Neural correlates of susceptibility to group opinions in online word-of-mouth recommendations

Christopher N. Cascio¹, Matthew Brook O’Donnell¹, Joseph Bayer², Francis J. Tinney Jr.², & Emily B. Falk¹.

University of Pennsylvania¹, University of Michigan²

Correspondence:
Christopher N. Cascio
Annenberg School for Communication
University of Pennsylvania
3620 Walnut St.
Philadelphia, PA 19104
Phone:
Email: ccascio@asc.upenn.edu

Emily B. Falk
Annenberg School for Communication
University of Pennsylvania
3620 Walnut St.
Philadelphia, PA 19104
Phone:
Email: falk@asc.upenn.edu

Acknowledgments: The research was supported by (1) the intramural research program of the Eunice Kennedy Shriver National Institute of Child Health and Human Development contract # HHSN275201000007C (PI:Bingham); (2) A University of Michigan Injury Center Pilot Grant (PI:Falk); and (3) An NIH Director's New Innovator Award #1DP2DA03515601 (PI Falk). The authors gratefully acknowledge the Communication Neuroscience lab and University of Michigan Transportation Research Institute for research assistance and the staff of the University of Michigan fMRI Center as well as C. Raymond Bingham, Jean T. Shope, Marie Claude Ouimet, Anuj K. Pradhan, Bruce G. Simons-Morton, Kristin Shumaker, Jennifer LaRose, Farideh Almani, and Johanna Dolle. We also thank Sylvia Morelli, Elliot Berkman, Will Moore and the Pfeifer lab for provision of anatomical regions of interest.
Abstract

The present study examined the relationship between social influence and recommendation decisions among adolescents in the new media environment. Participants completed the App Recommendation Task—a task that captures neural processes associated with making recommendations to others, with and without information about peer recommendations of the type commonly available online. Our results demonstrate that increased activity in the striatum and orbitofrontal cortex in response to peer recommendations are significantly correlated with changing recommendations to be consistent with this feedback within subjects. Furthermore, individual differences in activation of the temporoparietal junction during feedback that peer recommendations differed from those of the participant correlated with individual differences in susceptibility to influence on recommendation decisions between subjects. These brain regions have previously been implicated in social influence and being a successful idea salesperson, respectively. Together, they highlight a potential combination of internal preference shifts and consideration of the mental states of others in recommendation environments that include peer opinions.

**Keywords:** Social influence, recommendations, word-of-mouth, apps, fMRI, mentalizing, valuation
Introduction

Sharing ideas and information is an essential aspect of communication and has substantial impact on human preferences and behaviors (Bone, 1995; Tzourio-Mazoyer et al., 2002). People frequently make recommendations about using or avoiding specific products and services, willingly sharing their experiences and opinions with others. In turn, word-of-mouth recommendations can significantly shape consumer decisions (Anderson & Magruder, 2012; Berger, 2014; Chevalier & Mayzlin, 2006; Chintagunta, Gopinath, & Venkataraman, 2010; Duan, Gu, & Whinston, 2008; Ye, Law, Gu, & Chen, 2011). This phenomenon is particularly highlighted in the new media environment, where people can instantly share with a wide range of friends, strangers and imagined others online. In the online space consumer recommendations are made for everything from what services are most reliable to where to eat to what car to buy.

From a marketing perspective, consumer recommendations can influence product and brand popularity and are commonly found within the competitive marketplace. In fact, successful product launches often rely on the pairing of the right product with recommendations from the right group of people (Aral & Walker, 2011, 2012; Hinz, Skiera, Barrot, & Becker, 2011; Van der Lans, Van Bruggen, Eliashberg, & Wierenga, 2010; Watts & Dodds, 2007). Indeed, it is well documented that social influence (e.g., social proof (Cialdini & Goldstein, 2004)), or more generally learning about the preferences and behaviors of others can powerfully affect consumer’s personal decisions (Senecal & Nantel, 2004). Less is known, however, about the processes through which recommenders make recommendation decisions, especially in relation to how social information impacts consumers’ decisions about the recommendations that they make. The ubiquity of opportunities to generate recommendations, combined with the power that the resulting decisions can have on other potential recommenders, highlights the importance of
understanding the underlying processes through which recommendation decisions are made and affected by the preferences and opinions of others.

Neuroimaging is one valuable tool for understanding such mechanisms. Neuroimaging methods such as functional magnetic resonance imaging (fMRI) allow simultaneous examination of multiple neurocognitive processes in real time, as decisions unfold. In particular, behaviors that appear similar on the surface may be produced by different underlying processes (Lieberman, 2010)—for example, neuroimaging may be well suited to discriminate between outcomes that would appear the same on the surface (e.g., observed shifts in a recommendation), but that might have very different underlying psychological interpretations (e.g., public compliance with the opinions of others while still maintaining an initial set of beliefs privately versus actual shifts in privately held opinions (Zaki, Schirmer, & Mitchell, 2011)). Following this logic, a growing body of literature has characterized the neural systems associated with conformity and social influence on individual opinions and behaviors ((Berns et al., 2005; Berns, Capra, Moore, & Noussair, 2010; Campbell-Meiklejohn, Bach, Roepstorff, Dolan, & Frith, 2010; Chein, Albert, O’Brien, Uckert, & Steinberg, 2011; Falk, Berkman, Mann, Harrison, & Lieberman, 2010; Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009; Mason, Dyer, & Norton, 2009; McClure, Li, et al., 2004; Stallen, Smidts, & Sanfey, 2013; Zaki et al., 2011); for reviews, see (Falk, Way, & Jasinska, 2012; Izuma & Adolphs, 2013)). One overarching theme from this work is that social influence seems not only to change surface level decisions and reported preferences, but also to genuinely alter the value of stimuli ascribed in the brain (Mason et al., 2009; Zaki et al., 2011). However, no prior studies have investigated the neural processes involved in making and updating other-directed recommendations in response to peer recommendations. This is a critical gap in the literature given the importance of
recommendation decisions for the outcomes highlighted above; other-directed recommendations may differ in key ways from self-oriented preferences and may be changed through mechanisms not apparent in previous studies of social influence.

In considering the neural processes that might be involved in decisions to update (or not update) a recommendation in the face of peer opinions that differ from one’s own, we draw on two distinct bodies of research that have investigated two fundamental parts of this novel question. First, we review the neural processes that distinguish individuals who are more and less successful in making recommendations to others. Second, we review the neural processes that are associated with updating personal preferences in response to social influence. We hypothesize that decisions to update other-directed recommendations in response to peer opinions may bring together these brain systems to arrive at final recommendation decisions.

Neural correlates of successful recommendations.

A small number of neuroimaging studies have characterized neural processes involved in how people influence others through recommendation and related behaviors (Dietvorst et al., 2009; Falk, Morelli, Welborn, Dambacher, & Lieberman, 2013; Falk, O’Donnell, & Lieberman, 2012). These preliminary studies converge on the importance of activity in the communicator’s temporoparietal junction (TPJ) for the successful transmission of ideas and recommendations. The TPJ is key to understanding the mental states of others (Saxe & Kanwisher, 2003; Saxe & Powell, 2006)—termed mentalizing. Previous work has speculated that successful recommenders may more actively consider what others are likely to think of ideas before recommending them (Falk et al., 2013).

More specifically, research has examined individual differences in the effectiveness of individuals in promoting their ideas to others (termed the “idea salesperson effect”). Increased
activation of the TPJ was associated with being a successful idea salesperson (Falk et al., 2013), and was the only brain region tracking this ability. Examination of the coordinates observed using the Neurosynth database suggests that the probability of mentalizing given the activations observed is high (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011). It is possible that those who are better at persuading or conveying their ideas to others may already be thinking about how to make shared information useful to others during initial idea encoding (Falk et al., 2013). These individuals may also be more receptive to social cues more broadly, and may make more use of social information as they formulate their recommendations, a focus of the current investigation.

In addition, research has examined related neural processes associated with increased ability of salespeople to get inside the minds of their consumers—a salesperson theory of mind index (Dietvorst et al., 2009). These researchers also found that increased activity in the TPJ and medial prefrontal cortex (MPFC) was associated with greater tendency to mentalize about consumers, and which was ultimately associated with better sales performance (Dietvorst et al., 2009). Taken together, these results suggest that activity in TPJ (and MPFC) may be important for dynamically updating in the face of social signals that could play an especially important role in the context of making recommendations.

**Neural correlates of social influence on individual preferences and decisions**

Building on decades of literature demonstrating the power of social proof to alter individual preferences and decisions, a separate body of neuroimaging literature has documented the neural shifts that occur in evaluating stimuli that are judged more or less favorably by others. In attempting to explain why the brain would alter its representation of objectively identical
inputs in response to different group opinions, much of this work has focused on the broader evolutionary benefits of fitting in with a social group; for a review, see: (Falk, Way, et al., 2012).

Given the benefits of group membership, susceptibility to social influence is thought to be reinforced, in part, by activity in the brain’s valuation system, including parts of the ventral striatum (VS) and orbitofrontal cortex (OFC)/ ventromedial prefrontal cortex (VMPFC) (Campbell-Meiklejohn et al., 2010; Chein et al., 2011). A substantial body of literature has established that social feedback is encoded in similar parts of the valuation system as primary rewards such as food and sex (Bartra, McGuire, & Kable, 2013; Lieberman & Eisenberger, 2009; McClure, York, & Montague, 2004). This responsivity to social signals in the valuation system may help to maintain group harmony and encourage cohesion. In line with this argument, functional magnetic resonance imaging (fMRI) studies of social influence have used neural signals within the brain’s valuation system to demonstrate that group opinions actually changes the underlying responses in these regions to social stimuli (Klucharev et al., 2009; Mason et al., 2009; Zaki et al., 2011). These studies suggest that valuation may be one key driver of susceptibility to social influence, with individuals updating their internal preferences according to social norms.

Likewise, humans have developed alarm systems that detect conflict and respond to social threats (Cacioppo et al., 2002; Eisenberger, 2012; Hawkley, Burleson, Berntson, & Cacioppo, 2003; Hawkley, Thisted, Masi, & Cacioppo, 2010; Peters, Riksen-Walraven, Cillessen, & de Weerth, 2011). For example, it is believed that the brain’s response to social exclusion built on the evolutionarily older neural system that responds to physical pain in service of maintaining group cohesion (Eisenberger, Lieberman, & Williams, 2003; Eisenberger, 2012; Panksepp, 1978). Neural regions include the dorsal anterior cingulate (dACC) and anterior
insula in adults (Eisenberger et al., 2003; Eisenberger, 2012), and additionally the subgenual cingulate (subACC) in adolescents (Falk et al., 2014; Masten et al., 2009). Beyond studies of social pain, the ACC has also been implicated in basic cognitive processes such as conflict monitoring and error detection (C. S. Carter et al., 1998; Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Kerns et al., 2004), which would also be highly relevant to maintaining alignment with group opinions.

In the domain of social influence, neural sensitivity within these brain regions has been implicated in conformity (Berns et al., 2005; Gunther Moor, van Leijenhorst, Rombouts, Crone, & Van der Molen, 2010; Peake, Dishion, Stormshak, Moore, & Pfeifer, 2013). In one study, individual differences in sensitivity to popularity ratings of music within anterior insula and ACC were associated with tendency to conform (Berns et al., 2010). In another recent study, individual differences in neural activity within the subgenual cingulate and anterior insula, as well brain regions selected for their role in mentalizing (TPJ, posterior cingulate, dorsomedial prefrontal cortex) during exclusion predicted later susceptibility to social influence in teens (Falk et al., 2014). In this same investigation, self-reports of sensitivity to social cues (distress during exclusion) did not predict susceptibility to social influence, highlighting the value of fMRI for helping unpack mechanisms that may not be apparent using traditional self-report measures alone. Although one of several possible interpretations, these data are consistent with the idea that teens whose brains are more sensitive to a range of social cues may attend more strongly to the potential for social consequences of their actions and take steps preemptively to gain attention or fit in by conforming. More broadly, to the extent that individuals are more sensitive to social conflict and experience greater physiological reactivity to being out of line with a
group, they might be more inclined to behave in ways that preemptively avoid exclusion and promote bonding by conforming (Falk, Way, et al., 2012).

The current study

In the current study we bring together the two literatures reviewed above on the neural mechanisms underlying recommendations (Dietvorst et al., 2009; Falk et al., 2013; Falk, O’Donnell, et al., 2012) and the separate literature on social influence (Berns, Capra, Moore, & Noussair, 2010; Mason, Dyer, & Norton, 2009; and Zaki, Schirmer, & Mitchell, 2011) to test predictions about mechanisms that lead participants to update their recommendations in response to feedback about the recommendations of peers. We bring these previously disjoint literatures together to examine the intersection of recommendation decisions and social influence in an adolescent population.

We examined neural and behavioral responses as participants made recommendation decisions and then updated those recommendation decisions in response to the recommendations of other peers. We hypothesized that both neural systems previously implicated in successfully recommending ideas to others as well as neural systems previously implicated in susceptibility to social influence would come together when participants updated their recommendations to others based on peer recommendations.

Unlike previous research on social influence that examines how social feedback influences our own opinions, the current investigation examines how social feedback influences the recommendations we make for others. Thus, the current study examines social influence that goes beyond the end user, and reflects how information passed on to other potential consumers may be biased by the current average group opinion. The current findings associated with other-directed recommendations can then be qualitatively compared to previous studies that have
examined self-directed recommendations, though the primary purpose of our study is to first describe the neural processes implicated in other-directed recommendations. In addition to examining the neural processes associated with socially prompted shifts in recommendation behavior on average, the present study also seeks to understand individual differences that lead some young consumers readily and dynamically update their recommendations in the face of peer group feedback whereas others do not.

In parallel with such basic science objectives, we also sought to create an experimental manipulation that mimics the new media recommendation environment; recommendations are made frequently online with limited information, with large consequences for sales and marketing. Recommendation platforms often offer anonymity and require limited effort to engage. To maximize the external validity of this research, the current study addresses the intersection of recommendation decisions and social influence in adolescents in a task that mimics several of the qualities noted above. The task involves recording recommendations of real mobile game apps based on information provided by app developers at the iTunes store. This task allows us to explore real-world relevant marketing stimuli in the context of a well-controlled lab setting, giving us a high level of external and internal validity.

We focused on ratings of mobile game applications, which are a fast growing component of the new media market; forecasts estimate that 102 billion apps will be downloaded worldwide in 2013 and an estimated 268 billion apps will be downloaded per year by 2017 (The Guardian, 2013). Further, in 2012 the mobile app industry generated approximately 18 billion in revenue and this figure was estimated to rise to 26 billion in 2013 (The Guardian, 2013). The ubiquity of mobile technology and constant contact with mobile devices makes it especially important to
understand how people make choices about what to consume and recommend to others in this arena.

Finally, we focus on adolescents given that preferences and ways of processing social information are learned during this developmental period (Cummings, Hyland, Lewit, & Shopland, 1997; Schindler & Holbrook, 2003; Valkenburg & Cantor, 2001). In addition, adolescents have a high level of engagement with the new media environment, such as the use of mobile apps (Bellman, Potter, Treleaven-Hassard, Robinson, & Varan, 2011). There is growing recognition that substantially more research is needed to understand how social, cognitive and affective processes interact in the adolescent brain during social influence (Pfeifer & Allen, 2012), and no prior research has investigated the neural processes at play as adolescents make recommendation decisions or how social influence might affect neural processes underlying recommendation decisions.

Methods

Pilot Study for the App Recommendation Task

Prior to running the main fMRI study, behavioral pilot data were gathered on the App Recommendation Task (described below) in order to test whether group recommendation information could affect participants’ final recommendations. Initial pilot testing was carried out using 106 undergraduate students enrolled in an introductory communications class at the University of Michigan. Participants completed a computer-based version of the App Recommendation Task in exchange for course credit. Pilot study and behavioral results were analyzed using repeated measures ANOVAs to detect overall group differences and planned contrasts to determine whether the mean likelihood of changing one’s final recommendation was altered by specific group recommendation condition.
**fMRI Study Participants**

Seventy eligible adolescent males took part in the current study and were recruited from the Michigan Driver History Record through the University of Michigan Transportation Research Institute as part of a larger series of studies examining adolescent driving behavior. One subject was excluded because he noted that he had used the incorrect finger when making final ratings for a portion of the task, two subjects were excluded because they did not complete enough of the initial/final recommendations to model behavior, one subject was excluded due to incomplete data resulting from scanner error, and one participant was excluded due to a lack of variability in recommendations which prevented behavior change models from running. Removing these participants resulted in a final sample size of 65. All participants were between the ages of 16 to 17 ($M = 16.9$, $SD = .30$, right-handed, did not suffer from claustrophobia, were not currently taking any psychological medications, had normal (or corrected to normal) vision, did not have metal in their body that was contraindicated for fMRI, and did not typically experience motion sickness. Legal guardians provided written informed consent following telephone discussion with a trained research assistant, and teens provided written assent.

**App Recommendation Task**

We developed the App Recommendation Task for the fMRI environment to examine the intersection between recommendation decisions and social influence on such decisions. The task captures neural processes associated with sharing online recommendations for a mobile game website and manipulates social feedback regarding the recommendations of peers. The task stimuli consist of real puzzle based game app titles, images and their associated descriptions acquired from the iTunes App Store. Actual apps from the App Store were used in order to maximize external validity and engagement for the target participants, maintain a sense of
realism and present a product that adolescents and young adults are likely to buy and rate online in real life. As part of the task, participants are exposed to information that is available at the App Store—game titles, logos, and brief descriptions of the games (Figure 1). Games from one category (puzzle based games) were used in order to reduce strong preferences for one particular game genre over another (e.g., shooter game versus sports games) and all game descriptions were limited to a consistent two sentence structure (e.g., Zombie Grandmother: “Fight your way through the army of the Undead blasting them with fireballs, cutting ropes, and breaking chains. Defeat your main target, the Zombie Grandmother!”).

Participants completed two rounds of the App Recommendation Task. First, an initial set of recommendation intentions were recorded during a pre-scan session in which participants initially learned about the games. During the initial rating session participants were asked to give their preliminary opinions on 80 previously unknown mobile game apps in response to a prompt asking “how likely would you be to recommend the game to a friend”. Participants rated the games on a 1 to 5 Likert scale, where 1 represented “wouldn’t recommend” and 5 represented “would recommend”. The 80 games were randomly ordered within participants.

During the fMRI session participants completed a second round of the App Recommendation Task, which occurred approximately 40 minutes after the initial recommendations were given. Participants were told that they would be re-rating the same 80 mobile game apps to be recorded for a review website, however mimicking the experience of several online rating platforms, this time participants would be shown the title, logo, and a reminder of how they initially rated the game. It was explained that they would then be shown information about whether their peers in the study were more likely, less likely, or equally likely to recommend the games to others, but that for some games, we hadn’t yet collected
recommendation information from others, so no peer recommendation information was available. Peer group recommendations were pseudo randomly computer generated in order to maintain 20 trials for each feedback type. Finally, participants were instructed that they would be given an opportunity to update their initial recommendations if they wished, and to lock in a final response in the scanner. In other words, during the fMRI portion of the task, each game rating block consisted of three parts. Consistent with these instructions, in the scanner, participants first saw a reminder of the game using the title and logo along with a reminder of how they initially rated the game (2 seconds). Next participants were exposed to manipulated peer group recommendations relative to their own (higher, lower, or same) or no peer group feedback (not rated) (3 seconds). Finally, participants were asked to lock in a final recommendation for each game for the website (3 seconds; Figure 2). Following the scanning session participants completed a debriefing interview where participants were asked what they felt the goal of the task was (e.g., “What type of strategy did you use during this task”, “What did you think of your group members ratings”, “What do you think the purpose of the experiment was today”, and “What was the experiment trying to study”). No participants reported any explicit connection between social influence and the App Recommendation Task. As expected, given that the task was completed as part of a larger study on teen driving, participants commonly indicated that they felt the study was attempting to examine processes related to driving behaviors, such as decision-making skills, emotions, judgments made in different situations, and individual differences in focus and memorization. In addition, participants completed the App Recommendation Task as part of a larger fMRI session that examined 3 additional tasks that were not the focus of the current investigation, which also served to reduce demand artifacts. Finally, we took several measures to increase the plausibility of the task:
participants were told that we were conducting a marketing study in order to understand how relatively unknown apps become popular given that when they are introduced on sites such as iTunes there is generally very little information to make purchasing decisions. Also, participants were specifically told that we were interested in how they made recommendations based on exposure to limited information and that we wanted them to give their best recommendation for their peers as they would on the type of mobile game site from which the app descriptions were originally pulled.

*fMRI data acquisition and analysis*

Imaging data were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3mm; voxel size = 3.44 x 3.44 x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 x .86 x 3.0mm) and high-resolution T1-weighted images (SPGR; 124 slices; slice thickness = 1.02 x 1.02 x 1.2 mm) for use in coregistration and normalization.

Functional data were pre-processed and analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). To allow for the stabilization of the BOLD signal, the first four volumes (eight seconds) of each run were discarded prior to analysis. Functional images were despiked using the 3dDespike program as implemented in the AFNI toolbox. Next, data were corrected for differences in the time of slice acquisition using sinc interpolation; the first slice served as the reference slice. Data were then spatially realigned to the first functional image. We then co-registered the functional and structural images using a two-stage procedure. First, in-plane T1 images were registered to the mean functional image. Next, high-resolution T1 images were registered to the in-plane
image. After coregistration, high-resolution structural images were skull-stripped using the VBM8 toolbox for SPM8 (http://dbm.neuro.uni-jena.de/vbm), and then normalized to the skull-stripped MNI template provided by FSL (“MNI152_T1_1mm_brain.nii”). Finally, functional images were smoothed using a Gaussian kernel (8 mm FWHM). Following the pre-processing steps motion parameters from SPM were examined and no participants displayed greater than 3mm (translation) or 2 degrees (rotation) of head movement during a task run.

Data were modeled at the single subject level using the general linear model as implemented in SPM8. The four feedback conditions in the group feedback trials (not rated, same, higher and lower) were combined with outcomes pertaining to whether participants updated their initial recommendation or not following feedback about group recommendations (change and no change) as regressors in the model (e.g., gHIGHER_bCHANGE indicates a block during which a participant receive higher feedback during the group feedback trial and made a change to their initial rating during the final rating trial). We modeled the three-second period during which participants were exposed to the feedback as a boxcar (duration = 3 sec). Two of these combinations gNOTRATED_bCHANGE and gSAME_bCHANGE did not have sufficient instances across participants to be modeled on their own and so the few instances where this occurred were grouped with trials where no response was recorded under an ‘OTHER’/nuisance regressor condition. The six rigid-body translation and rotation parameters derived from spatial realignment were also included as nuisance regressors. Data were high-pass filtered with a cutoff of 128s. Volumes were weighted according to the inverse of their noise variance using the robust weighted least squares toolbox (Diedrichsen, Hashambhoy, Rane, & Shadmehr, 2005).

Neural responses to group feedback across participants
First, we aimed to understand which neural processes were associated with recommendation change across participants in response to feedback that group recommendation differed from one’s own. We first examined neural activity associated with receiving feedback that the peer group had made different recommendations (gDIFFERENT = average of higher and lower) than the participant compared to receiving no social feedback (not rated). This contrast identifies aggregate neural processes associated with the core feedback conditions of interest, controlling for processes associated with considering the games and the act of making recommendations, without such feedback. In addition, we compared neural activity associated with receiving feedback that the peer group had made different recommendations (gDIFFERENT) to feedback that the peer group had made the same recommendation (same). This second contrast compares receipt of conflicting vs. affirming social feedback. The contrasts gDIFFERENT > gNOTRATED and gDIFFERNET > gSAME were modeled for each participant at the single subject level using SPM8. Results from the first level models were combined at the group level using a random effects model implemented in SPM8, using a Gaussian filter width of 8 mm.

Next, we aimed to identify neural mechanisms associated with changing one’s recommendations in response to feedback that group recommendations differed from the participants’. In order to explore this substantive question we examined differences in behavior (change versus no change) while receiving feedback that the peer group made different recommendations (higher and lower) than the participant. The contrast gDIFFERENT_bCHANGE > gDIFFERENT_bNOCHANGE was modeled for each participant at the single subject level, and combined at the group level using a parallel random effects model as described above, implemented in SPM8.
All results were thresholded at $p = .001$, uncorrected. All coordinates are reported in MNI space.

**Individual differences in receptivity to peer feedback**

We next examined individual differences in the tendency to update one’s recommendations based on peer recommendations. More specifically, we examined neural activity in regions of interest (ROI) that have previously been implicated in successful recommendations (bilateral TPJ and MPFC) and social influence (VS, subACC, AI, dACC, DMPFC, PC/PCC) as defined by a meta analysis of studies on social influence (Cascio, Shumaker, Beard, Albarracin, & Falk, in prep). We examined neural activity (average percent signal change) within each ROI between subjects as a potential correlate of the overall tendency for participants to update their recommendations in the face of feedback that peer recommendations differed from the participant’s (% of trials in which participant changed their initial rating in response to group feedback). Thus, an ROI analysis allows us to examine how individual differences in average levels of intensity within specific neural regions during social feedback relates to one’s overall susceptibility to update their recommendation. This analysis differs from our whole brain analysis in that neural activity is extracted based solely on group feedback and does not consider behavioral outcomes. In addition, unlike our whole brain contrasts, which examine within subject differences in neural activity, our ROI analysis allows us to examine between subject differences in neural activity. Neural and behavioral data from the App Recommendation Task were combined in an ordinary least squares regression, implemented in R (version 3.0.1).

*ROIs based on literature on recommendations.* Right and left TPJ and MPFC ROIs (figure 3) were constructed in Wake Forest University Pickatlas toolbox within SPM (Maldjian,
Laurienti, Kraft, & Burdette, 2003), combining Brodmann areas intersected with x,y,z bounds as noted below to restrict sub-regions and refined in FSLview based on review of literature relevant to social cognition (courtesy of the Pfeifer Lab). MarsBar (Brett, Anton, Valabregue, & Poline, 2002) was used to convert these anatomical images to ROIs. The right TPJ ROI was defined as all voxels within Brodmann areas 22, 39, and 40 intersected with a box-shaped mask centered at $(x = 60, y = -52, z = 30)$ and extending 40, 16, and 24 mm along the $x$, $y$, and $z$ axes. The left TPJ was a mirrored version of the right TPJ. The MPFC ROI was defined as all voxels within Brodmann area 10 and restricted medially by intersecting a box-shaped mask that extends from $x = -20$ to 20, $y = 45$ to 70, $z = -10$ to 30.

**ROIs based on literature on social influence.** Regions of interest were also constructed within regions most strongly associated with social influence (AI, dACC, DMPFC, PC/PCC, and VS) based on a meta-analysis examining social influence (Cascio et al., in prep) using GingerALE (version 2.3) (Eickhoff et al., 2009; Eickhoff, Bzdok, Laird, Kurth, & Fox, 2012; Turkeltaub et al., 2012). GingerALE performs a activation likelihood estimation on coordinates in Montreal Neurological Institute (MNI) and/or Talairach space (Eickhoff et al., 2009, 2012; Turkeltaub et al., 2012). MarsBar (Brett et al., 2002) was used to convert these images to ROIs (figure 4). Additional details are provided in table S1 of the web appendix.

**Results**

**Pilot testing of the App Recommendation Task**

Results from our pilot participants indicated that information about peer recommendations significantly altered the proportion of the time that participants’ changed their final recommendations ($(M_{\text{notrated}} = 15.38\%, SD_{\text{notrated}} = 18.68\%; M_{\text{same}} = 7.36\%, SD_{\text{same}} = 12.67\%; M_{\text{higher}} = 22.83\%, SD_{\text{higher}} = 22.07\%; M_{\text{lower}} = 33.77\%, SD_{\text{lower}} = 26.24\%), F(3,103) =$
In addition, results of planned t-tests confirmed that participants changed their recommendation significantly more often when peer group recommendations differed from the participants’ initial rating (combined average of higher and lower) versus the same, $F(1,105) = 85.14, p < .001$, and versus the no-feedback (not rated) control condition $F(1,105) = 28.91, p < .001$. Results from piloting increased our confidence that participants could easily understand the task, and the feedback provided regarding group recommendations in the App Recommendation Task could alter participants’ likelihood of changing their recommendations.

**fMRI Participants’ Behavioral data**

Within our main fMRI dataset, participants’ recommendation decisions were well dispersed across the recommendation scale (initial ratings: Definitely would not recommend (1): 14.82%, (2): 24.18%, (3): 24.00%, (4): 22.38%, Definitely would recommend (5): 13.83%). Replicating the behavioral results from pilot testing, we first examined the relationship between the type of peer feedback provided and participants’ changes from their initial recommendations to final recommendations. The peer feedback manipulation exerted effects parallel to those observed in our pilot testing, such that there were significant differences in how frequently participants changed their recommendations across feedback conditions ($M_{\text{notrated}} = 17.38\%$, $SD_{\text{notrated}} = 18.84\%; M_{\text{same}} = 9.31\%, SD_{\text{same}} = 14.06\%; M_{\text{higher}} = 40.15\%, SD_{\text{higher}} = 23.07\%; M_{\text{lower}} = 54.00\%, SD_{\text{lower}} = 22.87\%), F(3,62) = 60.93, p < .001 ; figure 4). Participants changed their recommendations significantly more often when peer group feedback was different from their initial rating (combined average of higher and lower; $M_{\text{different}} = 46.66\%, SD_{\text{different}} = 22.92\%$) versus the same, $F(1,64) = 178.07, p < .001$, and versus the no-feedback (not rated) control condition $F(1,64) = 102.82, p < .001$. In addition, changes in recommendation behavior were examined across initial recommendation conditions in order to determine if participants were
more likely to change their behavior depending on how they initially rated the apps. Results indicated that participants did not significantly change their recommendations more or less often depending on their initial recommendation, \( F(4,61) = 1.13, p = .291 \).

*Neural processes associated with recommendation change across participants*

We examined the neural mechanisms within subjects that preceded participants changing their recommendations. We broke this process down by first examining neural activity associated with feedback that the group made different recommendations than the participant (compared to not receiving any social feedback: \( g_{\text{DIFFERENT}} > g_{\text{NOTRATED}} \)). This contrast controls for processes related to exposure to the mobile game app information, and for general processes associated with considering one’s own recommendation. The resulting contrast highlights activity related to receiving socially relevant feedback that peers’ recommendations differ from that of the participant. On average, we found the precuneus, dACC, putamen, dorsolateral prefrontal cortex (DLPFC), and parahippocampal gyrus, among other regions were significantly more active while receiving feedback that the peer group made different recommendations from the participant versus receiving no social feedback, (uncorrected \( p = .001 \); figure 5). No significant activity was found in the reverse contrast (\( g_{\text{NOTRATED}} > g_{\text{DIFFERENT}} \)). For a full list of activations see table 1.

Next, we examined neural activity associated with feedback that the group made different recommendations than the participant (compared to receiving social feedback that is the same as the participant: \( g_{\text{DIFFERENT}} > g_{\text{SAME}} \)). This contrast controls for the task-related activity noted above, but compares to a socially affirming condition. On average, we found that the precuneus, TPJ/angular gyrus, and globus pallidus, among other regions, were significantly more active while receiving feedback that the peer group made different recommendations from the
participant versus receiving feedback that the peer group made the same recommendations as the participant, (uncorrected \( p = .001 \); figure 6). No significant activity was found in the reverse contrast (\( \text{gSAME} > \text{gDIFFERENT} \)). For a full list of activations see table 2\(^1\).

Finally, we examined the neural mechanisms associated with changing (vs. not changing) recommendations when group recommendations differed from the participants’. More specifically, we examined neural activity while participants received feedback that the group made different recommendations than the participant and changed their behavior versus receiving feedback that the group made different recommendations than the participant and did not change their behavior (\( \text{gDIFFERENT}_b\text{CHANGE} > \text{gDIFFERENT}_b\text{NOCHANGE} \)). On average, we found regions of VS and OFC were significantly more active when participants changed their recommendations versus not changing their recommendations when receiving feedback that the group made different recommendations than the participant (uncorrected \( p = .001 \); Table 3; Figure 7). In other words, on trials when participants showed more activity in the VS and OFC in response to group recommendations that conflicted with their initial recommendations, they were more likely to change their recommendations in response to this social feedback. No regions were significantly more active in the inverse contrast (\( \text{gDIFFERENT}_b\text{NOCHANGE} > \text{gDIFFERENT}_b\text{CHANGE} \)).

*Activity in right TPJ correlates with individual differences in one’s tendency to incorporate group feedback into recommendations*

Finally, we examined whether activity in ROIs previously implicated in successful recommendation behavior and social influence, during peer feedback that diverged from the participants’ initial recommendation (\( \text{gDIFFERENT} \)), related to who was most likely to change

\(^1\) Note: Whole brain results examining differences between higher and lower feedback are provided the web appendix, tables S2-S4.
their initial recommendations in the face of this feedback. We found that within our hypothesized ROIs, only increased activity in right TPJ during feedback that the group made recommendations different from the participant significantly correlated with participants’ tendency to change their recommendation in the face of peer feedback ($r = .25$ $t(63) = 2.09$, $p = .041$). However, one participant had neural activity that was 3.88 standard deviations above the mean, thus the analysis was reanalyzed removing this participant. Results were consistent after this outlier removed ($r = .27$, $t(62) = 2.25$, $p = .028$; Figure 8). In other words, participants who showed more activity in the right TPJ when receiving social feedback that the group made different recommendations than the participant changed their recommendations of the game apps more frequently than participants who showed less activity in right TPJ during feedback that the group’s recommendation differed from their own. A full list of results is shown in table 4.

Discussion

The recent rapid growth of online and mobile technology (Bold & Davidson, 2012; Hampton, 2012) has increased reliance on aggregated recommendation systems for choosing everything from mobile game apps to household products to restaurants and vacation destinations. Consumers use opinions of unknown peers in making relatively important decisions, and such recommendations can facilitate decision making by making the processes easier and more helpful (Dabholkar, 2006; Mudambi & Schuff, 2010). Furthermore, in aggregate, viral trends can be a result of cascading recommendations reinforcing one another (Phelps, Lewis, Mobilio, Perry, & Raman, 2004). This suggests that information shared with

---

2 In addition, it should be noted that the ROI results have been presented without Bonferroni correction and therefore should be interpreted with caution; future studies that replicate these findings will strengthen confidence in the effects observed.

3 Note: Anatomically defined versions of the meta-analytic ROIs (AI, dACC, DMPFC, PC/PCC, and VS) were also examined. All ROIs yielded null results ($p > .05$).
other potential consumers may be influenced by the current average group recommendation, however, prior research has not examined underlying mechanisms that lead consumers to update their feedback in the face of peer recommendations, or what leads some individuals to do so more readily.

We report evidence from two groups of participants (behavioral pilot and fMRI) that online recommendations can be significantly influenced by information about what others recommend, but that people are not uniformly susceptible to such influence. Participants changed their recommendations most often when receiving feedback that others had made different recommendations than their own and least often when group opinions reinforced their initial recommendation or when no social feedback was given. The tendency to incorporate this social feedback into the final ratings, however, varied across participants with some participants readily updating their initial recommendations and others sticking consistently to their initial views.

With behavioral data alone it is difficult to address the extent to which people might conform in their public recommendations to avoid social consequences of deviating from group opinions, conform because they come to see value in the recommendations of the group, or both, and whether additional processes beyond what have been found to correlate with conformity in prior studies of influence might be at play for influence on recommendation decisions; people are notoriously limited in their ability to accurately report on the internal psychological states that precede such decisions (Dijksterhuis, 2004; Nisbett & Wilson, 1977), and may have self-presentation concerns related to their decision making process. Thus, to complement our behavioral results, we examined neural activity using fMRI as participants engaged with an online recommendation system in the presence and absence of information about peer
recommendations. We focused on the neural mechanisms associated with decisions to update one’s recommendation to be consistent with group recommendations within subjects, as well as individual differences in susceptibility to social influence on recommendation behavior, observed as tendency to update recommendations (proportion of trials on which each participant changed their initial recommendation when the group’s recommendation differed from their own).

Recommendation change within subjects

Although relatively widespread activity was associated with feedback that group recommendations differed from the participant’s, only neural activity within the VS and OFC were significantly greater when participants changed their recommendation rather than maintaining their initial recommendation. While these results should be interpreted with caution due to the relatively small cluster sizes, these findings are consistent with past research on social influence. In prior studies, the VS and OFC have been implicated in changing individual preferences in response to different forms of social influence in a range of individual decision making contexts (Campbell-Meiklejohn et al., 2010; Chein et al., 2011; Mason et al., 2009), and in positive valuation more broadly (Bartra et al., 2013). This may suggest that beyond mere self-presentation concerns, adolescent recommenders may update their recommendations, on average, when they experience actual positive value in the recommendations of others, as opposed to merely conforming publicly, while privately derogating the opinions of others. In this sense, social influence on recommendation behavior may parallel social influence on other types of decision-making.

Prior research on adolescent samples has also demonstrated that the mere presence of peers sensitizes these neural regions, which in turn influence decision making (Chein et al.,
the recommendation context may effectively surround adolescent recommenders with imagined others (e.g., potential recipients of their recommendations, other recommenders) and heighten receptivity to relevant social information and potential for social rewards resulting from making socially-consistent recommendations. It is possible that the effects observed are particularly pronounced during adolescence, a developmental period characterized by heightened sensitivity to social cues. Future developmental comparisons are warranted to establish whether similar processes also support updating recommendation decisions into and across adulthood.

Diverging partially from past studies of conformity in adolescents and young adults, however, we did not find that neural activity in brain regions associated with conflict monitoring, social pain or broader social cognition were associated with increased recommendation change within subjects. As reviewed by Izuma and colleagues (2013) and Falk and colleagues (2012), several studies have implicated regions of posterior medial prefrontal cortex (including dACC and DMPFC) in conformity, in addition to affective processing regions (e.g., the anterior insula). For example, Berns and colleagues (2010) examined the relationship between music preferences and popularity ratings. They found that increased activity within the anterior insula and ACC were correlated with an increased likelihood to change one’s evaluation in the face of social feedback in comparison to evaluations made in the absence of social feedback. Given that these neural regions had previously been associated with affective salience and conflict monitoring (C. S. Carter et al., 1998; Critchley et al., 2005; Eisenberger et al., 2003; Eisenberger, 2012; Kerns et al., 2004), Berns and colleagues interpreted these findings as suggesting that conflict detection and negative affect associated with diverging from peer opinions may prompt conformity. Likewise, Klucharev and colleagues (2009) reported that dACC was associated with both feedback that group opinions differed from those of the participant and with actual conformity.
We observed increased activity in dACC when participants were exposed to peer recommendations that were different from their own in comparison to exposure to no peer feedback, however, in the current study this activity was not associated with actual recommendation behavior change. One possibility is that our participants were less rejection sensitive than the participants observed by Berns and colleagues (who reported that their participants were particularly risk averse, potentially carrying over to social domains), however Klucharev and colleagues did not specifically highlight such an explanation. Although our data cannot speak directly to this point, it is also possible that recommendation decisions may differ from personal preference endorsement in the perceived affective consequences of the decision--recommendations may not reflect a participant’s personal opinion but rather what he or she believes others will value.

More directly consistent with Klucharev and colleagues (2009), we also observed a significant increase in precuneus activity during group recommendations that were different than the participant’s when compared to feedback that the group made the same recommendation and when receiving no group feedback. Consistent with the explanation offered by Klucharev and colleagues (2009), in the context of recommendation decisions, the precuneus may also aid in conflict monitoring or tracking divergent group recommendations. The precuneus has also been implicated in mentalizing processes (Fletcher et al., 1995; Spunt, Falk, & Lieberman, 2010). For example, a study examining why versus how people perform actions found that why actions were associated with increased activity in the precuneus and right TPJ (Spunt et al., 2010). Also consistent with this explanation, we observed activity in the ventral putamen during exposure to conflicting group recommendations versus not receiving feedback. Similarly, increased ventral putamen activity has been associated with maintaining prediction error in the actor/critic model.
of reinforcement learning, suggesting that the ventral putamen contributes to the prediction of future outcomes (O’Doherty et al., 2004). Finally, going beyond what has previously been highlighted in studies of social influence on individual preferences we also observed activity within the TPJ, a key component of the mentalizing system, during divergent compared to reinforcing group recommendations.

Taken together, our results suggest that the process of updating recommendations in response to peer recommendations shares some qualitative commonalities, but evidences some potential differences, with social influence on individual preferences. In particular, consistent with past work on social influence for personal preferences, the precuneus is associated with receiving divergent social information, whereas neural activity within the valuation system is associated with actual change. Furthermore, although activity in subregions of posterior medial frontal cortex were observed both in our study with conflicting recommendations and in past studies of individual preference shifts, we did not observe further relationships between activity in these regions and recommendation behavior change. Future research that directly compares recommendation and personal preference ratings may be able to speak more directly to the robustness and potential causes of such divergence.

**Individual differences in susceptibility to recommendation change**

In addition to examining the processes that were associated with recommendation change on average across participants, we also examined individual differences in tendency to change recommendations in response to peer recommendations. Our results demonstrated that increased activation in the right TPJ was significantly associated with an increased susceptibility to social influence on recommendation behavior. These results dovetail with prior studies demonstrating that increased activation of the TPJ is associated with successful message propagation/
more effective communicator or “idea salesperson” (Dietvorst et al., 2009; Falk et al., 2013). More specifically, previous work examining the spread of ideas has found that activation of the TPJ was able to differentiate between communicators who were able to successfully propagate their preferred ideas to others versus those who were not (Falk et al., 2013). As noted by Falk and colleagues (2013), the TPJ may be key to simulating the mental states of others both in current interactions, as well as in preparing to have successful social interactions in the future. Our findings extend these results to suggest that TPJ is involved not only in the simulation of the mental states of others, but also in more actively using social information provided to arrive at a final recommendation decision. Consistent with the idea that TPJ may facilitate both preparation and execution of successful social interactions, activity in the TPJ also associated with higher ability of actual sales people to get inside the minds of their customers—a salesperson theory of mind index (Dietvorst et al., 2009). This salesperson theory-of-mind index was also associated with indicators of better sales performance. In conjunction with these prior studies, our data may suggest that adolescents who have an increased tendency to consider the mental states of others are also more likely to incorporate that information into their own recommendation. Future research is needed to explore whether this might also increase the chance of successfully transmitting ideas that are preferred by more peers.

More generally, these results also expand our understanding of the role of TPJ in theory of mind to include an increasingly common task in day-to-day life—publicly committing our recommendations for the benefit of others. The right TPJ is shown to be particularly active when considering the mental states of others (Saxe & Kanwisher, 2003; Saxe & Wexler, 2005). Furthermore, a meta-analysis examining theory of mind, empathy, attention orientation, and sense of agency demonstrates that the right TPJ is active across all four conditions (Decety &
Thus, the authors suggest that the right TPJ is involved in generating, testing, and modifying our internal predictions based on external stimuli (Decety & Lamm, 2007). Finally, work examining how participants make socially guided decisions found that the right TPJ helped individual’s track socially relevant stimuli in the environment which were then used to help guide future decisions and behavior (R. M. Carter, Bowling, Reeck, & Huettel, 2012). Results from the current study demonstrate that those who show increased activity in TPJ when making a recommendation are more influenced by social feedback. Thus, although our current data cannot speak directly to this conclusion, in combination with prior studies (Dietvorst et al., 2009; Falk et al., 2013) this may suggest that people who are more influential communicators in society might also more readily incorporate social norms and cues in their final recommendations and that those who effectively influence others may be more open to social information regarding an issue, idea, product, or brand.

**Implications for marketing**

The influence of word-of-mouth is becoming increasingly apparent as we move towards online commerce and recommendation systems, where consumer recommendations are quantified and attached to everything from where to eat to what car to buy. Researchers have posited that the presence of consumer recommendations improves a consumer’s perception of the usefulness and social presence of a website (Kumar & Benbasat, 2006)—our results suggest one set of possible mechanisms that could underpin such effects and demonstrate effects that go beyond what has been observed in prior studies of social influence on individual preferences. The present findings lay the groundwork for future research that integrates neural mechanisms into the exploration of whether increased susceptibility to social influence when making recommendations leads to more effective propagation, and whether individuals who exhibit such
susceptibility derive mental health, social benefits or connection from doing so. Furthermore, future studies examining social influence, word-of-mouth, and the spread of ideas may use the neural regions identified to prospectively predict when and how individuals are most likely to update their recommendations, and how these processes interact with social network position. A successful campaign launch depends on having a good product or idea coupled with the right community of people to spread and reinforce information in the most direct way (Aral & Walker, 2011, 2012; Hinz et al., 2011; Van der Lans et al., 2010; Watts & Dodds, 2007).

**Study limitations**

As with any study, several limitations should be considered when interpreting the reported findings. One such limitation is that this study is a first attempt at creating an fMRI task that examines the influence of social feedback on participant’s recommendations; for simplicity feedback conditions were limited to lower, higher, same, and not rated. However, additional comparison conditions could be useful in further specifying the psychological mechanisms responsible for effects observed. For example it would be interesting to examine non-social feedback that differs from that of the participant (e.g., feedback that is believed to be computer generated, mimicking recommendations one may get from websites while online shopping). This would allow for the comparison of social versus non-social feedback that differs from that of the participant in order to better understand what is unique about processing social feedback. Future studies might also benefit from directly comparing influence on recommendation and personal preference decisions. The current study makes qualitative comparisons with other published studies that have examined social influence on user opinions, however, direct examination of these differences within the same study would allow quantitative comparison of neural differences in processing social feedback associated with one’s opinion versus one’s
recommendation. Finally, given the set regions previously implicated in social influence, we explored several potential ROIs as correlates of individual differences in susceptibility to influence on recommendations. Future research that replicates the results uncovered with even more targeted hypotheses will add confidence to the results.

A second category of limitations stems from the fact that participants were told that the group feedback provided within the task is an average recommendation calculated from peers that have previously taken part in the study, however no specific information is given about these ‘peers’. Future studies might manipulate who is providing the social feedback in order to understand how similar versus dissimilar social others may change the way in which social information is processed. Recent research has begun to examine neural responses associated with conforming to ingroup and outgroup opinions (Stallen et al., 2013). In this work, in-group conformity > non-conformity was associated with increased activity in the subACC, pSTS/insula, caudate, and hippocampus, suggesting potential roles for both positive valuation of ingroup opinions and mentalizing in conforming to ingroup opinions.

A third limitation is that participants were asked to make recommendations about each app, however in a real world context not all of these participants may engage in this type of behavior. Therefore, it would be useful to know which participants are more likely to carry out these behaviors in the real world, which could be tracked using observational downstream behavioral measures. Similarly, our peer recommendations were pseudo randomly computer generated, and similar studies might benefit from naturalistic observation of how such processes evolve with real peers to confirm similar processes occur c.f., (Salganik, Dodds, & Watts, 2006).

Finally, the current study examined social influence in the context of male adolescents given that this study was part of a larger investigation of risky adolescent driving behavior. This
limits generalizations that can be made to other populations of interest. It would be valuable to expand these results to include females, young adults, and adult populations in order to compare whether neural patterns of activation are similar across development and other demographic groups. In particular, adolescent cognitive control systems that facilitate self-regulation mature differently than affective processing systems (Blakemore, 2008, 2012; Casey, Getz, & Galvan, 2008; Steinberg, 2008), and function differently according to social context (Pfeifer & Allen, 2012). Social cues are especially salient during adolescence and it is possible that sensitivity to social cues may differ in adolescents compared to adult populations. In parallel, brain systems that support recommendation decisions would also vary across development. Each of the limitations reviewed here offers opportunities for future research that could easily be integrated into the App Recommendation Task.

Conclusion

The present study examined the intersection of social influence and social sharing (recommendations) in the context of a rapidly growing market sector—mobile game applications. We found that the recommendations of peers had significant impact on the final recommendations of adolescent recommenders. Although neural activity in a constellation of regions previously implicated in susceptibility to social influence was associated with processing feedback that group recommendations differ from one’s own, actually updating recommendations in response to this feedback within subjects was limited to activity in the VS and OFC. These results highlight the possibility that incorporating peer recommendations into one’s own goes beyond mere public compliance and may also reflect updating of internal valuation of the opinions of others. We also observed individual differences in the tendency to incorporate peer recommendations into one’s own; only neural activity within the right TPJ was
related to individual differences in susceptibility to social influence on recommendation behavior. In conjunction with previous studies finding that those who show increased activity in TPJ during initial idea exposure are better at propagating their preferred ideas, this may suggest that recommenders who are most attuned to the social environment might incorporate the recommendations and views of others more in developing their own recommendations. More broadly, results of this study lend insight into the psychological and neurocognitive processes underlying recommendations, and speak to important basic psychological forces that help humans share and spread ideas.

References


Figures

Figure 1. Participants completed the initial recommendation portion of the App Recommendation Task prior to the scanning session. Recommendations were given on a 5 point Likert scale, where 1=wouldn’t recommend and 5=would recommend. Recommendations were based on exposure to game titles, logos, and brief descriptions of the games.

Round 1: Pre-scan baseline ratings

Figure 2. Participants completed the group feedback portion of the App Recommendation Task during the fMRI session. Recommendations were given on a 5 point Likert scale, where 1=wouldn’t recommend and 5=would recommend. Ratings were based on exposure to peer group feedback (higher, lower, same, or not rated) in conjunction with a reminder of the participants’ initial recommendation.
Round 2: fMRI group ratings

Figure 3. Regions of Interest

Regions of Interest

Previously Associated with Social Influence

PC/PCC  dACC  Ventral Striatum  DMPFC

Anterior Insula

Previously Associated with Successful Recommendations

left TPJ  right TPJ  MPFC
Figure 4. The change in initial recommendations was calculated by examining the percent of time participants changed their initial pre-scan recommendation in response to peer group feedback. Participants gave their final recommendations during the Final block of the fMRI group App Recommendation Task. All conditions are significantly different from one another, \( p < .001 \). Error bars represent standard error of the mean.

![Change in Initial Recommendations](image)

Figure 5. Whole brain analysis examining the contrast gDIFFERENT > gNOTRATED during the group block of the App Recommendation Task (uncorrected \( p = .001, K \geq 5 \)).

![Group Feedback: Different vs. Not Rated](image)
Figure 6. Whole brain analysis examining the contrast gDIFFERENT > gSAME during the group block of the App Recommendation Task (uncorrected $p = .001$, $K \geq 5$).

**Group Feedback: Different vs. Same**

Figure 7. Whole brain analysis examining the contrast gDIFFERENT_bCHANGE > gDIFFERENT_bNOCHANGE during the group block of the App Recommendation Task (uncorrected $p = .001$, $K \geq 5$).

**Different Group Feedback: Recommendation Change vs. No Change**
Figure 8. Scatterplot of the anatomical right TPJ correlated with the percent of time participant changes recommendation when receiving feedback that the group made different recommendations than the participant $r = .27, p = .028$. 
Tables

Table 1. Whole brain analysis during the group block of the App Recommendation Task examining the difference between exposure to group feedback that differed from the participants initial recommendation versus not receiving group feedback (gDIFFERENT > gNOTRATED), (uncorrected $p = .001$, $K \geq 5$).

<table>
<thead>
<tr>
<th>Region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>K</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Putamen (left)</td>
<td>-23</td>
<td>-2</td>
<td>-5</td>
<td>40</td>
<td>3.81</td>
</tr>
<tr>
<td>Parahippocampal Gyrus (right)</td>
<td>11</td>
<td>1</td>
<td>-32</td>
<td>6</td>
<td>3.58</td>
</tr>
<tr>
<td>Frontal Pole (right)</td>
<td>25</td>
<td>70</td>
<td>-5</td>
<td>6</td>
<td>3.37</td>
</tr>
<tr>
<td>Dorsolateral Prefrontal Cortex (left)</td>
<td>-26</td>
<td>60</td>
<td>31</td>
<td>107</td>
<td>4.19</td>
</tr>
<tr>
<td>Dorsal Anterior Cingulate (left)</td>
<td>-23</td>
<td>15</td>
<td>31</td>
<td>69</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>-13</td>
<td>21</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-20</td>
<td>-5</td>
<td>34</td>
<td>5</td>
<td>3.48</td>
</tr>
<tr>
<td>Dorsal Anterior Cingulate (right)</td>
<td>15</td>
<td>12</td>
<td>40</td>
<td>42</td>
<td>4.41</td>
</tr>
<tr>
<td>Precuneus (right)</td>
<td>4</td>
<td>-43</td>
<td>40</td>
<td>32</td>
<td>3.95</td>
</tr>
<tr>
<td>Supramarginal Gyrus (right)</td>
<td>32</td>
<td>-53</td>
<td>25</td>
<td>9</td>
<td>3.64</td>
</tr>
<tr>
<td>Middle Temporal Gyrus (right)</td>
<td>49</td>
<td>-57</td>
<td>13</td>
<td>36</td>
<td>4.26</td>
</tr>
<tr>
<td>Middle Temporal Gyrus (left)</td>
<td>-51</td>
<td>-47</td>
<td>7</td>
<td>40</td>
<td>4.43</td>
</tr>
<tr>
<td>Inferior Temporal Gyrus (left)</td>
<td>-64</td>
<td>-57</td>
<td>-11</td>
<td>6</td>
<td>3.9</td>
</tr>
<tr>
<td>Inferior Temporal Gyrus (right)</td>
<td>49</td>
<td>-60</td>
<td>-20</td>
<td>12</td>
<td>3.52</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>-9</td>
<td>-38</td>
<td>34</td>
<td>4.51</td>
</tr>
<tr>
<td>Caudate Tail (right)</td>
<td>25</td>
<td>-40</td>
<td>10</td>
<td>14</td>
<td>3.83</td>
</tr>
<tr>
<td>Occipital Lobe (right)</td>
<td>49</td>
<td>-74</td>
<td>28</td>
<td>28</td>
<td>4.19</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>-88</td>
<td>-14</td>
<td>29</td>
<td>3.71</td>
</tr>
<tr>
<td>Occipital Lobe (left)</td>
<td>-30</td>
<td>-91</td>
<td>34</td>
<td>8</td>
<td>3.7</td>
</tr>
<tr>
<td>Cerebelum (left)</td>
<td>-37</td>
<td>-57</td>
<td>-44</td>
<td>156</td>
<td>4.37</td>
</tr>
</tbody>
</table>
Table 2. Whole brain analysis during the group block of the App Recommendation Task examining the difference between exposure to group feedback that differed from the participants initial recommendation versus receiving feedback that the group made the same recommendation (gDIFFERENT > gSAME), (uncorrected $p = .001$, $K \geq 5$).

<table>
<thead>
<tr>
<th>Region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>K</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globus Pallidus (left)</td>
<td>-26</td>
<td>-16</td>
<td>-5</td>
<td>8</td>
<td>3.57</td>
</tr>
<tr>
<td>Precuneus (right)</td>
<td>21</td>
<td>-49</td>
<td>18</td>
<td>33</td>
<td>4.03</td>
</tr>
<tr>
<td>Angular Gyrus (left)</td>
<td>-47</td>
<td>-77</td>
<td>40</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>TPJ/Supramarginal Gyrus (left)</td>
<td>-54</td>
<td>-40</td>
<td>28</td>
<td>12</td>
<td>3.53</td>
</tr>
<tr>
<td>Inferior Temporal Gyrus (right)</td>
<td>56</td>
<td>-19</td>
<td>-32</td>
<td>25</td>
<td>4.32</td>
</tr>
<tr>
<td>Inferior Temporal Gyrus (left)</td>
<td>-61</td>
<td>-5</td>
<td>-38</td>
<td>11</td>
<td>3.62</td>
</tr>
<tr>
<td>Cerebelum</td>
<td>-2</td>
<td>-78</td>
<td>-20</td>
<td>48</td>
<td>3.63</td>
</tr>
<tr>
<td>Cerebelum (left)</td>
<td>-57</td>
<td>-64</td>
<td>-29</td>
<td>11</td>
<td>3.93</td>
</tr>
<tr>
<td>Cerebelum (right)</td>
<td>-40</td>
<td>-81</td>
<td>-32</td>
<td>22</td>
<td>3.96</td>
</tr>
<tr>
<td>VS/OFC (left)</td>
<td>-19</td>
<td>-91</td>
<td>-32</td>
<td>17</td>
<td>4.02</td>
</tr>
<tr>
<td>VS/OFC (right)</td>
<td>-33</td>
<td>-57</td>
<td>-44</td>
<td>10</td>
<td>3.97</td>
</tr>
<tr>
<td>VS/OFC (left)</td>
<td>39</td>
<td>-29</td>
<td>-32</td>
<td>15</td>
<td>4.99</td>
</tr>
<tr>
<td>OFC/Temporal Pole (right)</td>
<td>32</td>
<td>-84</td>
<td>-38</td>
<td>56</td>
<td>4.04</td>
</tr>
<tr>
<td>VS/OFC (right)</td>
<td>28</td>
<td>-70</td>
<td>-47</td>
<td>13</td>
<td>3.84</td>
</tr>
</tbody>
</table>

Table 3. Whole brain analysis during the group block of the App Recommendation Task examining the difference between changing one’s recommendation while being exposed to group feedback that differed from the participants initial recommendation versus maintaining one’s initial recommendation (gDIFFERENT_bCHANGE > gDIFFERENT_bNOCHANGE), (uncorrected $p = .001$, $K \geq 5$).

<table>
<thead>
<tr>
<th>Region</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>K</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS/OFC (left)</td>
<td>-16</td>
<td>8</td>
<td>-23</td>
<td>10</td>
<td>3.68</td>
</tr>
<tr>
<td>OFC/Temporal Pole (right)</td>
<td>39</td>
<td>22</td>
<td>-23</td>
<td>12</td>
<td>3.92</td>
</tr>
<tr>
<td>VS/OFC (right)</td>
<td>15</td>
<td>8</td>
<td>-23</td>
<td>8</td>
<td>3.77</td>
</tr>
</tbody>
</table>
Table 4. Summarization of the zero order correlations between neural activity in regions of interest (ROI) derived from literature on successful recommendations and based on a meta-analysis of social influence and participants’ overall likelihood of updating their recommendation in the face of peer group feedback that was different from their own.

### Anatomically Defined ROIs

<table>
<thead>
<tr>
<th>Region</th>
<th>t</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporoparietal Junction</td>
<td>2.25</td>
<td>0.27</td>
<td>0.028*</td>
</tr>
<tr>
<td>Left Temporoparietal Junction</td>
<td>0.75</td>
<td>0.09</td>
<td>0.458</td>
</tr>
<tr>
<td>Medial Prefrontal Cortex</td>
<td>-1.43</td>
<td>-0.18</td>
<td>0.158</td>
</tr>
</tbody>
</table>

### Meta-Analytically Defined ROIs

<table>
<thead>
<tr>
<th>Region</th>
<th>t</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Insula</td>
<td>0.36</td>
<td>0.05</td>
<td>0.721</td>
</tr>
<tr>
<td>Dorsal Anterior Cingulate Cortex</td>
<td>0.22</td>
<td>0.03</td>
<td>0.827</td>
</tr>
<tr>
<td>Dorsomedial Prefrontal Cortex</td>
<td>0.93</td>
<td>0.12</td>
<td>0.354</td>
</tr>
<tr>
<td>Precuneus/Posterior Cingulate Cortex</td>
<td>-0.03</td>
<td>-0.00</td>
<td>0.975</td>
</tr>
<tr>
<td>Ventral Striatum</td>
<td>-0.41</td>
<td>-0.05</td>
<td>0.683</td>
</tr>
</tbody>
</table>

*Results reported with outlier removed, df = 62.*