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# Changing our minds: the neural bases of dynamic impression updating

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While a great deal of initial work in social neuroscience addressed the functional bases of our first impressions, our social evaluations of other people are anything but static. Just as our impressions can change, so too has our understanding of the neural underpinnings supporting this dynamic form of social learning. First, I review initial neuroimaging work on behavior-based impression updating, which observed that a distributed network of regions works in concert to revise trait representations in light of new behavioral information. Next, I discuss more recent research detailing how the updating process may be influenced by both bottom-up (e.g. experience) and top-down factors (e.g. motivation). Finally, I explore the contributions of more computational work studying similar processes via tasks that model social learning through repeated interactions and feedback-based reinforcement. Taken together, this work illustrates the expansion of our understanding of social impression formation, beyond static initial snapshots and towards a more dynamic process in which our representations of other people are continuously revised and reinterpreted in light of new information.

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We rapidly form social impressions of other people, which, in turn, provide us with a means of making accurate predictions about their subsequent behavior. When we learn that a person is generous, for example, we may be more likely to place our trust in them in the future because we have some basis for inferring that they will not violate that trust. Such impressions are built up over time on the basis of a variety of direct interactions, passive observations, and third-person communication. Given the social importance of impression formation (e.g. [1,2]), it is perhaps not surprising that social neuroscience placed such an emphasis on this area of inquiry during its first decade. However, initial examinations into the neural bases of impression formation focused on relatively static 'first impressions,' whether formed based on facial appearance or behavior. This work yielded particularly consistent patterns of results: social evaluations gleaned from facial characteristics like trustworthiness recruit the amygdala (e.g. [3]), while behavior-based impression formation is critically dependent on the dorsomedial prefrontal cortex (dmPFC; e.g. [4]). However, despite the relative robustness [5,6], automaticity (e.g. [7,8]), and consequences [9] of such impressions, they only tell a fraction of the story.

## The neural dynamics supporting impression updating

In our everyday experience, our impressions of others are anything but constant, and are rarely based on a single piece, or even a single channel of social evidence. Instead, we dynamically integrate across a continuous cascade of information (e.g. behaviors, appearances, preferences, social categorizations, prior knowledge) implying dispositional tendencies, each unit of which might interact with or contradict another. A subsequent wave of neuroimaging work on updating has sought to characterize the neural dynamics supporting our ability to *update* social impressions in light of behavioral inconsistencies.

In these studies, participants typically form first impressions in response to some piece of information implying a particular disposition (e.g. a trustworthy facial appearance or a positively valenced behavior), which are then contradicted by some subsequent piece of information implying the opposite disposition. For example, Mende-Siedlecki and colleagues conducted three experiments in which participants learned about a series of individuals over the course of five consecutive behaviors [10,11,12••]. Within inconsistent individuals, the first three behaviors were always internally consistent in terms of valence, while the last two behaviors violated that expectation, thus necessitating an updated impression.

This general approach has been used to examine the neural bases of impression updating across a variety of social inconsistencies, including behavior-appearance incongruities [13,14] and behavior-stereotype incongruities [15], as well as trait-related inconsistencies within an individual's behavior [16–18]. Taken together, this work highlights a distributed network of supporting brain regions. For example, the dmPFC, which is associated with mentalizing and trait inference (e.g. [4,19,20]), has been consistently identified as responding to unexpected, update-provoking social information. Subsequent work employing transcranial magnetic stimulation (TMS) during updating has confirmed the dmPFC's causal role in combining multiple pieces of social information to form a cohesive trait impression [21,22]. However, the updating process also depends on the recruitment of other regions involved in social perception (e.g. superior temporal sulcus; STS), theory of mind (e.g. temporoparietal junction/inferior parietal lobule; TPJ/IPL), expectancy violation (e.g. dorsal anterior cingulate; dACC), and cognitive control (e.g. lateral prefrontal cortex; lPFC).

## Bottom-up and top-down influences on the updating process

Having begun to establish the neural framework of impression updating, subsequent research has tackled fundamental questions regarding the underlying processes. For example, do updating-related changes in activity reflect altered trait representations elicited by attributionally meaningful changes in behavior, as opposed to mere moment-to-moment inconsistencies? Recent work suggests that different components of the network described above make separate contributions supporting updating [12••]. For example, while left ventrolateral prefrontal cortex (vlPFC) and inferior frontal gyrus (IFG) are preferentially recruited during updates triggered by inconsistent immoral behaviors, others structures (e.g. dACC, PCC, TPJ/IPL) respond preferentially to more mundane inconsistencies.

What, then, makes a behavior meaningful in the context of impression updating? What kinds of behavior elicit the strongest, most resilient changes in impressions? Previous behavioral research dovetails with the results described above. When it comes to learning about another person's moral character, immoral behaviors are more heavily weighted than their positive counterparts [23], and lead to more substantial revisions of both explicit (e.g. [24]) and implicit impressions (e.g. [25,26]). However, when considering a person's ability, positive (e.g. competent) behaviors are more diagnostic than negative (e.g. incompetent) behaviors [23]. This apparent asymmetry in diagnosticity can be explained parsimoniously: immoral and competent behaviors are given more weight in our impressions because they carry greater informational value [27]. They are perceived as being comparatively statistically infrequent [10] and are thereby more diagnostic [28]. Furthermore, when updating impressions of individuals whose behavior varies in terms of either morality or ability, vlPFC and IFG also show preferential recruitment during diagnostic updates in either domain (e.g. updates triggered by highly immoral and highly competent behaviors [10]).

A wealth of research in social cognition suggests that not all incongruent behaviors are incorporated into impressions to the same degree [29,30]. Rather, the deployment of updating processes may be moderated by motivational and situational factors. For example, a perceiver's tendency to ignore or attend to unexpected information may be contingent on the degree to which a perceiver's goals depend on the individual they are learning about (e.g. outcome dependency), or as a function of that individual's group membership.

In one study employing a particularly rich, ecologically valid design, participants interacted with (and formed impressions of) two real people prior to scanning, during which they learned additional information about both partners [16]. Critically, outcome dependency was manipulated across the two individuals (via whether or not the participants' reward was tied to the partners' performance), as was social expectancy. Results revealed that dmPFC activity increased in response to expectancy-disconfirming information pertaining to outcome-*dependent* partners, but that this pattern was reversed for outcome-*independent* partners. Thus, depending on someone to produce a self-relevant outcome can flexibly shape whether unexpected behavior is interpreted as being diagnostic or erroneous.

In a related vein, other researchers have examined how group membership might exert its own top-down, motivational influence on updating processes. For example, perceivers might be motivated to discount undesirable information that reflects poorly on their own compatriots, or conversely, might display an exaggerated response to similarly negative reports about their rivals. In line with the former account, unexpected negative information about in-group members elicited less activation in subset of neural structures involved in updating (including dACC, lPFC, and TPJ), compared to out-group or control individuals [31••]. In turn, this diminished recruitment of updating-related regions led to biased (e.g. more positively skewed) impressions of in-group individuals. These results once again suggest that motivational factors exert an influence on the updating process: while participants reliably engaged the distributed network of regions involved in updating for out-group and control individuals, this effortful process was disrupted when learning unpleasant, unflattering information about the in-group, allowing for the potential maintenance of a self-serving evaluation of one's own group. (See also [32], which found that mPFC activity in response to new, individuating information was observed for same-race targets, but not for other-race targets.)

## Forming and updating impressions via social reinforcement

A parallel literature on social decision-making has considered similar learning processes from a slightly different perspective. Using tasks that model the formation of trust through repeated economic interaction and exchange (see [33] for review), this research proposes a more computational account of dynamic impression formation. In general, this approach offers a host of theoretical and methodological advances. Such tasks sidestep issues of predictability and demand, but more importantly, they allow for the possibility of identifying computational contributions of specific regions involved in updating. Moreover, they move beyond the passive, observational form of learning used in prior work to capture the inherently interactive and feedback-based nature of dynamic impression formation. Given the nature of such paradigms — in which participants make choices and receive prediction-error eliciting feedback — this work heavily implicates structures involved in reinforcement and reward learning, such as the ventral striatum and ventromedial prefrontal cortex (for meta-analysis, see [34]).

Over time, these two approaches to updating have begun to converge. Initially, this took the form of work examining how trial-by-trial updating mechanisms are influenced by other sources of social information. For example, Delgado and colleagues tested whether setting priors regarding moral character would shape indices of interpersonal trust on both behavioral and neural levels. Although trust game payoff rates were held constant across partners described through initial vignettes as being 'bad,' 'neutral,' or 'good,' participants made more risky investments in the good partner. Moreover, feedback-related activity in the caudate nucleus regarding the good and bad partners was blunted, compared to the neutral partner, suggesting that strong social expectations can lessen reliance on moment-to-moment reinforcement [35]. Other work has considered similar top-down modulation of social decision-making processes as a function of facial trustworthiness [36,37], racial group membership [38], and familiarity or prior knowledge [39–41].

Since dynamic social learning in these tasks is typically modeled in the form of monetary gains and losses, do they truly characterize the updating of *trait* representations? More recent research has attempted to disentangle reward-based and trait-based updating mechanisms from one another [42••]. When trait generosity and reward are orthogonalized, both attributes guide instrumental learning and are associated with feedback-related activity in ventral striatum. However, trait learning exerts a stronger influence on social choice behavior, and furthermore, elicits activity in the same distributed network of regions associated with behavior-based impression updating described above [10,11,12••]. Nevertheless, while feedback-based trait learning seems especially well-suited to human social contexts, it may be recruited while developing representations of non-social agents, as well (though see [43], which observed socially specific prediction error activity in precuneus).

Work in this vein continues to examine how we make sense of others' social tendencies over time. For example, a growing body of literature has employed model-based techniques to study neural computations underlying the formation of representations of status and dominance (e.g. [44••,45,46••]). Other research has used this approach to examine our dynamic ability to learn about others' emotional expressivity [47] and the reliability of their advice [48,49], as well as complex phenomena like the formation of group-based stereotypes [50] and the propagation of inequality [51]. Ultimately, a model-based account of dynamic social learning appreciates and captures a core function of our impressions of others: to serve as the basis for making effective predictions about future behavior.

## Conclusion

The past decade has enhanced our understanding of dynamic impression updating in both depth and nuance. While several core brain areas are critical to the formation of initial impressions (e.g. dmPFC, amygdala), their subsequent revision recruits a distributed network including areas implicated in reinforcement learning, cognitive control, and theory of mind. Future work should continue to investigate the interaction of these processes, with the goal of producing one comprehensive framework of dynamic social learning (e.g. akin to work on the multiple memory systems supporting implicit cognition [52]). Ideally, this framework would characterize the relationships between multiple channels of social information contributing to our impressions (e.g. appearance-based judgments, passive observation of behavior, third-person communication, direction interaction). For example, it's still unclear if our underlying social representations vary across these modalities (or if they share a common neural code; e.g. [53]), or whether the process of updating itself differs as a function of the type of incoming social information. Moreover, it remains to be seen whether interactions between channels are fixed (e.g. with one channel exerting dominance, if available), or if this interplay is flexible and contextually dependent. Subsequent work on impression updating should also address questions about updating across multiple contexts (e.g. [54]) — for example, discrepancies between impressions formed online and later updated face-to-face (e.g. [55]). Little work has addressed this particular form of updating, which makes for a particularly relevant and ecologically valid test of the prevailing models of social impression formation.

Moving forward, researchers should also continue to probe the dynamic nature of trait inference and representation [56], and in particular, should incorporate recent insights regarding neural representations of trait information that extend beyond classic two-dimensional models of person perception [57]. Finally, the next wave of research should examine updating across multiple, concentric levels of analysis, such that learning at the level of the individual influences representations of groups, contexts, and environments, in turn.

## Conflict of interest statement

Nothing declared.

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