Social Cognitive and Affective Neuroscience, 2018, 699–707

doi: 10.1093/scan/nsy051
Advance Access Publication Date: 7 April 2018
Original article

What the brain 'Likes': neural correlates of providing feedback on social media

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Abstract

Evidence increasingly suggests that neural structures that respond to primary and secondary rewards are also implicated in the processing of social rewards. The 'Like'—a popular feature on social media—shares features with both monetary and social rewards as a means of feedback that shapes reinforcement learning. Despite the ubiquity of the Like, little is known about the neural correlates of providing this feedback to others. In this study, we mapped the neural correlates of providing Likes to others on social media. Fifty-eight adolescents and young adults completed a task in the MRI scanner designed to mimic the social photo-sharing app Instagram. We examined neural responses when participants provided positive feedback to others. The experience of providing Likes to others on social media related to activation in brain circuitry implicated in reward, including the striatum and ventral tegmental area, regions also implicated in the experience of receiving Likes from others. Providing Likes was also associated with activation in brain regions involved in salience processing and executive function. We discuss the implications of these findings for our understanding of the neural processing of social rewards, as well as the neural processes underlying social media use.

Key words: social reward; social feedback; social media; ventral striatum

Introduction

A limitation of fMRI research on social cognition is that the environment in which data is collected is decidedly nonsocial: in the bore of an MRI scanner, the participant is always alone. In 2018, however, physical isolation is no longer necessarily social isolation, thanks to the rise and vast popularity of the Internet. Indeed, many social cognitive tasks in the MRI scanner resemble social media: these tasks exist on a screen, and they involve interactions that have been simplified, and perhaps even rendered binary. A particularly salient example of a simplified digital interaction is the 'Like'. Although face-to-face communication involves a qualitative exchange of information through facial expressions, gestures, and vocal prosody, social media allow for quantitative means of providing feedback. Although very recent research suggests that receiving positive feedback on social media is associated with activity in the brain's reward network (Sherman *et al.*, 2016), little is known about the neural correlates of providing such feedback to others.

Although many fMRI paradigms resemble social media environments, few studies in the area of social cognitive neuroscience have explicitly examined experiences on social media. Drawing on the social cognitive neuroscience literature more generally, Meshi *et al.* (2015) posited that the neural networks implicated in self-referential thought, mentalizing and reward

Received: 29 September 2017; **Revised:** 18 April 2018; **Accepted:** 28 June 2018

may be especially relevant. The brain's reward circuitry, which includes the dorsal and ventral striatum [including the nucleus accumbens (NAcc)], ventromedial prefrontal cortex (vmPFC), and ventral tegmental area (VTA), has been implicated in several aspects of processing socially relevant information in online environments. Receiving many Likes on one's own Instagram photo leads to activation of this network, including the NAcc and vmPFC (Sherman *et al.*, 2016), and the experience of sharing information with others elicits response in the NAcc and VTA (Tamir and Mitchell, 2012). Although we refer to this system as a 'reward circuit', it is important to know that this circuitry is involved not only in the subjective experience of pleasure but also in recognizing, evaluating, predicting and responding to rewards (Bhanji and Delgado, 2014).

Much of the early literature on reward processing investigated brain responses to monetary reward as feedback on task performance (e.g. Delgado *et al.*, 2000; Knutson *et al.*, 2001; Galvan *et al.*, 2005). Though money is not a primary reward, it is nonetheless highly salient and has the advantage of containing discrete, objective value. Izuma *et al.* (2008) first demonstrated that a social reward—acquiring gains in social reputation—activated brain regions overlapping with those found during the receipt of monetary rewards. This finding has been replicated many times since (e.g. Davey *et al.*, 2010; Jones *et al.*, 2012; Korn *et al.*, 2012). Izuma *et al.* (2008) thus posited that the brain contains a 'common neural currency' for the processing of all types of rewards.

Izuma and colleagues paper was published in 2008, just months after the original 'Like' feature was announced on FriendFeed, a small online social network later purchased by Facebook (Taylor, 2007). The Like soon became ubiquitous; it is now a feature not only on Facebook, but Instagram, Twitter, YouTube, Tumblr, Pinterest and LinkedIn. The Like is a new kind of reward: as with money, it is a secondary reinforcer, and it is represented by discrete values. Unlike money, however, the Like is explicitly social in nature. Researchers and anthropologists have hypothesized that the evolutionary history of the primate brain, and especially the human brain, is directly tied to the increasing importance of social interaction and group membership (e.g. Adolphs, 2009; Dunbar, 2009). Features of the human brain, in other words, may have developed in response to evolutionary pressures that favored increasingly complex social relationships. Thus, while the Like shares features with money that make it easy to manipulate and measure in an experimental setting, it also represents an aspect of a basic human need: the need to connect and foster social relationships. When compared with money, the Like is a very new concept, but it represents an ancient human need.

How, then, are 'Likes' represented in the human brain? Researchers have examined neural responses to viewing or receiving Likes, and established that these Likes affect neural responses to information posted online. Receiving Likes on one's picture or social media content, is associated with greater activation of reward circuitry, and these Likes influence attentional focus (Gunther Moor *et al.*, 2010; Silk *et al.*, 2011; Achterberg *et al.*, 2016; Sherman *et al.*, 2016). Even Likes on strangers' photos influence neural and behavioral responses: we previously reported that when young people viewed Instagram photos with many Likes, compared with few, they showed greater responses in brain regions associated with reward and visual attention, and were themselves more likely to click Like (Sherman *et al.*, 2016). Less is known about the neural underpinnings of 'providing' Likes to others, despite the frequency of this behavior in social media environments. A recent meta-analysis of brain responses during vicarious rewards and charitable giving (Morelli *et al.*, 2015) found that the vmPFC, was activated across 25 studies whereas the striatum was not. On the other hand, some social media users report that Likes function as a form of social support (Hayes *et al.*, 2016), and work by Inagaki and Eisenberger (2012) and Inagaki *et al.* (2016) suggests that provision of social support to others elicits responses in the ventral striatum. Furthermore, while Likes are often provided as an indicator of social support, affiliation or acknowledgement of shared experience, they are frequently used to indicate approval or enjoyment (Hayes *et al.*, 2016). Thus, reward circuitry may be implicated in the provision of Likes because the user is simultaneously viewing an image or piece of information that brings them pleasure.

Here we investigated the neural correlates of providing Likes to others in a sample of young social media users as they engaged with a tool designed to mimic the popular social photo-sharing app Instagram. While undergoing fMRI, participants viewed a series of images ostensibly provided by peers and decided whether or not to Like each image. Based on the literature reviewed above, we expected that the vmPFC would be more active when participants Liked images, compared to when they did not. Given that vicarious rewards were not reliably associated with striatal activation (Morelli *et al.*, 2015), but that striatal activation was associated with other relevant social activities, such as sharing information with others (Tamir and Mitchell, 2012), we hypothesized that the striatum would potentially be involved in the experience of providing Likes. Furthermore, we were eager to investigate which other areas of the cortex responded during Liking, and how these compared with the experience of receiving Likes from others.

Materials and methods

Participants

A total of 61 participants took part in the study; of these, three were excluded from fMRI data analysis because of scanner console malfunction, failure to complete the entire protocol, or low-quality structural image. The final sample consisted of 34 female and 24 male participants, ranging in age from 13 to 21 (M_{age} = 18.2). Participants were recruited through message board postings and flyers posted in the Los Angeles community and on a college campus. Mean relative motion for any individual the final sample did not exceed 0.2 mm (mean relative motion for the entire sample: 0.06 mm). Participants had no reported neurological, psychiatric, or developmental diagnosis or MRI contraindications. Participants gave written consent (or, for individuals under 18, written assent and parental consent), and were fully debriefed and compensated monetarily according to study procedures approved by the Institutional Review Board of the University of California, Los Angeles. These participants have been previously reported upon (Sherman *et al.*, 2016, 2017).

Experimental procedures

A complete experimental protocol is available on the Open Science Framework (https://osf.io/tscmf/). A few weeks before visiting the lab, participants were asked to submit several of their own photographs from Instagram to be included in an 'internal social network'. During the laboratory visit, participants were instructed that they would interact with a tool that resembles Instagram in the MR scanner: specifically, they would see the photographs submitted by all of the participants in the study and decide whether to Like each image. Participants were instructed to view each photograph and to either select 'Like' to Like the photograph, or 'Next' to move on without Liking the photograph. Participants were asked to use the same criteria they would typically use on social media when deciding whether to Like content posted by others, and were told that the Likes they provided would be added to the total tally for that photograph. Finally, participants were told that they would see several of their own Instagram photos, accompanied by the Likes provided by individuals who had already completed the experiment. In reality, the images ostensibly submitted by other participants were actually selected by the study team from publicly available images on Instagram, and the existing Likes were randomly assigned to the images, as detailed in Supplementary Materials and Methods.

After completing a practice trial, participants viewed the feed of photographs in the MR scanner and indicated their decision to Like photos using an MR-safe button box. Following the MRI scan, participants answered survey questions about their Instagram use and decision-making during the task, and completed a rating task, described below.

fMRI task

The fMRI paradigm was a fast event-related design, with each event consisting of an individual Instagram photo, presented using E-Prime. Each photo was accompanied by (i) two buttons prompting the participant to select 'Like' or 'Next', (ii) the Instagram menu bar, appearing as it looked in 2014 at the time of data collection and (iii) the total number of 'Likes' ostensibly provided by other participants. Each photograph was presented for 3 s, regardless of how long it took participants to choose 'Like' or 'Next'.

In all, participants saw 148 unique photos. Images consisted of three types: (i) neutral images resembling typical Instagram photos (e.g. depicting food, friends and possessions; Hu *et al.* (2014); 66 total images); (ii) images depicting risk-taking behaviors such as drinking alcohol or marijuana paraphernalia (42 total images); and (iii) images submitted by the participant (40 total images). To gain insight into the neural correlates of providing Likes to others, we focused on images in the first category (neutral images). Variability in Like responses to risky images was too low to provide sufficient power to contrast Liked and non-Liked risky images: e.g. while all participants Liked at least seven neutral photographs, only 50% of participants of participants Liked at least seven risky photographs. Risky trials were therefore excluded from further analysis. Participants were able to Like their own photographs and were typically consistent in their decision to do so: some participants chose to Like all of their own photos and some chose to Like none of them. Thus, variability in responses was low for participants' own photos: only 38% of participants chose both 'Like' and 'Next' more than seven times for their own photos.

MRI data acquisition

Participants were scanned on a Siemens 3-Tesla MRI scanner. A high-resolution structural scan (echo planar T2-weighted spin-echo, TR = 5000 ms, TE = 34 ms, matrix size 128 × 128, FOV = 192 mm, 34 slices, 1.5-mm in-plane resolution, 4-mm thick) coplanar with the functional scans was obtained for functional image registration during fMRI analysis preprocessing. The social media paradigm was presented during a functional scan lasting 11 min and 44 s (echo planar T2*-weighted gradient-echo, TR = 2000 ms, TE = 28 ms, flip angle = 90, matrix size 64 × 64, 34 axial slices, FOV= 192 mm; 4-mm thick, skip 1-mm).

Instagram survey

Participants completed a short survey about their experiences during the Instagram task. Participants were prompted to 'Think about everyone else's Instagram images. How did you decide which pictures to Like today in the study?' and asked to rank the following five items from most to least important: 'The image was visually appealing', 'the image was funny', 'the image was similar to one that I might take', 'the image contained one or more attractive people' and 'the image depicted an activity that I enjoy'. Participants were also able to add one or more write-in responses to include in the ranking. Participants were also asked 'Would you say that you went with your 'gut instinct' to choose images, or that you thought about each image before deciding to Like it?'

Rating task

Finally, participants were asked to provide a rating for each of the photographs they had seen during the MRI scan. Photographs were presented individually in E-Prime, but without the number of Likes, the Instagram menu bar, or the 'Like' and 'Next' buttons. Instead, the numbers 1–7 appeared beneath each photo. Participants were instructed to now rate the photo on a scale from 1 to 7. Participants were told that the ratings would give the researchers more information about their opinions, but were not instructed to rate the photographs on any particular dimensions. The rating task was introduced after data had been collected on several participants; rating data were available for 41 out of 58 participants.

fMRI data analysis

fMRI data were preprocessed and analyzed using AFNI (Cox, 1996) and the FMRIB Software Library (FSL) (Jenkinson *et al.*, 2012); full details are available in Supplementary Materials and Methods. The contrast of interest for this study modeled trials for which participants selected 'Like' *vs* 'Next' (i.e. querying brain regions more active during 'Like' trials compared with 'Next'). Other regressors, including the popularity of images, participants' reaction time and luminosity of individual images, are discussed in the Supplementary Materials and Methods. FSL's FLAME 1 was used to carry out group analysis, with a voxel-wise threshold of $Z > 2.3$ and a cluster-wise threshold of $P < 0.001$.

Our main contrast of interest compared blood-oxygen-level-dependent (BOLD) responses when participants selected 'Like' compared with when they selected 'Next' on others' non-risky images ('Giving Likes'). Given our interest in the potential for shared neural circuitry of giving and receiving Likes, we also examined a second contrast of interest, which compared responses when participants received many Likes on their own images compared to when they received few Likes ('Getting Likes'). This contrast has been previously reported upon in a high school and college sample which are combined here (Sherman *et al.*, 2016, 2017). Group differences for the high school and college subsamples are presented in Supplementary Figure S1.

To examine brain regions activated by both the Like > Next contrast ('Giving Likes') and the Receiving Many Likes > Receiving Few Likes contrast ('Getting Likes'), we performed a conjunction analysis using the tool easythresh_conj (Nichols *et al.*, 2005), with a cluster correction of $P < 0.001$. Rather than simply displaying the overlap of two brain activation maps, this tool uses a cluster approach to account for the issue of multiple comparisons in fMRI analysis. Significant clusters are interpreted as significantly activated in both contrasts of interest, and assumption of independence of effects is not necessary. This approach tends to be conservative, so we present these results, as well as a map of all voxels of overlapping activation (i.e. without cluster correction) for the two contrasts of interest. To create the map of overlapping activation, we multiplied the two thresholded maps from the parametric analyses described earlier.

Given the recent concern about the validity of parametric cluster thresholding (Eklund *et al.*, 2016), we also performed a confirmatory analysis of our main contrasts of interest using FSL's permutation-based testing tool RANDOMISE to obtain nonparametric statistics with 10 000 random permutations and threshold-free cluster enhancement (TFCE). Results of the nonparametric analyses are highly similar to the parametric analyses in terms of locations of activation, though clusters differ somewhat in size (both larger and smaller). Complete unthresholded and thresholded, cluster corrected maps of the parametric and non-parametric group analyses are available on NeuroVault: https://neurovault.org/collections/3038/.

Follow-up analysis

A limitation of the present study is the difficulty in disentangling the meaning of a reward response during Liking; does the reward derive from the social nature of giving a Like, or from the experience of looking at a more appealing image? To aid in interpretation of our initial hypothesized findings, we conducted a series of follow-up analyses using data from the post-scan rating task. These analyses were performed on a subsample of participants that provided rating data ($n = 41$). First, we conducted a correlation analysis to determine if photographs with higher average participant ratings were also Liked by more participants. Next, we examined which brain regions were more active for more highly rated images. To do this, we conducted a new analysis in which we replaced the regressors modeling participants' Like choices with regressors that parametrically modelled participants' post-scan ratings for each photograph. Finally, to examine how much, if at all, Liking and rating independently explained variance in neural responses, we conducted an analysis that modeled both post-scan ratings and Like choices at the single-subject level. Because of the reduced sample size, all findings are presented with a threshold of $Z > 2.3$, uncorrected.

Results

Behavioral findings: which images did participants Like and why?

Images depicting objects (e.g. food, possessions) were significantly more likely to be Liked than images depicting faces [$t(42) = 2.21$, $P = 0.03$). When asked to rank the reasons they Liked an image, 64.1% of participants selected, 'The image was visually appealing', as their top choice, followed by 'The image was similar to one that I might take' (12.8%), 'The image depicted an activity that I enjoy' (10.3%), 'The image was funny' (5.1%), 'The image contained one or more attractive people' (2.6%) or other, write-in responses (5.1%). Complete descriptive statistics of participants' ranking are available in Table 1. When asked whether they thought about liking an image before selecting, or if they went with their gut instinct, 63.4% responded 'Gut instinct' and 36.6% responded, 'thought about it'.

Table 1. Participants' reasons for Liking photographs.

Reason	Percentage of participants ranked as top reason
Visually Appealing	64.10%
Similar to one I would take	12.82%
Depicted an activity I enjoy	10.26%
Funny	5.13%
Other	5.13%
Attractive people	2.56%
Reason	**Percentage of participants ranked as second reason**
Similar to one I would take	33.33%
Depicted an activity I enjoy	20.51%
Visually appealing	17.95%
Funny	17.95%
Attractive people	5.13%
Other	5.13%
Reason	**Percentage of participants ranked as third reason**
Funny	30.77%
Attractive people	23.08%
Similar to one I would take	15.38%
Visually appealing	10.26%
Depicted an activity I enjoy	10.26%
Other	10.26%
Reason	**Percentage of participants ranked as fourth reason**
Depicted an activity I enjoy	38.46%
Funny	28.21%
Similar to one I would take	17.95%
Attractive people	10.26%
Visually appealing	5.13%
Other	0.00%

Neuroimaging findings

Figure 1 (panel A) depicts the results of the whole-brain analysis comparing trials for which participants selected 'Like' and trials for which they selected 'Next.' As hypothesized, when participants Liked an image, they showed activation in the ventral striatum and vmPFC. A complete list of activation clusters is provided in Table 2. In addition to demonstrating activation in our hypothesized regions, the Like > Next contrast was associated with greater activation in the dorsal striatum (caudate and putamen), thalamus, bilateral insula/orbitofrontal cortex, hippocampus, amygdala, a considerable portion of the anterior cingulate and paracingulate cortex, inferior frontal gyrus and the bilateral intraparietal sulcus. Several regions of occipital cortex also exhibited greater activation, in primary visual cortex and extending along both the dorsal and ventral stream. In our parametric analysis, three brain regions demonstrated greater activation for the Next > Like contrast, including the right angular gyrus (MNI coordinates of max voxel: $x = 52$, $y = -56$, $z = 40$, *Max* $Z = 4.28$), right frontal pole ($x = 30$, $y = 56$, $z = 10$, *Max* $Z =$

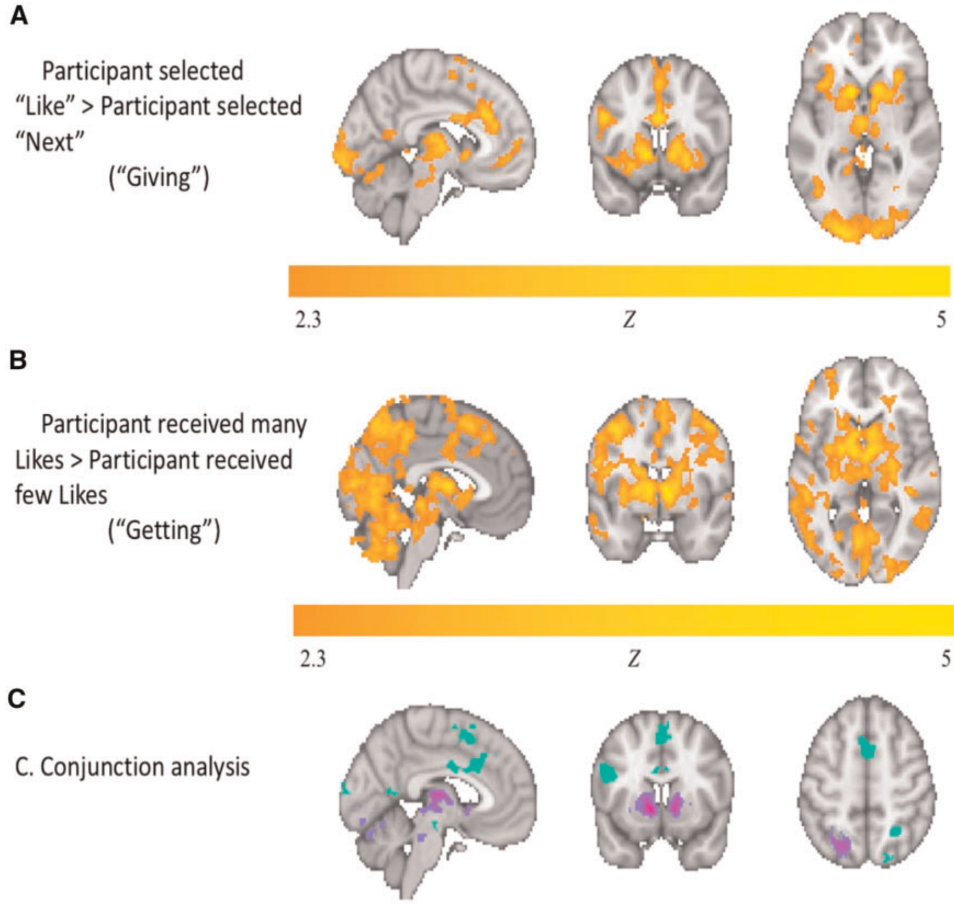

Fig. 1. Panels (A and B) depict, respectively, activation when participants provided a Like to others (compared with choosing 'Next') and when participants received many Likes from others (compared with few Likes); $Z > 2.3$, $P < 0.001$. Panel (C) depicts areas of overlap between these contrasts. Brain regions in purple survived cluster correction at $P < 0.001$ ($Z > 2.3$) in a conjunction analysis of these contrasts; brain regions in light green depict overlap in significant findings but do not survive cluster correction.

Table 2. Peak coordinates of activation for regions obtained from the contrast of Like > Next.

	MNI peak (mm)			Max
	x	y	z	Z
Left inferior frontal gyrus	–50	10	26	4.14
Left frontal pole/ inferior frontal gyrus	–46	42	6	3.15
ACC	0	6	28	4.41
Supplementary motor area/ paracingulate cortex	6	0	70	3.79
vmPFC	–4	48	–4	3.3
Left lateral occipital cortex/ fusiform cortex/ parahippocampal gyrus/ hippocampus	–28	–88	18	4.98
Left caudate/accumbens/putamen/thalamus/pallidum/insula/amygdala/brainstem	–12	10	–2	4.85
Left inferior temporal gyrus	–50	–65	–10	4.6
Right fusiform cortex/ parahippocampal gyrus/ hippocampus	30	–46	–12	4.57
Right lateral occipital cortex/ intraparietal cortex	30	–78	18	4.24
Left superior occipital cortex/ intraparietal cortex	–24	–64	48	4.12
Right caudate/accumbens/putamen/thalamus/pallidum/insula/amygdala/brainstem	24	4	–8	4.1
Occipital pole/cerebellum	4	–92	–6	3.9

Coordinates are in Montreal Neurological Institute space. Note: at threshold of $Z > 2.3$, cluster corrected $P < 0.001$, findings consist of three clusters. Reported peaks in this table are based on the top eight local maxima with a minimum distance of 35 mm. Local maxima are based on parametric analysis, but all brain regions and peaks described in this table are also activated in a nonparametric analysis with TFCE ($P < 0.01$).

3.60), and right middle frontal gyrus ($x = 42$, $y = 22$, $z = 42$, *Max Z* $= 3.73$). However, these did not survive at $p < .05$ using the nonparametric approach, and therefore are not considered in greater detail in the Discussion.

Figure 1 (panel B) depicts areas of greater activation when participants 'received' many compared to few Likes on their own photographs (these results have been reported previously in two separate subsamples; they are combined here for purposes of comparison with our main contrast of interest). Neural regions implicated in the experience of receiving many Likes included the dorsal and ventral striatum (caudate, putamen, NAcc), thalamus, brain stem/VTA, medial and bilateral prefrontal cortex, primary and supplementary motor cortex, occipital cortex and the cerebellum.

The experience of providing a Like to another person and receiving many Likes from others was related to activation in several of the same brain regions. These are depicted in Figure 1 (panel C). Our conjunction analysis yielded two large clusters of overlap. The first cluster was left lateralized and included the lateral occipital cortex leading into the fusiform cortex, temporoccipital cortex and parahippocampal gyrus ($x = -22$, $y = -66$, $z = 46$, $Max\ Z = 3.76$). The second cluster included bilateral ventral and dorsal striatum, thalamus, hippocampus, and VTA/brain stem ($x = -10$, $y = 8$, $z = -2$, $Max\ Z = 4.32$). Several additional regions also exhibited overlap that did not survive cluster thresholding (depicted in light green in Figure 1, panel B), including right occipital cortex (lateral occipital, fusiform and temporoccipital), regions of primary and supplemental motor cortex, anterior cingulate and posterior cingulate/precuneus. While we observed significant overlap in brain regions implicated in the giving and receiving of Likes, some areas were significantly more activated when participants received Likes, compared to when they gave a Like. These findings are depicted in Supplementary Figure S2.

Follow-up analyses

What might explain the response in reward-related regions when participants Liked photos? Photographs that were more highly rated for their overall quality were Liked by a higher proportion of participants ($r = 0.88$, $P < 0.001$), suggesting that neural responses to Liked photos may have been due at least in part to the aesthetic quality of the image. Certainly, the majority of participants reported Liking images because they were visually appealing (Table 1). If neural responses to Liked images were due at least in part to the quality of the image itself (instead of, e.g. a reward associated with engaging in prosocial behavior), it would be expected that brain regions that were more active when participants chose 'Like' would also increase in activation as a function of participants' ratings. As shown in Figure 2A, this was indeed the case. Findings of this analysis, which modeled ratings parametrically, were highly similar to the results for the 'Like' > 'Next' contrast. Nonetheless, ratings and Likes independently predicted activation in reward-related regions. When regressors for both ratings and Likes were included in the model, participants' Like responses independently predicted activation in parts of the striatum, as did their rating scores (Figure 2B). Ratings additionally predicted activation in the vmPFC. These findings suggest that participants' subjective ratings of the images contributed to, but did not completely explain, neural responses while providing Likes to others.

Discussion

We hypothesized that the provision of Likes on social media would be related to responses in regions associated with reward processing and prosocial behavior, including the ventral striatum and vmPFC. Our hypothesis was supported, as both regions showed significantly greater response when participants selected 'Like' *vs* 'Next.' Furthermore, Liking others' photographs was also associated with greater activation in the dorsal striatum, including the caudate, putamen, and pallidum. Like the ventral striatum, the dorsal striatum is also implicated in reward; additionally, these structures seem to mediate action-contingent learning and decision-making (for a review, see Balleine *et al.*, 2007). Significant activation was also observed in the midbrain and the amygdala, regions associated with reward processing in a variety of contexts (see Fareri and Delgado, 2014 for a review).

In recent work from our laboratory, we reported that regions of the ventral and dorsal striatum, including the NAcc and caudate, were more active when adolescent participants received many Likes on their own Instagram photos, and replicated this finding in an independent sample of college students. In a different fMRI paradigm, Davey *et al.* (2010), found that when participants viewed photographs of people who had ostensibly Liked them, they showed activation of a similar set of regions to our present findings, including the ventral striatum, midbrain, vmPFC and amygdala. These findings highlight the partially overlapping neural circuitry of receiving and providing positive feedback. Indeed, in our conjunction analysis, a considerable portion of thalamus, dorsal and ventral striatum and midbrain/VTA were both activated for giving Likes and receiving many Likes.

Past work has documented that response in the striatum/vmPFC is associated with receipt of both monetary and social rewards (Bhanji and Delgado, 2014). Here, our finding that giving positive social feedback is associated with response in these regions is parsimonious with a large body of previous work suggesting that the striatum and vmPFC are activated when one makes monetary contributions to others (e.g. Harbaugh *et al.*, 2007; Telzer *et al.*, 2010), and provides social support to loved ones (e.g. Inagaki and Eisenberger, 2012). Many have discussed the evolutionary importance of seeking and receiving feedback from others (e.g. Baumeister and Leary, 1995; van Winden *et al.*, 2008; Fareri and Delgado, 2014), but it would also be adaptive for the act of providing positive feedback to be rewarding, insofar as this feedback can contribute to the forging of new social relationships, strengthening of existing bonds, and ultimately elicit reciprocal prosocial behavior. In adolescence, a period of intensified peer relationships, it may be especially important that youth be motivated to provide this feedback to others in order to strengthen social bonds.

It is also possible, however, that the reward signal associated with liking an image relates not to the act of providing a Like, but rather to experience of viewing an image considered 'likable'. Viewing artistic images versus non-artistic images is related to greater recruitment of the VS (Lacey *et al.*, 2011), and the experience of viewing attractive faces has been related to several brain regions implicated in this study, including the anterior cingulate, amygdala and vmPFC (e.g. Kampe *et al.*, 2001; Winston *et al.*, 2007). Preference for products and brands is also related to activation in this circuitry (e.g. Erk *et al.*, 2002; McClure *et al.*, 2004; Knutson *et al.*, 2007). In an attempt to disentangle the phenomena of providing Likes *vs* viewing more visually appealing images, we conducted follow-up analyses using rating data provided by our participants. The rating task did not include a social component, as participants were instructed that ratings would be used for research purposes, rather than shared with other study participants. Highly rated images were more likely to be Liked during the fMRI task. Rating data also related to activation in the striatum and vmPFC, suggesting that the aesthetic quality of images can, in part, account for the reward response while Liking others' photos. Importantly, however, participants showed greater striatal activation on trials where they gave a Like, even when rating data were taken into

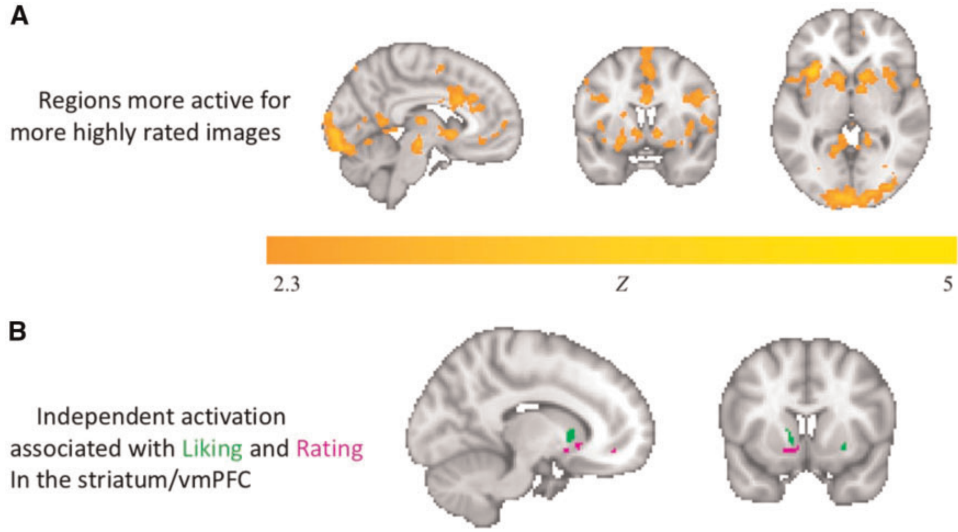

Fig. 2. Panels (A and B) depict the results of a follow-up analysis intended to differentiate between neural responses related to providing a Like and those related only to participants' subjective rating of the images ($n = 41$). Panel (A) depicts brain regions which were more active for more highly rated images, without taking into account participants' Likes. Panel (B) depicts independent contributions of Liking (in green) and rating (in purple) to neural responses while looking at images. Results in panel (B) are masked by the boundaries of the striatum and the vmPFC. Images are presented thresholded at $Z > 2.3$, without correction for multiple comparisons.

account. This suggests that while aesthetic quality may motivate users to Like an image, its visual appeal does not completely explain the reward response.

We hypothesized that neural circuitry implicated in reward would be activated when providing Likes; our whole-brain analysis revealed several additional neural regions implicated in this experience. For example, the superior lateral occipital cortex as well as inferior portions such as the fusiform gyrus, were significantly more active on trials when participants pressed 'Like' compared to 'Next.' Certainly, it is possible that the visual properties of Liked images lead to differences in neural responses. Participants were significantly more likely to Like photographs containing objects than faces. (this finding is at odds with earlier work suggesting young people more frequently like Instagram photos depicting people; Bakshi *et al.*, 2014; the difference may result from the presence of strangers' photos in our study). It is also possible that the increased response in visual cortex reflects a difference in how participants attended to images.

On trials in which participants provided a like, we also observed greater activation in the bilateral insula, dorsal anterior cingulate cortex (dACC) and paracingulate cortex, lateral prefrontal cortices (lPFC), and lateral parietal cortices. This set of regions, which often co-activate during cognitively demanding tasks, has been dubbed the 'task activation ensemble' (Seeley *et al.*, 2007). Despite frequent coactivation of these brain regions, Seeley and colleagues posited that these regions make up two dissociable networks: the insula and dACC and anterior insula form hubs of a network implicated in interoceptive/autonomic processing ('salience network', see also, Menon and Uddin, 2010), whereas the lPFC and a more dorsal portion of mPFC are implicated in executive control ('central executive network'). In the present study, the coactivation of these networks may reflect the orchestration of multiple cognitive processes during decision-making about photographs.

When participants received many Likes, we observed robust activation in hubs of the 'default mode' or 'mentalizing network,' reliably implicated in social cognition and self-referential thought, including the precuneus and bilateral temporoparietal junction.

These findings lend support to Meshi *et al.* (2015) hypothesis that overlapping neural regions implicated in self-referential thought and mentalizing are implicated in social media use. However, our results suggest that social media use recruits more than just the three networks proposed by Meshi and colleagues. Meshi *et al.* (2015, p. 774) suggested that when providing feedback to others, 'a user may think about how this specific user may react upon receiving this feedback'. Our findings do not preclude this possibility, but neither do they provide strong support for it. A large percentage of our participants reported using their 'gut instinct' when deciding whether to Like a photograph, suggesting less thoughtful consideration and more implicit processing. Furthermore, rather than finding that giving Likes recruited brain regions involved in mentalizing about others (as we saw for receiving Likes), we instead observed activity in a set of brain regions not identified in Meshi and colleagues' review, including the dACC and the bilateral insula. These regions have been described in past work as major hubs of the 'salience network'. This network, and in particular the anterior insula, are involved in organizing behavioral responses as they relate to emotional states (for a review, see Menon and Uddin, 2010), as well as in autonomic processing and interoceptive awareness, also known as a 'gut feeling'.

Limitations and future directions

Although this inquiry provides initial insight into the neural correlates of providing feedback online, and suggests additional brain systems that are relevant to our understanding of the neuroscience of social media, several limitations should be noted. For example, in the present study, we wished to recreate the user experience of viewing images on Instagram. Therefore, information about the popularity of images (i.e. the number of Likes the image had supposedly received from previous participants) appeared with each image. As we have reported previously, image popularity had a small but significant effect on participants' decision to Like photos. Thus, popularity of an image is somewhat confounded with the Like > Next contrast that we investigated in the present paper. In order to account for this confound, we accounted for the popularity of images in our model; thus, the Like > Next contrast represents brain responses related to this contrast over and above the effects of popularity. Similarly, results of our 'Getting Likes' contrast may in part reflect the neural correlates of giving Likes to 'oneself', since participants were more likely to select Like on their own photographs when these images appeared popular (Sherman *et al.*, 2016, 2017), although they also frequently Liked their own unpopular images.

Second, we cannot completely disentangle the neural response to a Liked image itself, and the neural response associated with the experience of providing this friendly feedback to another individual. This issue is, as we note, inherent to the cognitive construct of the Like itself. If indeed it 'feels good' to give a Like to another individual, does this feeling reflect an inherent and adaptive prosocial response, similar to giving to charity or providing social support? Or rather, are the likable features of the photograph responsible for eliciting a positive emotion? Our follow-up analysis suggested that both factors are at play, but future research could corroborate the results of this exploratory analysis. For example, participants could complete a second round of the task in which they are asked to provide Likes simply as a means of connecting with others, rather than in response to a specific photograph or other social media post. When surveying our participants about their reasons for choosing to Like images, we did not include an item that addressed possible prosocial motivation, a limitation that could be addressed in future work.

Third, our results must be considered in light of the fact that participants were responding to strangers instead of friends, acquaintances, and classmates. While many social media users interact with strangers, interactions with known individuals are much more common (e.g. Subrahmanyam *et al.*, 2008), and teens tend to less frequently Like photos of strangers (Greenfield *et al.*, 2017). The use of strangers' photographs enabled us to show the same images to all participants, which is to say, we heightened experimental control at the cost of ecological validity. This approach may nonetheless have limited the salience of the images. We would hypothesize that findings, particularly in the ventral striatum, would be enhanced if participants Liked their friends' images (e.g. Fareri *et al.*, 2012).

Finally, while we strived to include a variety of typical images found on social media (see https://osf.io/atj4d/ for a complete list), it is unclear whether our findings would generalize to all types of photographs. For the present study, we elected to exclude risk-taking images because the variability in liking responses was much lower. As we have previously reported, neural responses to risky and neutral, nonrisky photographs differ (Sherman *et al.*, 2016, 2017). It is possible, therefore, that motivations for liking risky images, and associated neural responses, would be different.

Conclusions

Our findings represent a first step in understanding neural mechanisms underlying individuals' experiences with quantifiable forms of peer endorsement on social media. In line with the notion of a 'common neural currency' of monetary and social reward, giving and receiving Likes—a unique feature of online environments that resembles both social and monetary reward-robustly recruits brain circuitry implicated in other reward tasks. Our findings also contribute more broadly to understanding of the neural mechanisms underlying social media, and provide initial support for the notion that many individuals use a 'gut feeling' approach when deciding to provide Likes on social media. Future research can help to disentangle the extent to which this neural signature reflects the experience of viewing attractive images or the pro-social act of providing a like, and may even allow us to predict future behavior on social media using neural data.

Funding

This research was supported by Grants C06-RR012169 and C06-RR015431 from the National Center for Research Resources, by Grant S10-OD011939 from the Office of the Director of the National Institutes of Health (NIH), by National Institute on Drug Abuse National Research Service Award F31-DA038578-01A1 (to L. E. Sherman), and by Brain Mapping Medical Research Organization, Brain Mapping Support Foundation, Pierson-Lovelace Foundation, The Ahmanson Foundation, Capital Group Companies Charitable Foundation, William M. and Linda R. Dietel Philanthropic Fund, and Northstar Fund. Authors are solely responsible for the content, which may not represent the official views of NIH.

Supplementary data

Supplementary data are available at *SCAN* online.

Conflict of interest. None declared.

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