1895/2002). However, the discovery that social influence builds on a neural architecture devoted to reward and subjective value suggests that humans may, in fact, be actively motivated to seek consensus and interpersonal coordination. Rather than being the result of individual weakness and faulty character, conformity appears to arise from the same neural systems that guide behavior toward highly valued outcomes, including satisfying basic needs such as food, water, and opportunities for reproduction. This emerging understanding of the neural basis of social influence suggests that people are remarkable not only in their willingness to adopt the opinions and norms of other people, but also in their fundamental motivation for doing so.

## Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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## Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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