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Social Media Use and Peer Influence in Adolescence: Perspectives from Neuroimaging

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Social Media Use and Peer Influence in Adolescence:

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by

Lauren Elizabeth Sherman

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ABSTRACT OF THE DISSERTATION

Social Media Use and Peer Influence in Adolescence: Perspectives from Neuroimaging

by

Lauren Elizabeth Sherman

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2016

Professor Mirella Dapretto, Co-Chair

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Social media use is extremely prevalent among adolescents, leading to continued public interest in its effects on social interaction. Understanding the neural underpinnings of social media use will allow researchers to better understand these effects; but the literature on social media and the brain is, at present, remarkably limited. This dissertation examined a unique feature of digital interaction- “Quantifiable Social Endorsement” - and demonstrated that this indicator of peer opinion significantly influences both neural and behavioral responses to content posted online.

In Study 1, adolescents underwent an fMRI scan while using a tool that mimics Instagram, a popular photo-sharing social media platform. Participants viewed photos that had been ostensibly “Liked” by peers. In reality, the number of Likes was experimentally manipulated such that half of the photos appeared with many Likes (‘popular’) and half with few Likes (‘unpopular’). Included among these photos were images submitted by the participants from their own Instagram accounts and images depicting risky behaviors (e.g., drinking alcohol, smoking). Participants demonstrated significantly different behavioral and neural responses as a

function of photo popularity. Participants were more likely to Like photographs if they were popular than unpopular, and popular photos elicited significantly greater activity in neural regions implicated in reward processing, social cognition, and visual attention. Behavioral effects were significantly stronger for participants' own photographs than for photographs ostensibly supplied by peers, and participants showed significantly greater activity in the nucleus accumbens - a hub of the brain's reward circuitry - for the popular > unpopular contrast when viewing their own photographs compared to others' photographs.

Study 2 replicated and extended the findings of Study 1 in an expanded sample that additionally included 27 college students. Like the high-school students, college students also were significantly more likely to Like popular than unpopular photographs, and popular photographs elicited significantly greater activity in brain regions involved in social cognition, visual attention, and reward. When high-school students, but not college students, viewed risky (vs. non-risky) photographs, activation in the cognitive control network decreased. For high-school students, nucleus accumbens response to social reward (i.e., receiving many Likes on one's own photographs) increased with age.

The findings reported in this dissertation suggest that Quantifiable Social Endorsement is a means by which peer socialization and influence occurs in online environments, including to behaviors like drinking and drug use, which represent a significant public health concern in adolescence. Furthermore, social media provide a unique opportunity to examine the neural correlates of social interaction and peer influence in an ecologically valid manner.

The dissertation of Lauren Elizabeth Sherman is approved.

Naomi Ilana Eisenberger

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DEDICATION

This dissertation is dedicated in loving memory to my grandparents,

Maryann and Charles Adams.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Everything I have accomplished over the past six years as a doctoral student was only possible because of my incredible network of family, friends, and mentors. One of the greatest lessons I have learned as a student of psychology is the fundamental importance of close bonds: this concept has been demonstrated through behavioral experiments, surveys, and studies of

hormones, brain activity, and immune functioning. More than any empirical endeavor, however, the support of those I love has taught me this lesson.

When I was a freshman at Vassar College, I read a paper about self-presentation and identity in online chat rooms. This paper stayed with me for three years and inspired my senior project. In my final year at Vassar, I applied to UCLA's doctoral program to work with one of the authors of that paper, Patricia Greenfield. I was relatively inexperienced compared to many applicants, but Patricia trusted that I could thrive at UCLA. Patricia, I consider myself incredibly lucky that you chose to mentor me. You are a champion for your students; you have always made it clear that you care deeply about our wellbeing, both in our academic and personal lives. Your career, and in particular your commitment to interdisciplinary methods and to the study of culture, is a continuing source of great inspiration to me.

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PUBLICATIONS

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Hernandez, L.M., Krasileva, K., Green, S.A., **Sherman, L.E.,** Ponting, C., McCarron, R., Geschwind, D.H., Bookheimer S.Y., & Dapretto, M. (under review at *Molecular Psychiatry*). Oxytocin receptor gene polymorphisms act additively to disrupt reward circuitry in youth with autism.

Guan, S.S.A, Chiang, J.J., **Sherman, L.E.,** Tsui, Y, & Robles, T.F. (under review at *Cyberpsychology, Behavior, and Social Networking*). Culture moderates the effect of social support across communication contexts in young adult females.

I. General Introduction

During adolescence, youth spend increasing time with their peers and these relationships become more complex and intense (Berndt, 1982; Brown, 2004). Peers play a progressively more important role in the socialization process, and can exert considerable influence on one another's decisions through modeling of behaviors and attitudes, direct attempts to influence behavior, and reinforcement or punishment of exhibited traits and behaviors (Brown et al., 2008). Peer influence is multidirectional; adolescents can encourage one another to engage in prosocial or antisocial activities. However, given that adolescence is marked by an increase in risky behaviors like experimentation with alcohol and drugs, risky sexual behavior, and reckless driving (Williams, Holmbeck, & Greenley, 2002), and that adolescents are more likely to engage in risky decision-making when in the presence of peers (Gardner & Steinberg, 2005), much of the recent literature has focused on peer influence and conformity in the context of risky decision-making. The studies presented in this dissertation used behavioral and neuroimaging approaches to examine peer influence as it occurs on social media, an environment where adolescent interactions and socioemotional processes are increasingly played out.

Indeed, with the current availability and popularity of social media technologies, adolescents are connected to peers even when separated by physical distance. One recent report (Common Sense, 2015) finds that 67% of American adolescents own their own smartphone, suggesting that online peer interaction is available to the majority of American youth in virtually any location, at any time. Despite the prevalence of digital technologies in adolescent lives, our knowledge of the ways in which social media environments motivate both risky and normative behaviors is still limited.

Social media and peers.

Typically, youth use social media to interact with their existing offline peer networks (Subrahmanyam et al., 2008; Valkenburg & Peter, 2007), and many aspects of in-person social interaction are paralleled in digital contexts. Nonetheless, other aspects of digital environments are unique. A feature of many social networking sites and apps is the ability to Like or "favorite" an image, text, or other piece of information. These "likes" allow for a simple, quantifiable measure of peer's endorsement of online content. This form of online social endorsement is significant for several reasons. First, though it appears in different forms, it is ubiquitous across social networking platforms. Second, it operates in a fundamentally different fashion from typical social interactions, in that the *quantity* of endorsements is the most salient feature (and individuals have little or no ability to customize the *quality* of the endorsement, as they do when posting a comment, for example). For adolescents, who are particularly attuned to the opinions of peers, such clear markers of positive validation may serve as powerful motivators. However, this possibility has not previously been empirically investigated. Indeed, this "Quantifiable Social Endorsement" has received very little attention in the developmental psychology literature.

More generally, the existing literature does suggest that sensitivity to peer influence motivates behavior in digital environments. Peer influence appears to occur particularly through the mechanism Brown (2008) identifies as "behavioral display:" as in classic social cognitive learning theory (Bandura & Walter, 1963), individuals display a behavior or attitude that is considered socially desirable, and peers then imitate that behavior. For example, when asked about their likelihood to engage in risky behavior like smoking marijuana or getting in a fight, adolescents were more likely to endorse these behaviors if a popular classmate first endorsed them during an online chat room session (Cohen & Prinstein, 2006; Freeman, Hadwin, & Halligan, 2011). Social networking sites like Facebook can also provide a platform for peers to endorse risky behavior: exposure to friends' online photographs of alcohol consumption and partying are associated with increased tendency to engage in both smoking and drinking (Huang et al., 2014). Boyle and colleagues (in press) conducted a longitudinal study of exposure to alcohol-related content on Facebook, Instagram, and Snapchat, and found that reported exposure predicted college students' level of drinking six months later, over and above students' drinking behaviors and their friends' behaviors at the first time point.

The extant literature has largely focused on exposure to images and text posted by peers, (Brown's "behavioral displays"). Importantly, however, social media users see not only content posted by friends online, but also learn how other friends have reacted to this information. Quantifiable Social Endorsement provides an opportunity not only for peers to model behavior—deciding to like a peer's picture is in itself a behavioral display—but also for peers to provide feedback to others on what is socially desirable or acceptable. This feedback is another essential component of peer influence: what Brown calls *behavioral reinforcement* (2008). This dissertation addresses the lack of research on Quantifiable Social Endorsement by examining a) behavioral responses to and b) the neural correlates of viewing online content with many or few Likes. Furthermore, the dissertation examines online peer influence specifically as it applies to risky decision-making, a significant threat to healthy development in adolescence.

Risky decision-making, peer influence, and the brain.

Neuroimaging techniques allow researchers a unique opportunity to understand the mechanisms underlying peer influence and risky decision-making. Indeed, evidence from the field of developmental cognitive neuroscience suggests that risky decision-making and susceptibility to peer influence in adolescence cannot simply be explained by heightened emotional reactivity or by immature cognitive control processes alone. Rather, these processes, and the neural systems thought to subserve them, interact (e.g. Casey, Getz & Galvan, 2008; Casey, Somerville, & Galvan, 2016; Steinberg, 2008; 2010; Shulman et al., 2016). The developmental trajectory of the striatum and other subcortical regions associated with emotional reactivity and reward salience differs considerably from that of the lateral and dorsomedial prefrontal cortex, which is implicated in cognitive control and emotion regulation. The imbalance between these sets of regions is greatest during the adolescent period. Several researchers (Casey, Getz & Galvan, 2008; Steinberg, 2008; 2010) have hypothesized that the imbalance contributes significantly to increases in risky decision-making during the adolescent years. Not all evidence from neuroimaging supports this hypothesis, however (Pfeifer & Allen, 2012), suggesting a need for further research on the neural correlates of risky decision-making and the role peers play in risky decision-making. In the research presented here, I investigated the neural correlates of peer influence and risk-taking behaviors in an ecologically valid social context; namely, while adolescents and young adults used the popular social networking platform Instagram.

Social media and fMRI.

Until very recently, mimicking the social networking experience in the confined space of an MRI scanner was quite challenging. The increasing popularity of photo-sharing apps like Instagram, which features a simple user interface, has made this goal attainable. Instagram is a social media platform, or "app," designed primarily for smartphones. Users create an account and use the account to share photographs and (more recently) videos. While each user has an individual profile page displaying their content, much interaction on the app takes place on each user's personalized feed. By scrolling through the feed, users see images and videos posted by friends. Here, they can Like or comment on friends' content. Instagram has risen rapidly in popularity over the past several years. In the second half of 2013, the year preceding Study 1, Instagram grew by 23% (Lunden, 2014). The app is especially popular among youth: according to one recent poll, 52% of adolescents ages 13-17 are Instagram users (Lenhart, 2015). In the two studies presented here, adolescents and young adults underwent fMRI while using a simulation of Instagram.

Overview of Studies

Study 1. Study 1 investigated a unique way in which adolescent peer influence occurs on social media. Adolescents underwent fMRI while viewing photographs ostensibly submitted to Instagram. Adolescents were more likely to Like photos depicted with many Likes and refrain from Liking photos with few Likes – indicating the influence of virtual peer endorsement, a finding that held for both neutral photos and photos of risky behaviors (e.g., drinking, smoking). Viewing photographs with many (vs. few) Likes was associated with greater activity in neural regions implicated in reward processing, social cognition, imitation, and attention. Furthermore, when adolescents viewed risky (vs. non-risky) photographs, activation in the cognitive control network decreased. These findings suggest that the neural regions associated with peer influence and risky decision-making in previous and often context-free fMRI paradigms are also implicated in real-world experiences with risky content and peer feedback. Furthermore, our findings support the notion that peers' positive feedback on social media (i.e., Likes) may motivate use of social media through recruitment of brain's reward circuitry. This study is currently in press at *Psychological Science*.

Study 2. In Study 1, we demonstrated that the number of Likes appearing on content posted online (i.e., an Instagram photograph) affects adolescents' behavioral and neural response to the content. Study 2 took a developmental approach: The high-school sample from Study 1 was compared with a college sample using the same procedure as in Study 1. As we previously observed in adolescents, college-age participants more often Liked photos that had received many (vs. few) Likes. Popular photos elicited greater activation in multiple brain regions, including the *nucleus accumbens*, a hub of the brain's reward circuitry. Nucleus accumbens responsivity increased with age for high-school but not college students. When viewing images depicting risk-taking (vs. non-risky photographs), high-school students, but not college students, showed a down-regulation of neural regions implicated in cognitive control. When participants viewed images depicting risk-taking, the level of response in neural regions associated with social cognition and visual attention was positively correlated with participants' tendency to engage in real-world risk-taking behaviors, and to appraise these behaviors more positively. The developmental difference findings suggest that college-aged youth are also susceptible to peer influence through Quantifiable Social Endorsement, but also provide evidence for age-related changes in reward and cognitive control circuitry during an ecologically valid social task. The findings also demonstrate a connection between neural response to images depicting risk-taking and actual risk-taking behavior in the real world.

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II. The Power of the Like in Adolescence: Effects of Peer Influence on Neural and Behavioral Responses to Social Media

Social media are immensely popular among adolescents: Nearly ninety percent of American teens report being active users, and youth have continually outpaced other age groups in adopting new media (Lenhart, 2015). Given this prevalence, it is unsurprising that parents, educators, and the popular press have expressed concerns about the effects of social media on social skill development and interpersonal interactions. Frequently, these concerns manifest in questions about the effect of social media on the developing brain. Nonetheless, few studies have examined neural mechanisms underlying any kind of social media use (Choudhury & McKinney, 2013; Mills, 2014).

The neural correlates of social media use are particularly important to understand in adolescence, and not only because adolescents are enthusiastic users. Adolescence is especially important for social cognitive development; it is theorized to be a sensitive period during which youth are uniquely attuned to the complexities of interpersonal relationships (Baird, 2012; Blakemore & Mills, 2014). Subcortical regions functionally associated with emotion processing and reward undergo considerable changes and reorganization during puberty (Brenhouse & Anderson, 2011; Sisk & Foster, 2004). The dopaminergic system and related regions in the striatum are potential mechanisms underlying two features of adolescence: escalation in risk-taking behaviors, and increased desire to spend time with and earn the approval of peers (Steinberg, 2008). For example, when adolescents completed a risky driving task alone or in the presence of peers, risk-taking and activation in the nucleus accumbens (NAcc), a hub of reward circuitry, increased when peers were present (Chein et al., 2011). Smith and colleagues (2014) replicated these behavioral effects when peers were virtually connected, demonstrating that peer influence also occurs online (see also Cohen & Prinstein, 2006).

Less is known about how features *unique* to social media contribute to peer influence. One significant way in which digital and in-person communication differ is in their affordance for interactions that are quantitative. While in-person communication is necessarily qualitative and involves subjective interpretation, many online environments allow for feedback that is purely quantitative. For example, a feature of most social media tools is the ability to Like an image, text, or other piece of information, allowing for simple, straightforward measure of peers' endorsement. For adolescents, who are particularly attuned to peer opinion, this "Quantifiable Social Endorsement" may serve as a powerful motivator. Furthermore, Quantifiable Social Endorsement provides a unique research opportunity: while it is a form of interaction that occurs in the real world, it is simple enough to be experimentally manipulated.

While the present study is, to our knowledge, the first to replicate social media interaction in the MRI scanner, important earlier work using behavioral and fMRI methods has demonstrated how peer endorsement biases values (e.g., Campbell-Meikeljohn et al, 2010; Izuma and Adolphs, 2013; Klucharev, et al., 2009). In these studies, adults rated stimuli and then learned how others rated the same stimuli before rating a second time. Participants changed their ratings to conform to peers or experts and showed greater NAcc activation during trials when they agreed with these individuals, compared to conflicts of opinion. Our study differs from previous work in that adolescents viewed content posted on social media *simultaneously* with information about its popularity – much as content is typically experienced online. We thus tested if initial impressions were colored by the content's popularity, and explored overall effects of positive peer opinion on brain responses.

Specifically, we investigated the neural correlates of viewing photographs with many or few Likes to assess the role of Quantifiable Social Endorsement in peer influence. We recruited adolescents to participate in an "internal social network" that simulated Instagram, a popular photo-sharing tool. Participants submitted their own Instagram photographs, and believed that all photographs would be seen and Liked by peers. We tested the possibility that the number of Likes appearing under each photo would affect participants' responses. We hypothesized that participants would tend to Like photos Liked by more peers and refrain from Liking less popular photos. We hypothesized that neural responses to popular and unpopular photographs would differ. Given previous research suggesting that peer presence heightens NAcc response (Chein et al., 2011), we predicted that viewing *others'* photographs with many (vs. few) Likes would similarly elicit greater NAcc activation. Evidence linking NAcc response to social evaluation (Meshi, Morawetz, & Heekeren, 2013) and sharing information about the self (Tamir & Mitchell, 2012), as well as the well-documented role of the NAcc in reward and reinforcement generally, suggests that viewing one's *own* photographs with many (vs. few) Likes would also elicit greater NAcc activity.

Peer influence is very important during adolescence; it is one way adolescents learn how to behave appropriately in their sociocultural environment. However, peer pressure can be maladaptive when it reinforces dangerous behaviors like drunk driving or drug use. Furthermore, youth frequently post content online depicting risky behaviors, and this may affect others' tendency to engage in those behaviors (Huang et al., 2014). Thus, we also investigated if Quantifiable Social Endorsement specifically influences responses to risky behaviors, by including photographs depicting these behaviors. Well-established theories of adolescent risk-taking suggest that the NAcc interacts with neural regions implicated in cognitive control during risky decision-making (Casey, 2015; Steinberg, 2008). Accordingly, we directly compared neural activity while viewing "risky" images vs. non-risky images to examine whether exposure to risky content online would influence activity in these cognitive control regions, regardless of the supposed popularity of the photographs.

Methods

Participants and fMRI Paradigm. Thirty-four typically developing adolescents (17 female, age range 13-19) participated in the present study. Of the 34 participants, two were excluded from fMRI data analysis due to scan console malfunction and excessive motion. The sample size reflects the maximum number of participants the study team was able to recruit based on available funding, as well as timing constraints imposed by an institutional upgrade of the MRI magnet. Participants completed written consent in accordance with UCLA's Institutional Review Board.

During recruitment, participants were informed that they would be involved in a study examining the brain's responses during social media. Participants were asked to submit photographs from their own accounts on Instagram, a popular social media tool used for sharing photographs on mobile devices and the Internet. They were told that all of these photographs would be combined to form an "internal social network," and that every participant would see a feed of these photographs in the scanner, appearing as they would on Instagram. In reality, participants saw only some of their own photographs in the scanner; all other stimuli were selected by the study team from publicly available images on Instagram. During the laboratory visit, each participant was instructed that approximately 50 other adolescents had already viewed the feed of Instagram photos. This step was taken to establish the size of the "audience," and to standardize how many Likes would be regarded as "many" versus "few," irrespective of a participant's own social network size. Participants were told that they could see how many times each photograph was Liked by previous participants, and that the feed would be updated after their visit to reflect any new Likes they contributed. In reality, the number of Likes displayed under each image was assigned by the study team, as described below.

The social media task was presented to participants in the scanner using 800x640 resolution magnet compatible 3-D goggles (Resonance Technology, Inc.). The task mimicked the experience of browsing Instagram on a smartphone: Participants viewed a feed of photographs, each of which was accompanied by text indicating how many others already Liked the image. Photographs were displayed one at a time on a white background accompanied by two buttons prompting the participant to choose Like in order to Like the image or "Next" in order to move on to the next image without Liking it (Figure I-1). Images were presented for 3000ms, with a variable interstimulus interval of 1000-11000ms.

Figure I-1. Two examples of stimuli presented during the imaging paradigm. Participants saw innocuous photographs of adolescents or everyday objects, like the coffee drinks on the left, or images involving risky behavior, like the marijuana joint on the right. Images appeared as they would in Instagram on a smartphone in the year 2014: "Likes" were displayed underneath the photograph next to an image of a heart, and the Instagram menu screen was displayed beneath the Likes. Also displayed were two buttons, instructing participants to choose Like to Like an image or "Next" to move on without Liking the image.

Participants saw 148 unique photographs. These included 42 images of risky behavior, and 66 neutral, non-risky images. "Risky" photographs contain alcohol, cigarettes, marijuana, smoking paraphernalia, rude gestures, or adolescents (male and female) wearing provocative or "skimpy" clothing. Neutral photographs depicted typical images found on adolescent social media profiles (e.g., pictures of friends, food, and possessions). Participants also saw 40 of the images they had submitted from their own Instagram accounts. These images were selected to minimize risky content; therefore, they were comparable to the neutral photographs ostensibly submitted by peers. Across participants, all neutral and risky images were assigned both a “popular” value of 23-45 Likes and an “unpopular” value of 0-22 Likes. Two versions of the imaging paradigm were created: in Version One, half of the photographs in each category (Risky, Neutral) were displayed with a “high Like” value and half were displayed with a “low Like” value. In Version Two, the values were reversed. Thus, each image was shown to half of the participants with many Likes, and the other half with few Likes; this allowed us to hold content and aesthetic quality of images constant while manipulating popularity. Half of each participant’s own photographs appeared with 23-45 Likes, and the other half appeared with 0-22 Likes. To assign Likes to participants’ own images, the first author divided the 40 photos based on the content contained in the images (e.g., pictures containing people or objects only); a randomly-selected half of each category was then assigned to many or few Likes. Thus, the content of the “popular” and “unpopular” images was similar. Importantly, Likes were not distributed continuously and evenly across the spectrum of 0-45. Rather than expecting neural and behavioral responses to vary linearly as the number of Likes increased, we hypothesized that participants would display qualitatively different responses to popular vs. unpopular images. Thus, we used a bimodal distribution of Likes, in which the majority were clustered between 30-45 Likes (popular photographs) or 0-15 Likes (unpopular photographs). We chose to use a bimodal distribution in order to clearly differentiate popular and unpopular images. Of the 148 photographs displayed during the scan, only 8 were depicted with intermediate values of 23-29 Likes and 8 were depicted with 16-22 Likes; these 16 images were included to avoid any suspicion on the part of participants that might be caused by the obviously bimodal distribution. In light of our experimental manipulation, our categorical analyses reflect the difference between highly endorsed and unpopular images.

During the scan, participants were asked to view the images as they appeared, and to decide whether they personally Liked each image using the criteria they would normally use when deciding to Like pictures on Instagram. Participants selected Like or "Next" by pressing one of two buttons on a button box.

Data Acquisition and Analyses. Neuroimaging data were collected using a Siemens Trio 3 Tesla MRI scanner. The social media paradigm was presented during a functional scan lasting 11 minutes and 44 seconds (echo planar T2*-weighted gradient-echo, TR=2000ms, TE=28ms, flip angle=90, matrix size 64x64, 34 axial slices, FOV= 192 mm; 4-mm thick, skip 1-mm). Button-press data were recorded in E-prime and converted to SPSS Statistics format for analysis. Binomial tests were used to determine if participants conformed to peers' responses more often than would be predicted by chance. fMRI data were preprocessed and analyzed using AFNI (Cox, 1996) and the FMRIB Software Library (Jenkinson et al., 2012). Preprocessing for each individual's data included image realignment to correct for head motion, normalization to a standard stereotactic space (Montreal Neurological Institute 152-brain template), and spatial smoothing using a 5-mm FHWM Gaussian kernel to increase signal-to-noise ratio.

For each participant, linear contrasts were calculated for several planned comparisons. Specifically, we modeled three linear contrasts comparing popular ("Many Likes," 23-44 Likes) and unpopular photos ("Few Likes," 0-22 Likes) in the Neutral, Risky, and Participant's Own categories. In addition to modeling the six types of stimuli at the first level, we included several other parameters. These included the participant's button-press choice and reaction time for each trial, and the luminosity of each image as determined using Adobe Photoshop. Group-level random-effects analyses were then conducted across all participants. At the group level, a pre-threshold binary mask consisting of all regions exhibiting significant activity for any type of photograph > fixation ($Z > 1.7$, corrected for multiple comparisons at $p < .05$) was utilized in order to restrict our analyses to regions displaying significant task-related activity. This mask covered a considerable portion of the cortex and subcortex. Along with all of our group contrast maps, it is available for download at NeuroVault (http://neurovault.org/collections/RYSBTTMN/). We performed contrasts examining the effect of popularity (Many Likes > Few Likes and the reverse) for Neutral, Risky, and Participant's Own photographs. We also compared all Neutral (non-risky) photographs ostensibly submitted by peers to all Risky photographs ostensibly submitted by peers.

To test our a priori hypothesis that popular photographs would elicit significantly greater activation in the bilateral NAcc than unpopular photographs, a small-volume-correction approach was used. Our functional regions of interest (ROIs), derived from an independent sample of participants completing a Monetary Incentive Delay task (Tamir & Mitchell, 2012), consisted of two 8-mm spheres in the left and right NAcc (stereotaxic space of the Montreal Neurological Institute (MNI) coordinates: 10, 6, −4; −8, 4, −6). AFNI's 3dClustSim (AFNI version 16.0.00, January 2016), was used to determine that a contiguous cluster of 53 or greater voxels was necessary to meet statistical criterion within these ROIs. To examine whether the Many Likes > Few Likes contrast differed significantly as a function of type of photographs (Neutral, Risky, Participants' Own), we extracted parameter estimates (betas) from the bilateral ROIs for each contrast of interest and performed paired-sample t-tests using SPSS.

Results

To determine whether participants were significantly more likely than chance to "match" the supposed opinions of peers (i.e., Like popular images and refrain from Liking unpopular images), we conducted a series of binomial tests. Across all photographs presented during the scan, participants matched their peers significantly more frequently than expected by chance ($p < .00001$). This effect was also significant for each individual type of photograph, including non-risky neutral images ostensibly provided by peers ($p = .03$), images depicting risk-taking behaviors ostensibly provided by peers ($p = .03$) and participant's own images ($p < .00001$). The effect was significantly larger for participants' own photos than for either neutral images ($X^2 = 10.1$, $p = .001$) or risky images ($X^2 = 6.6$, $p = .01$).

Neural responses also differed as a function of number of Likes for neutral, risky, and participants' own photos. Figure I-2 (A) depicts regions in which activity was significantly greater when photographs were depicted as having garnered more versus fewer Likes for neutral, risky, and participant's own photographs. The regions of significantly greater activity for many vs. few Likes differed by photograph type. When participants viewed neutral photographs with many Likes, they showed significantly greater activity in visual cortex extending to the precuneus, and the cerebellum (Table I-1). When participants viewed risky photographs with many vs. few Likes, significantly greater activity was found in one cluster in the left frontal cortex, extending from the precentral gyrus through the middle frontal gyrus and inferior frontal gyrus (Table I-1). When participants viewed their own photos, significantly greater activity in response to photos with many Likes (vs. few) was observed in several regions (Table I-1). These included areas implicated in social cognition, such as the precuneus, medial prefrontal cortex, left temporal pole, lateral occipital cortex, hippocampus (Mars et al., 2012; Zaki & Ochsner, 2009, this set of regions also resembled the map for 'social' on Neurosynth as of January 2016; Yarkoni et al., 2011; http://neurosynth.org), as well as reward learning and motivation, including the nucleus accumbens, caudate, putamen, thalamus, and ventral tegmental area/ brain stem (e.g., Haruno and Kawato, 2006; Schott et. al., 2008, this set of regions also resembled the map for ‘reward’ on Neurosynth as of January 2016). Table I-1 includes a complete list of regions. For all three photo types, the reverse contrast (Few Likes > Many Likes) yielded no significant activation in the whole brain.

Neural responses also differed as a function of whether or not the photograph depicted risky behavior (*Figure. I-2B*). When participants viewed risky images, compared to neutral images, significantly greater activity was observed in bilateral occipital cortex as well as medial prefrontal cortex and the inferior frontal gyrus (See Table I-2 for a complete list of regions). Interestingly, when viewing Risky images, participants demonstrated significantly *less* activation in a network of regions implicated in cognitive control and response inhibition (e.g. Blasi et al., 2006; Bressler & Menon, 2010; Sherman et al., 2014; this set of regions also resembled the map for ‘cognitive control’ on Neurosynth as of January 2016), including dorsal anterior cingulate cortex, bilateral prefrontal cortex, and lateral parietal cortex (*Table I-2*).

Table I-1. Peak coordinates of activation for regions obtained from the random-effects contrasts of popular > unpopular for neutral, risky, and participants' own images (high-school sample)

	MNI peak (mm)			Max	Sig #
	x	*y*	*z*	*Z*	Voxels
Neutral Images, Popular > Unpopular					
Cerebellum	-6	-56	-16	3.53	389
Intracalcarine cortex/ precuneus	6	-72	16	3.40	544
Occipital pole	2	-90	0	3.44	728
Risky Images, Popular > Unpopular					
Left lateral frontal cortex (precentral gryus, middle frontal gyrus, inferior frontal gyrus)	-34	16	28	3.79	557
Participants' Own Images, Popular > Unpopular					
Left Ventrolateral prefrontal cortex	-32	58	8	4.09	351
Medial prefrontal cortex	10	48	28	3.82	908
Dorsomedial prefrontal cortex	-2	14	56	3.2	259
Left lateral frontal cortex (superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus)	-48	12	36	3.91	1510
Left temporal pole	-48	6	-26	3.37	208
Striatum (caudate, putamen, nucleus accumbens)	8	4	-4	3.98	675
Right lateral frontal cortex (precentral gryus, middle frontal gyrus, inferior frontal gyrus)	48	-2	52	3.69	343
Thalamus	-10	-8	14	3.76	1247
Left hippocampus	-18	-20	-16	3.95	81
Ventral tegmental area/ brain stem	-8	-28	-12	3.74	604
Left cerebellum	-18	-42	-24	3.83	1558
Left superior parietal lobe/ lateral occipital cortex	-26	-52	30	4.01	454
Precuneus	2	-72	36	4.04	1958
Occipital cortex (occipital pole/ fusiform gyrus)	-2	-88	10	3.96	1442
Right cerebellum	14	-88	-26	3.99	1857

Coordinates are in Montreal Neurological Institute space. For all maps, $Z > 2.3$, cluster corrected for multiple comparisons at $p < .05$. Contrasts were pre-thresholded using a binary mask consisting of all regions exhibiting greater activation for any type of photograph > fixation in order to restrict whole-brain findings to regions of significant task-related activity.

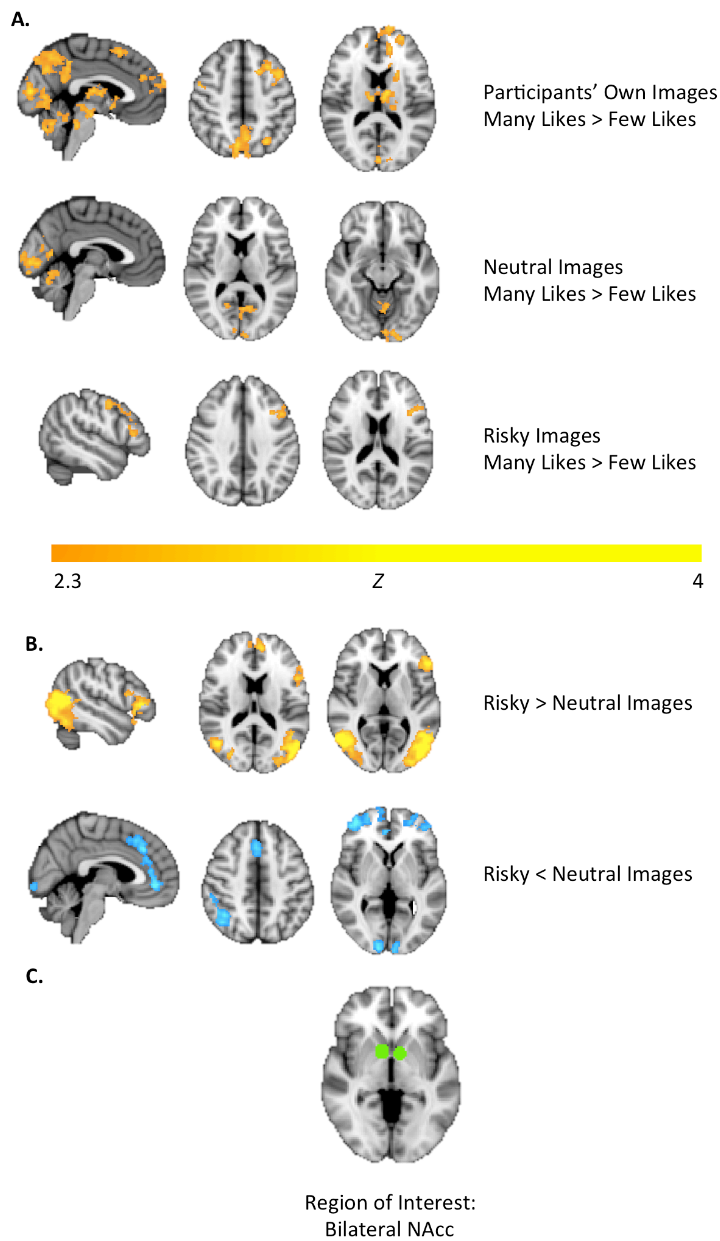

Figure I-2. Neural responses to photographs differed as a function of the perceived popularity of the photograph. (A). For participant's own photographs and photographs ostensibly submitted by peers (depicting neutral or risky behaviors), analyses revealed significant activity in several neural regions for the Many Likes > Few Likes contrast, Z > *2.3,* cluster corrected at p < *.05*. The reverse contrast (Few Likes > Many Likes) yielded no regions of significant activity for any of the three types of photographs*.* (B). For photographs ostensibly submitted by peers, neural activity differed significantly for risky and neutral images, Z > *2.3,* cluster corrected at p < *.05*. (C). Region of interest (ROI) analyses were conducted using an a priori ROI in the nucleus accumbens selected from a Monetary Incentive Delay task in an independent sample of young adults (Tamir & Mitchell, 2012). Brain images are shown by radiological convention (left on right).

Table I-2. Peak coordinates of activation for regions obtained from the random-effects contrasts of risky images > neutral images and risky images < neutral images (high-school sample)

	MNI peak (mm)			Max	Sig #
	x	*y*	*z*	*Z*	Voxels
Risky Images > Neutral Images					
Medial prefrontal cortex	-4	56	22	4.38	463
Inferior frontal gyrus	-52	30	4	4.49	966
Right lateral occipital cortex	54	-62	6	5.26	2441
Left lateral occipital cortex	-44	-74	8	5.47	5009
Risky Images < Neutral Images					
Dorsomedial prefrontal cortex/ anterior cingulate gyrus	2	30	36	4.20	979
Right lateral prefrontal cortex	42	44	18	4.70	1255
Left lateral prefrontal cortex	-42	48	-12	3.79	632
Right lateral parietal cortex	38	-54	44	3.96	762
Occipital pole	-4	-94	-8	3.92	707

Coordinates are in Montreal Neurological Institute space. For all maps, $Z > 2.3$, cluster corrected for multiple comparisons at $p < .05$. Contrasts were pre-thresholded using a binary mask consisting of all regions exhibiting greater activation for any type of photograph > fixation in order to restrict whole-brain findings to regions of significant task-related activity.

In addition to our whole-brain analyses, we conducted Region of Interest (ROI) analyses based on our a priori hypothesis that photos depicted with many Likes would elicit significantly greater activation in the bilateral nucleus accumbens (NAcc) than those depicted with few Likes. Consistent with our hypothesis, we observed greater activity in the left NAcc when participants viewed neutral images that had many Likes, as compared to neutral images that had few. We also observed greater bilateral NAcc activation when participants viewed their own images for the many Likes > few Likes contrast, but did not observe any difference in response as a function of number of Likes for images depicting risk-taking behavior. In the right NAcc, activation was significantly greater when participants viewed their own photographs, compared to viewing others' neutral (nonrisky) images ($t(31) = 2.34$, $p = .026$) and risky images ($t(31) = 2.45$, $p = .02$) but did not differ significantly in the left NAcc (for all comparisons, $p > .10$).

Discussion

The present study highlights a new and unique way in which peer influence occurs on social media: through Quantifiable Social Endorsement. We found that the popularity of a photograph had a significant effect on the way that photograph was perceived. Adolescents were more likely to Like a photograph – even one portraying risky behaviors like smoking marijuana or drinking alcohol – if that photograph had received more Likes from peers. This effect was especially strong for photos they themselves had supplied. Adolescence is a period during which self-presentation is particularly important, including on social media; thus, this significantly greater effect may reflect the relative importance of self-presentation versus providing feedback to others.

Neural responses also differed as a function of number of Likes. For all three types of photographs, participants exhibited greater brain activity for photographs with more "Likes."

The regions of greater activity included areas implicated in social cognition and social memories, including the precuneus, medial prefrontal cortex, and hippocampus (Mars et al., 2012; Zaki & Ochsner, 2009), as well as the inferior frontal gyrus, implicated in imitation (Pfeifer et al., 2008). For participants' own and others' photographs, greater visual cortex activity was observed in response to many Likes, even though we controlled for photographs' luminosity and content. The increased activation suggests that participants may have scanned popular images with greater care. Taken together, our imaging findings suggest that adolescents perceive information online in a qualitatively different way when they believe that this information is valued more highly by peers. Interestingly, the exact nature of these changes differs depending on the content depicted in the photograph.

Our ROI analysis suggests that the NAcc, an important hub of the brain's reward circuitry, is implicated in the experience of receiving positive feedback on one's own images as well as viewing others' images that have been endorsed by peers. The NAcc response, like our behavioral effects, was particularly robust for participants' own photographs, suggesting that self-presentation can be especially rewarding and a motivation for using social networks (cf. Manago, et al., 2008; 2010). NAcc response did not differ as a function of popularity for risky photographs. However, several participants in our adolescent sample reported no experiences with drugs and alcohol; this lack of familiarity may have contributed to the failure to detect a "peer effect" in the NAcc when comparing risky popular and unpopular images. Future research should examine the effect of popularity on NAcc response to risky photographs in adolescents who report greater experience with drugs and alcohol.

While Quantifiable Social Endorsement is a relatively new phenomenon, we believe that the implications of this experiment extend beyond the digital context. Quantifiable Social

Endorsement is a simple, but nonetheless significant example of sociocultural learning; a Like is a social cue specific to adolescents' cultural sphere, and adolescents use this cue to learn how to navigate their social world. A Like is both a representation of an attitude or affective response as well as a behavior that, in and of itself, affects others' experiences online. Adolescents learn from Quantifiable Social Endorsement in multiple ways, as evidenced by participants' differentiated neural responses to their own and others' photographs. Peers socialize one another to norms in multiple modes, including modeling appropriate behavior (behavioral display) and reinforcing appropriate behavior in others (behavioral reinforcement; Brown et al., 2008). Social media embody both modes of socialization: adolescents model appropriate behavior and interests through the images they post (behavioral display), and reinforce others' behavior through the provision of Likes (behavioral reinforcement). Unlike offline forms of peer influence, however, Quantifiable Social Endorsement is straightforward, unambiguous, and, as the name suggests, purely quantitative. While the present study does not allow us to directly compare in-person versus online peer influence, our findings are in line with previous research suggesting that the presence of peers heightens responses in reward circuitry and leads to differences in behavioral decision-making (Chein et al., 2011). Furthermore, the present inquiry is, to our knowledge, the first to document that Quantifiable Social Endorsement, a ubiquitous feature of social media, produces these measurable neural and behavioral effects. Future research should build upon our findings to investigate how individual differences in neural response map onto behavioral outcomes: can individual neural responses predict which adolescents will demonstrate greater conformity?

Sociocultural learning can be adaptive, as it allows adolescents to flexibly learn from their environment. In the case of socialization to risky behavior, however, it can also be maladaptive. Multiple theoretical models (Steinberg, 2008; Casey, 2015) posit that risk-taking in adolescence arises in part from heightened neural sensitivity to reward combined with immature capacity for cognitive control. In line with these models, we found that a network implicated in cognitive control (e.g., Seeley et al., 2007) was less active when participants viewed images depicting risky behavior. Certainly, viewing photographs online does not, in itself, constitute a risk. It is therefore all the more striking that when simply viewing photographs of risky behaviors ostensibly taken and posted by peers, adolescents exhibited downregulation of the cognitive control network. This decreased activation possibly reflects a mechanism by which peer behaviors disinhibit cognitive control in high-risk scenarios, thereby increasing the likelihood of engaging in risk-taking. Future research should examine whether this downregulation occurs into adulthood as well, or if this finding potentially reflects the immaturity of the prefrontal cortex in adolescence. Similarly, future research can shed light on whether the NAcc response to social reward shown in the present study is particularly heightened in adolescence, in line with previous research on monetary reward (Braams et. al., 2015).

Our findings and approach have implications not only for social media researchers, but also for those studying social cognition more broadly. Social media provide a compelling opportunity to examine social interaction in an ecologically valid context. Typically, in the confines of an MRI scanner, social interaction is limited and artificial. Because social media exist on a screen, however, they can be effectively imported into the scanner environment. Our study provides proof of concept for Quantifiable Social Endorsement, a ubiquitous form of online interaction that is easily experimentally manipulated. Future research can build upon this foundation in order to examine how neural responses to Quantifiable Social Endorsement predict individual differences in a variety of behavioral and psychological domains.

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III. Peer Influence Via Instagram: Effects on Brain and Behavior in Adolescence and Young Adulthood

Since the advent of early social networking sites like Friendster and Myspace, adolescents and young adults have been among the first and most enthusiastic users of social media. More recently, youth have flocked to social media designed for mobile devices, such as Instagram and Snapchat (Lenhart, 2015). Despite early concerns that adolescents might use the Internet to meet strangers, they primarily use social media to interact with existing friends (Valkenburg & Peter, 2007). Furthermore, many offline social and emotional processes typical of adolescence are also enacted on social media, including peer influence (Cohen & Prinstein, 2006; Huang et. al., 2014). Recent longitudinal work on exposure to alcohol-related content on Instagram and Snapchat suggests that such exposure predicts college students' future drinking behavior, over and above students' drinking behaviors and their friends' current behavior. Recently, we (Sherman et al., in press) investigated how features unique to newer forms of social media, including mobile apps, might play into adolescent peer influence at the behavioral and neural level. In the present study, we expanded upon these findings by examining possible developmental changes from adolescence to young adulthood.

While adolescence is a time of heightened risk-taking relative to childhood, certain risky behaviors such as binge drinking actually peak in the college years (Esser, et al., 2014), a period that has been characterized as a continuation of adolescence but also as a developmental stage of its own: emerging adulthood (Arnett, 2000). This increased risk-taking is likely the result of greater independence, as well as a shift for many young adults to living with peers and away from parents. Nonetheless, the neural systems hypothesized to underlie suboptimal decision-making in adolescence do mature considerably during the late teens and early 20s. Executive functions continue to improve throughout this period, likely as a result of ongoing pruning and myelination in the frontal and parietal lobes (Paus, 2005). The younger adolescent brain, which has not yet experienced this maturation, is also characterized by heightened sensitivity of areas involved in affect and reward processing. Theories about adolescent decision-making posit that this "imbalance" between the systems governing cognitive control and affective processing accounts at least in part for riskier decision-making (Shulman et al., 2016; Casey, Galvan, & Somerville, 2016). In particular, the extant literature has demonstrated the sensitivity of the nucleus accumbens (NAcc) during adolescence and into early adulthood (e.g. Braams et. al., 2015; Galvan et al., 2006). From both animal literature and human neuroimaging, the NAcc is widely known for its role as a hub of the brain's reward circuitry. It is involved in the subjective experience of reward and pleasure (Berridge & Kringleback, 2013), and in motivating goal-directed behavior (Ikemoto & Pankepp, 1999). It is also involved in the implicit learning of social cues, including culturally specific cues (e.g., Schaefer & Rotte, 2007). Importantly, as discussed above, the NAcc is particularly sensitive in adolescence. Recent longitudinal evidence suggests that NAcc sensitivity to (monetary) reward increases into late adolescence, at which point it peaks and declines (Braams et al., 2015). NAcc sensitivity also increases in the presence of peers, and may be linked to greater propensity to make risky decisions (Chein et al., 2011). For these reasons, we hypothesized that NAcc sensitivity to reward may play a critical role in the overwhelming popularity of social media in adolescence and early adulthood.

Social media easily afford the implicit learning of social norms, as they involve simple, fast, quantifiable measures of peer endorsement (e.g., "Likes"). We dubbed this feature "Quantifiable Social Endorsement" (Sherman et al., in press) and demonstrated that the level of Quantifiable Social Endorsement on Instagram photographs-- that is, the popularity of photographs posted online-- had a measurable effect on both behavioral and neural responses to those images. Adolescents were more likely to Like photographs when they believed the images were popular, and neural responses differed significantly as a function of the popularity of a photograph. These effects occurred for photographs submitted by strangers (depicting typical adolescent behaviors as well as risky behaviors) and for participants' own submitted photographs. When adolescents received many Likes (vs. few) on their own photographs, they showed significantly greater activation of the NAcc, lending confidence to the hypothesis that Likes motivate online behavior and continued use of social media. Is this motivation particularly high during adolescence? Given the trajectory of NAcc sensitivity through late adolescence, we tested if neural responses to social media increased throughout adolescence before tapering off or even decreasing in a cohort of young adults. We also investigated how responses to risky images posted online might be different in older, more independent college students. Additionally, we were eager to test if our original findings replicated in a new sample. We thus had several overarching goals for the present study:

1. *Replicate behavioral and neural research findings from the existing high school sample in an older population that is nonetheless still experiencing social and brain development (i.e., college students).* We hypothesized that, similar to high school students, college students would be significantly more likely to Like an Instagram photograph if they believed it was Liked by many peers, compared to few. We also hypothesized that college students' neural responses would differ as a function of photo popularity, and in particular that receiving many Likes on one's own photographs would elicit significant activation in the NAcc in comparison with fewer Likes.

2. *Examine between-group differences and age-related effects in the high school and college cohorts in neural regions implicated in reward and executive functions.* We hypothesized that NAcc activation in response to social reward (i.e., receiving many "Likes" on photographs) would increase with age in our high school sample, just as NAcc response to monetary reward increases throughout adolescence (Braams et al., 2015), but that NAcc response would not continue to increase in a college cohort. We previously reported that high school students showed significant down-regulation of neural regions implicated in executive function when viewing Risky images (*Sherman et al., in press*). Given the maturation of control regions in early adulthood, we expected stronger down-regulation to occur in college; in other words, we expected college students to show significantly greater activation in regions implicated in executive function than high-school students while viewing images of risk-taking behavior on social media.

3. *Explore individual differences in neural activity as a function of real-world risk-taking behavior.* Previous research suggests that, during fMRI paradigm involving social tasks or gambling, activity in brain regions involved in reward and social cognition relates to individuals' tendency to engage in real-world risky behaviors like drinking and smoking (e.g., Galvan et al., 2007; Saxbe et. al., 2015). In the present experimental paradigm, which involves viewing images of actual risk-taking behavior, we tested whether neural responses would similarly vary. We hypothesized that neural responses to risky images, particularly risky images deemed popular by peers, would vary as a function of participants' actual experiences with risky behaviors.

Methods

Participants. An adolescent sample of thirty-four typically developing high school students (M_{age} = 16.8, *SD* = 1.4, 18 female) was recruited from the Los Angeles community through flyers and message board postings; these participants have been previously reported upon (Sherman et al., in press; Chapter II of this dissertation). A young adult sample of 27 university students (M_{age} = 19.9, *SD* = 1.1, 17 female) was recruited through flyers posted on campus. Of these participants, two high-school participants and one college participant were excluded from fMRI data analysis due to scanner console malfunction or excessive movement during the MRI scan. The final fMRI samples did not differ in their overall average (p = .38) and maximum (p =.77) relative motion. Of the high school participants, 47.1% were European American, 23.5% were multiethnic, 8.8% were African American, 5.9% were Hispanic, .2.9% were Asian American/Pacific Islander, 2.9% were American Indian, 2.9% were other, and 5.9% did not report their ethnicity. Of the college, 51.8% were Asian American/ Pacific Islander, 22.2% were European American, 11.1% were Hispanic, 7.4% were multiethnic, 3.7% were other and 3.7% did not report ethnicity.

College participants were all enrolled in the same four-year university, where over 90% of students live on campus in their first year. Thus, our college sample was not only older on average than our high school sample, but had also entered a qualitatively different developmental stage. Given the unique experiences and challenges of the emerging adulthood period (Arnet, 2000), as well as evidence suggesting that some neural changes may be attributable specifically to higher education (e.g. Bennett and Baird, 2006; Noble et al., 2014), we performed all fMRI analyses, including examining age-related trends, separately in our high school and college samples.

Procedure. During recruitment, all participants were informed that they would be involved in a study examining brain responses during social media use. Participants were asked to submit photographs from their own accounts on Instagram, a popular iPhone and Android app used to share photographs with friends. Participants were told that these photographs would be used to create an "internal social network," and that each participant would see a feed of these images in the scanner, appearing as they would on Instagram. High school participants were told that other participants were fellow high school students from the same city. College participants were told that other participants were also students at their university. In reality, participants did not see one another's photographs in the scanner. Rather, participants saw a selection of their own photographs, as well as a standardized set of photographs selected by the study team from publicly available images on Instagram. On the day of the experiment, each participant was told that about 50 others had already viewed the internal Instagram feed, in order to establish the size of the "audience" (and thus the maximum number of Likes). Participants were told that they could see how many "Likes" each photograph had received by previous study participants. In reality, the number of Likes displayed with each photograph was manipulated by the study team, as described below.

fMRI Paradigm. In the scanner, participants viewed each photograph for 3s. Photographs appeared on a white background, with the number of Likes ostensibly provided by peers displayed underneath (Figure II-1). Participants saw three categories of images. "Risky" photographs depicted alcohol and partying behaviors, smoking paraphernalia, rude gestures, or adolescents (male and female) wearing provocative or "skimpy" clothing. Neutral photographs depicted typical images found on adolescent social media profiles (e.g., pictures of people, food,

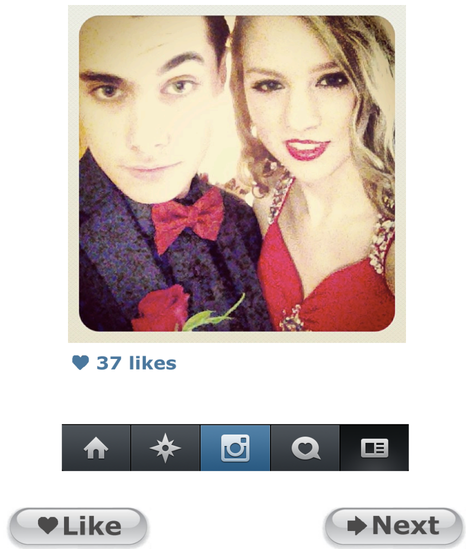

Figure II-1.Example of a photograph presented during the Instagram experiment. Participants viewed a series of photographs while in the MRI scanner, depicted in a simplified version of the Instagram user interface (as of 2014). Under each photograph was a blue heart, as well as the number of "Likes" ostensibly provided by peers. The Instagram menu bar appeared below the Likes. Beneath the Instagram display, participants saw two buttons, prompting them to choose Like to Like an image or "Next" to move on without Liking the image.

and possessions; Hu, Manikonda, & Kambhampati, 2014). Each participant also saw images he or she had submitted from his/her own Instagram account. Across participants, all neutral and risky images were assigned both a "popular" value and an "unpopular" value. Two versions of the imaging paradigm were created: in Version One, half of the photographs in each category (Risky, Neutral) were displayed with a "popular" value of 23-45 Likes and half were displayed with an "unpopular" value of 0-22 Likes. In Version Two, the values were reversed. Each image was therefore shown with many Likes to half of our participants, and with few Likes to the remaining half, thus allowing us to control for content and aesthetic quality while manipulating popularity. Similarly, half of each participant's own photographs appeared with many Likes, and the other half appeared with few Likes. Likes were not distributed continuously and evenly across the spectrum of 0-45. Rather than expecting neural and behavioral responses to vary linearly, we hypothesized that participants would display qualitatively different responses to popular vs. unpopular images. Thus, we used a bimodal distribution of Likes, in which the majority were clustered between 30-45 Likes (popular photographs) or 0-15 Likes (unpopular photographs), in order to clearly differentiate popular and unpopular images. The social media task was presented to participants in the scanner using MRI-compatible goggles (Resonance Technology, Inc.). During the scan, participants were asked to view the photographs and decide whether to Like each image using the criteria they would normally use when deciding to Like pictures on Instagram. Participants selected Like or "Next" by pressing one of two buttons on a button box. Neuroimaging data were collected using a Siemens Trio 3 Tesla MRI scanner.

Questionnaire. Following the MRI scan, participants completed The Revised Cognitive Appraisal of Risky Events (CARE-R; Katz, Fromme, & D'amico, 2000). This questionnaire consists of two sections. "Risks and Benefits" assesses participants' perception of the risks and benefits associated with risky drinking, drug use, and sexual behavior. "Past Experiences" assesses the frequency with which participants engaged in risky drinking, drug use, and sexual behavior in the past six months. For all items, participants can respond on a scale of 1-7 (higher scores indicate more risky responses). In order to create a composite score for each person, we calculated the average response to all questions. We elected to exclude questions about coercive sex from the questionnaire, as these were deemed irrelevant to the aims of the present study.

Behavioral Data Analysis. Button-press data were recorded in E-prime and converted to Stata (v14.1) format for analysis. We utilized a Random Intercept Logistic Model with participants modeled as a random effect, to determine if participants' likelihood to Like images was predicted by the popularity of the image (Popular, Unpopular), the image content (Neutral, Risky, Participant's Own), the samples (High School, College), and all possible interactions. To examine the individual effects of popularity for neutral, risky, and participant's own images, we conducted three tests of simple effects, with a Bonferroni correction to maintain a significance value of $p < .05$.

fMRI Data Analysis. Neuroimaging data were preprocessed and analyzed using AFNI (Cox, 1996) and the FMRIB Software Library (Jenkinson et al., 2012). Preprocessing for each individual's data included image realignment to correct for head motion, normalization to a standard stereotactic space (Montreal Neurological Institute 152-brain template), and spatial smoothing using a 5-mm FHWM Gaussian kernel to increase signal-to-noise ratio. For each participant, we modeled three linear contrasts comparing popular and unpopular photos in the Neutral, Risky, and Participant's Own categories. Also included in the model were participant's button-press choices, reaction time for each trial, and the luminosity of each photograph (as determined using Adobe Photoshop). Group-level random-effects analyses were then conducted across all participants, with the high school sample and college sample modeled as two groups, and each participant's mean relative head motion entered as a covariate.

To test our a priori hypothesis that viewing one's own popular photographs would elicit significantly greater activation in the bilateral NAcc than unpopular photographs, we used a region of interest (ROI) approach. The ROIs were derived from an independent sample of participants completing a Monetary Incentive Delay task (Tamir & Mitchell, 2012); they consisted of two 8-mm spheres in the left and right NAcc (stereotaxic space of the Montreal Neurological Institute (MNI) coordinates: 10, 6, −4; −8, 4, −6). We extracted the average signal from these ROIs for trials when participants saw their own photographs with many Likes (popular) compared to trials when they saw their photographs with few Likes (unpopular), and performed a one-sample t-test. We performed the same ROI analysis for photographs submitted by peers (risky and neutral). We also tested whether NAcc response to social reward (Popular > Unpopular for participant's own photographs) was significantly related to age in our high school and college samples using a correlational analysis.

In addition to our ROI analyses, a bottom-up approach was used to investigate effects across the whole brain. We modeled contrasts examining the effect of popularity (Popular > Unpopular and the reverse) for the three types of photograph. We also compared all Neutral photographs to all Risky photographs. Group means for each contrast were compared between our high school and college sample. At the group level, a pre-threshold binary mask consisting of all regions exhibiting significant activity for any type of photograph > fixation ($Z > 1.7$, corrected for multiple comparisons at $p < .05$) was utilized in order to restrict our analyses to regions displaying significant task-related activity. This mask covered a considerable portion of both the cortex and subcortex, and it (as well as our group maps) is available at http://neurovault.org/collections/1271/. Finally, we performed a second bottom-up analysis with composite scores on the CARE-R modeled at the group level, to examine if individual differences in neural responses related to individual differences in real-world risk-taking behavior and appraisal. This analysis involved 57 participants, because one high school participants did not complete the CARE-R. Because age and scores on the CARE-R were positively correlated ($r = .32$, $p = .02$), we included age as a control variable in this model.

Results

Goal 1: Replication of Behavioral Findings. We previously reported that high school participants were more likely to "match" peers (i.e., select Like for popular images and "Next" for unpopular images) than expected by chance, as determined by a binomial test (Sherman et al., in press). For the present inquiry, we used a multilevel logistic model, which additionally allowed us to 1) model within-subject variability for each participant, and 2) report the probability of a participant Liking an image given its popularity and type. The full model was significant (Chi-square = 1437.20, $p < .0001$). Overall, participants were significantly more likely to Like popular images than unpopular images ($z = 7.28$, $p < .001$), and this effect was significantly larger for participants' own images than for either neutral images ($z = 5.03$, $p < .001$) or risky images ($z = 3.86$, $p < .001$). We also performed tests of simple effects to examine the effect of popularity for each of the three photograph types. For each photograph type, participants more frequently "Liked" popular than unpopular photographs, and all effects were significant with a Bonferroni correction to maintain a significance value of $p < .05$. We report results for high school and college students combined because the cohorts did not differ in their overall tendency to Like images ($z = 1.34$, $p = .18$), and the interaction between popularity and cohort was not significant ($z = 1.04$, $p = 0.30$), suggesting that our cohorts did not differ in their tendency to Like popular vs. unpopular images. Table I-1 presents the probability of participants Liking a photograph, given its popularity and type.

Table II-1: Likelihood to Like Photographs Based on Popularity and Type

Image Type	Popular *Likelihood (SE)*	Unpopular *Likelihood (SE)*
Participant's Own	.88 (.01)	.74 (.02)
Neutral	.49 (.02)	.43 (.02)
Risky	.26 (.02)	.21 (.02)

Goal 1: Replication of fMRI Results. We previously reported that high school students showed significantly greater activation in the left and right NAcc when viewing their own photographs that had received many Likes compared to few. Using the same ROI, we replicated this finding in our college sample, in the left NAcc ($t(25) = 2.95$; $p = .007$) and right NAcc ($t\ (25)= 3.43$ $p = .002$). Furthermore, NAcc contrasts did not differ significantly for our high school and college samples for this contrast, or when viewing popular > unpopular risky or neutral images ($p > .05$ for all). In the college cohort, viewing popular > unpopular risky images was associated with significant activation in the left NAcc ($t(25) = 2.78$; $p = .01$) but activation in the right NAcc did not reach significance ($t\ (25)= 1.50$; $p = .146$). Viewing popular > unpopular neutral images was not associated with significant activation in the NAcc in either hemisphere (LH: $t(25) = 0.54$; $p = .596$; RH: $t(25) = 1.27$; $p = .216$).

Figure II-2 depicts the whole-brain results for popular > unpopular for Neutral, Risky, and Participant's Own Images in our college student sample. Much as previously reported in our high-school participants, when viewing photographs with many likes (popular) > few likes (unpopular), college students demonstrated significantly greater activation in several brain regions implicated in social cognition (e.g., precuneus, medial prefrontal cortex), reward (NAcc, caudate, orbitofrontal cortex), and visual attention (occipital cortex). Similarly, college students showed no areas of significant activation when viewing photographs of any type for the opposite contrast, unpopular > popular. Indeed, when directly comparing our college and high school samples, we only found a single contrast in which our college and high school sample differed in their response to the effects of popularity. Specifically, when viewing Neutral images with many likes (popular) > few likes (unpopular), high school students showed significantly greater activation than college students in one region of visual cortex (MNI coordinates of maximum voxel, x =6, y=-72, z=16; Max Z = 3.40, 526 voxels).

Goal 2: Age Differences in NAcc Responsivity to Social Media. Figure II-3 presents the results of the correlational analysis relating age to bilateral NAcc response when viewing one's own photographs with many Likes compared to few Likes. As hypothesized, bilateral NAcc responsivity to the many likes (popular) > few likes (unpopular) contrast increased with age in our high school sample (Left NAcc: r = .47, p = .006; Right NAcc: : r = .38, p = .03) but not in our college sample (Left NAcc: r = -.07, p = .72; Right NAcc: r = .05, p = .82). The difference between the slopes for college and high school students was significant in the left NAcc (p = .04), though not the right NAcc (p = .21).

Table II-2. Peak coordinates of activation for regions obtained from the random-effects contrasts of popular > unpopular for neutral, risky, and participants' own images (college sample)

	MNI peak (mm)			Max
	x	*y*	*z*	*Z*
Neutral Images, Popular > Unpopular				
Precentral/postcentral gyrus	-42	-20	62	3.43
Risky Images, Popular > Unpopular				
Medial prefrontal cortex	2	60	22	3.65
Left temporoparietal junction	65	34	42	3.60
Left temporal pole	-40	14	-40	3.81
Supplementary motor area	4	4	52	3.52
Precentral gyrus/ middle frontal gyrus/	50	4	44	3.43
Amygdala/Hippocampus	-22	-12	-14	3.74
Thalamus	6	-14	10	3.66
Left middle temporal gyrus	-52	-16	-16	3.62
Brain stem/ ventral tegmental area	-12	-22	-16	3.19
Left parahippocampal gyrus	-20	-36	-10	3.58
Right fusiform cortex	32	-44	-18	3.30
Cerebellum	10	-50	-38	3.75
Right temporal cortex	60	-54	-12	3.04
Precuneus/ Posterior cingulate cortex	-4	-62	34	3.80
Participants' Own Images, Popular > Unpopular				
Left superior frontal gyrus	-22	28	36	3.47
Right pallidum/ putamen	12	10	-4	3.49
Left pallidum/ putamen	-16	6	0	3.90
Thalamus/caudate/nucleus accumbens	10	2	2	3.98
Left precentral gyrus/ middle frontal gyrus/ inferior frontal gyrus	-26	2	48	3.88
Supplementary motor area	8	2	52	3.48
Left insula	-34	-14	-6	3.36
Left temporal cortex/ temporoccipital fusiform cortex	-54	-60	2	3.53
Precuneus	2	-64	14	3.82
Right temporal cortex/ temporoccipital fusiform cortex	34	-64	-24	4.16
Cerebellum	34	-64	-24	4.16
Right superior pariteal lobule/ lateral occipital cortex	42	-66	12	3.83
Left superior parietal lobule/ lateral occipital cortex	-32	-76	36	4.10
Right inferior lateral occipital cortex	32	-88	-14	3.97

Coordinates are in Montreal Neurological Institute space. For all maps, $Z > 2.3$, cluster corrected for multiple comparisons at $p < .05$. Contrasts were pre-thresholded using a binary mask consisting of all regions exhibiting greater activation for any type of photograph > fixation in order to restrict whole-brain findings to regions of significant task-related activity.

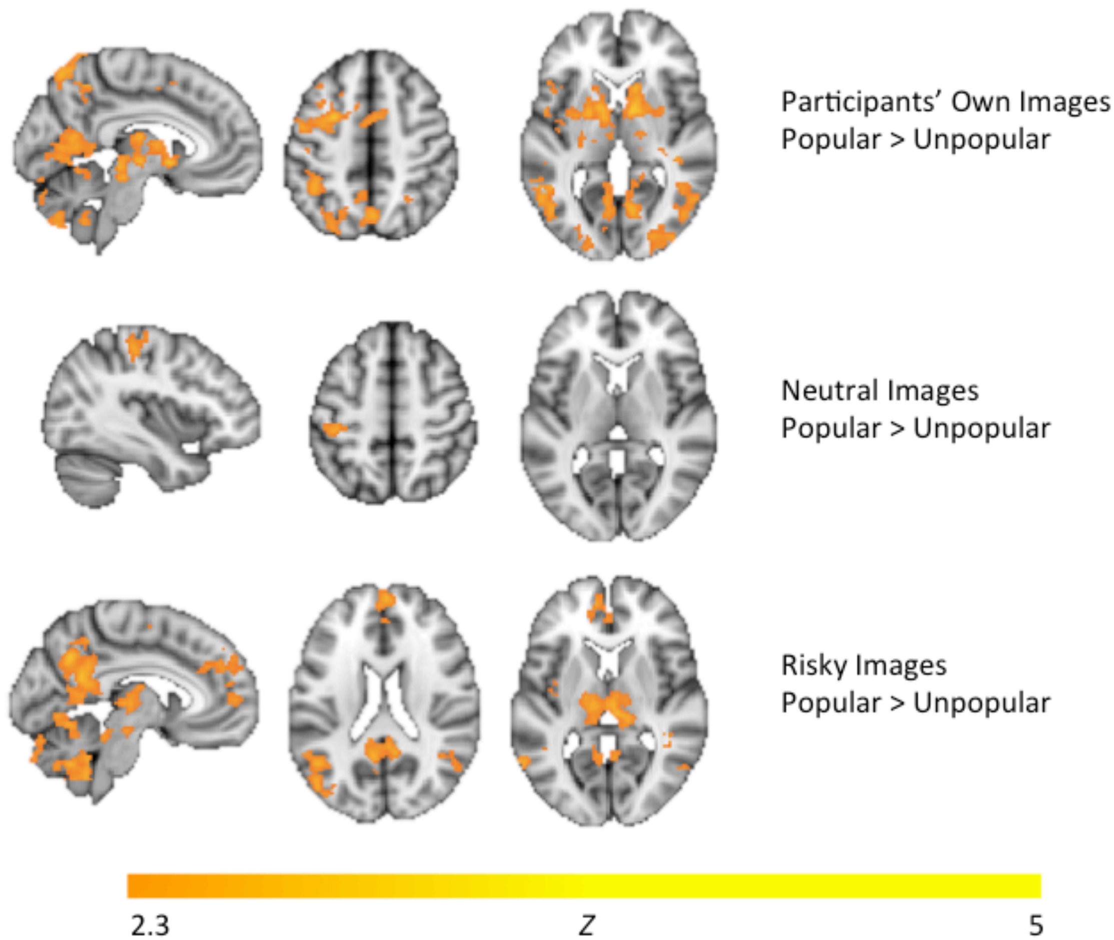

Figure II-2. College students' neural responses to photographs as a function of the perceived popularity of the photograph. For participant's own photographs and photographs ostensibly submitted by peers (depicting neutral or risky behaviors), analyses revealed significant activity in several neural regions for the Popular > Unpopular contrast, Z > 2.3, cluster corrected at p < .05. The reverse contrast (Unpopular > Popular) yielded no regions of significant activity for any of the three types of photographs.

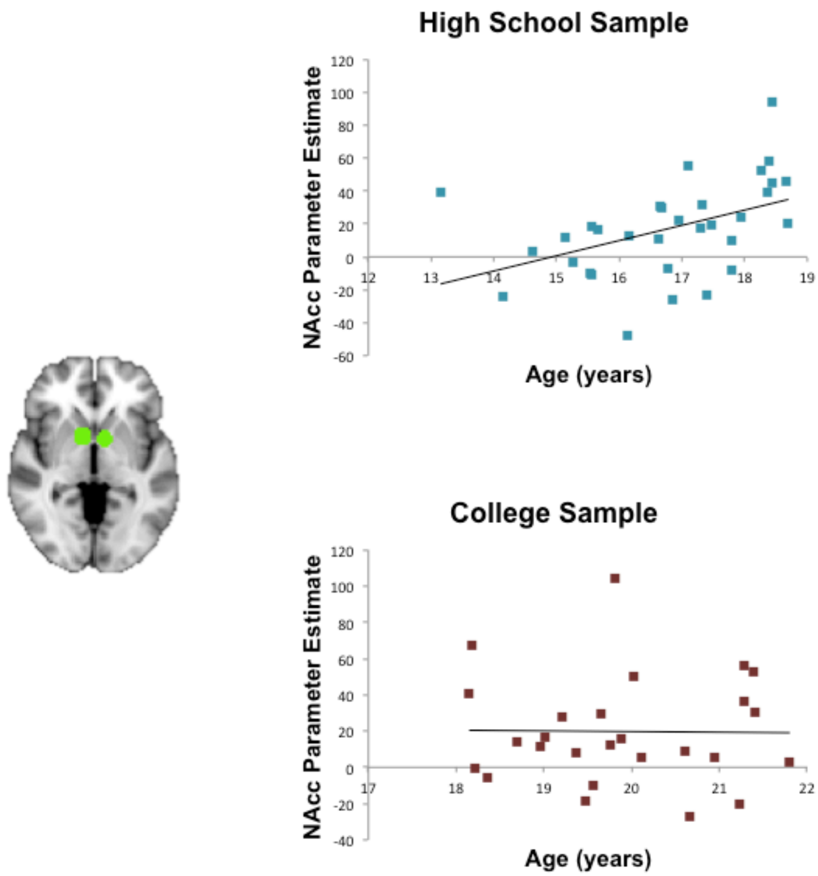

Figure II-3. Bilateral NAcc response to social reward and its relation to age. For participants in the high school cohort, NAcc response to the Popular (Many Likes) > Unpopular (Few Likes) contrast increased linearly with age ($r = 0.45$, $p < .01$). However, for participants in the college cohort, NAcc response was not associated with age ($r = -0.01$. $p = .96$). Parameter estimates presented here consist of a sum of the left and right NAcc response. The NAcc ROI was selected from an independent sample of young adults completing a Monetary Incentive Delay task (Tamir & Mitchell, 2013).

Goal 2: Cohort Differences in Neural Responses to Risky vs. Neutral Photographs. Interestingly, high-school and college participants differed significantly in their neural responses to Risky > Neutral photographs. We previously reported that when high-school students viewed images depicting risk-taking behavior (vs. neutral images), they demonstrated a significant down-regulation of several neural regions implicated in the Central Executive Network, including the dorsomedial prefrontal cortex (dmPFC), lateral parietal cortices, and bilateral prefrontal cortices, as well as a portion of the visual cortex. Notably, while the college student sample showed a similar decrease in activation in visual and right parietal cortices, we found no significant decreases in frontal areas. Indeed, significant differences between high-school and college students were observed in dmPFC (MNI coordinates of maximum voxel, $x = 14$, $y = 54$, $z = 24$; Max $Z = 3.60$, 706 voxels) and left dorsolateral prefrontal cortex (MNI coordinates of maximum voxel, $x = -44$, $y = 20$, $z = 38$; Max $Z = 3.77$, 393 voxels; Figure II-4), regions implicated in the Central Executive Network (e.g., Sherman et al., 2014).

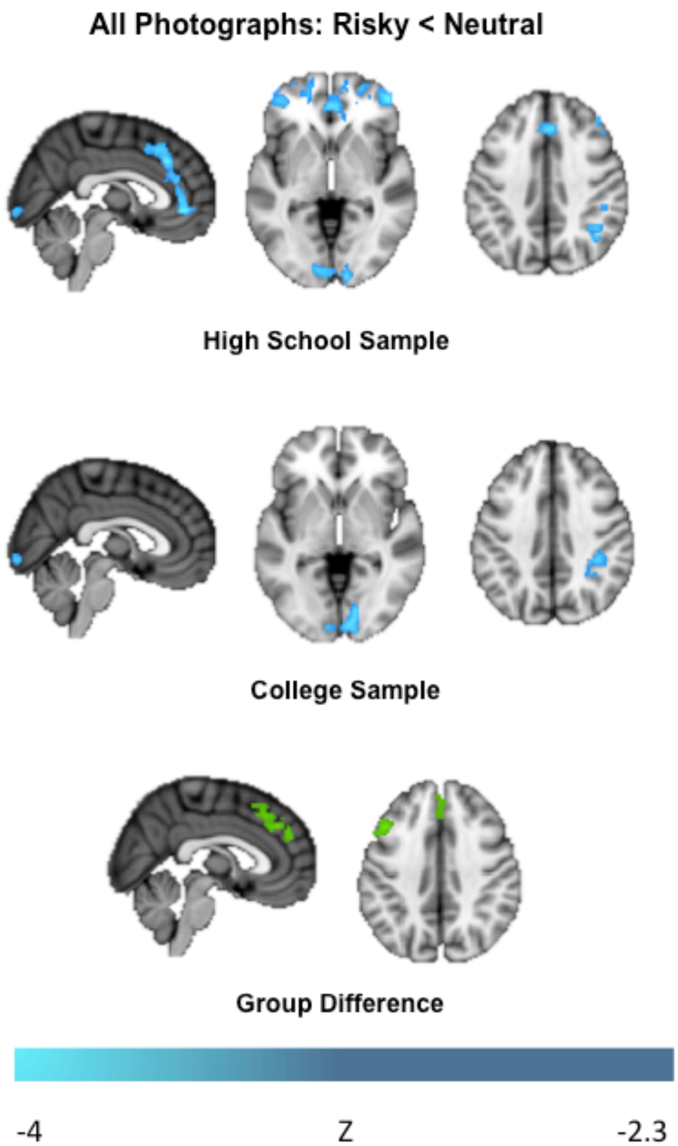

Figure II-4. Differences in down-regulation in the Central Executive Network. When viewing Instagram photographs depicting risk-taking activities, compared to photographs depicting non-risky, neutral activities, only high-school students showed a significant decrease in activity in frontal regions implicated in cognitive control, including the dorsomedial prefrontal cortex (dmPFC) and the dorsolateral prefrontal cortex (dlPFC). The group difference in this decrease was significant in the dmPFC and left dlPFC, depicted in green. All images thresholded at $Z > 2.3$, with cluster correction to maintain $p < .05$.

Table II-3. Peak coordinates of activation for regions obtained from the random-effects contrasts of risky images > neutral images and risky images < neutral images (college sample)

	MNI peak (mm)			Max
	x	*y*	*z*	*Z*
Risky Images > Neutral Images				
Medial prefrontal cortex	8	48	28	4.98
Orbitfrontal cortex/ frontal pole	-40	-34	18	3.6
Left lateral occipital cortex	-40	-78	2	3.89
Risky Images < Neutral Images				
Right lateral parietal cortex	36	-40	42	3.51
Occipital pole	10	-90	6	4.09

Coordinates are in Montreal Neurological Institute space. For all maps, $Z > 2.3$, cluster corrected for multiple comparisons at $p < .05$. Contrasts were pre-thresholded using a binary mask consisting of all regions exhibiting greater activation for any type of photograph > fixation in order to restrict whole-brain findings to regions of significant task-related activity.

Goal 3: Differences in Neural Responses to Risky Images as a Function of Real-World Risk-Taking. Composite scores on the CARE-R ranged from 0.9 - 3.7 in our participants (with higher scores indicating more past experiences with alcohol, drugs, and sexual risk-taking, as well as ratings of these activities as more beneficial and less risky). Composite scores on the CARE-R were not significantly related to brain activity when participants viewed their own photographs with Many vs. Few Likes or others' Neutral photographs with Many vs. Few Likes. However, when viewing Risky images with Many > Few Likes, high-school students with higher composite scores on the CARE-R showed greater activation in a region of the occipital cortex (MNI coordinates of maximum voxel, $x = -20$, $y = -74$, $z = 4$; Max $Z = 3.45$, 467 voxels). When comparing all Risky photographs to all Neutral photographs for all participants, those with higher CARE-R scores again showed significantly greater activation in visual areas (MNI coordinates of maximum voxel, $x = -6$, $y = -96$, $z = 0$; Max $Z = 3.78$, 598 voxels), as well as the precuneus/ posterior cingulate cortex (PCC; MNI coordinates of maximum voxel, $x = 8$, $y = -54$, $z = 12$; Max $Z = 3.14$, 321 voxels). For college students only, higher CARE-R scores were additionally associated with greater activation in the mPFC (mPFC; MNI coordinates of maximum voxel, $x = -8$, $y = 66$, $z = 4$; Max $Z = 3.70$, 672 voxels) and superior lateral occipital cortex (MNI coordinates of maximum voxel, $x = -28$, $y = -76$, $z = 50$; Max $Z = 3.45$, 304 voxels). Figure II-5 shows regions where higher CARE-R scores were associated with increased activation.

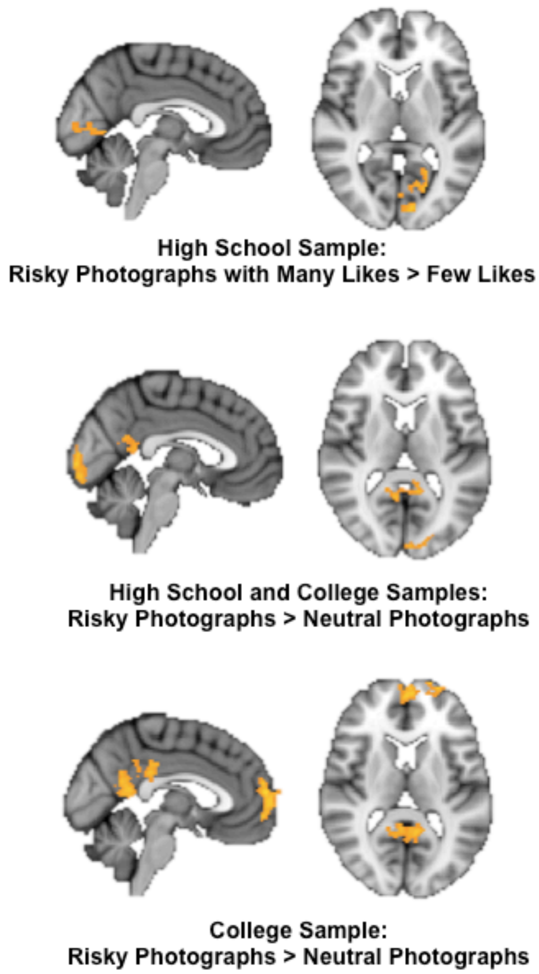

Figure II-5. Relation between neural responses to risky photographs and real-world risky behavior and appraisals. Higher scores on the Revised Cognitive Appraisal of Risky Events (CARE-R; Katz, Fromme, & D'amico, 2000) related to increases in neural responses in visual areas and brain areas implicated in social cognition (precuneus and medial prefrontal cortex). Higher scores on the CARE-R indicate more frequent use of drugs and alcohol and risky sexual activity, and/or appraisal of these behaviors as more beneficial and less risky. All images thresholded at $Z > 2.3$, with cluster correction to maintain $p < .05$.

Discussion

The first goal of the present study was to extend our prior findings from our sample of high-school social media users in a new, college-aged sample. As hypothesized, participants in both cohorts were more likely to Like photographs when they were popular, and this effect was especially strong for participants' own photographs. We also found that college students, like adolescents, showed significantly greater activation in the NAcc when viewing their own photographs that had received many Likes, as compared to few. Furthermore, as in our high-school sample, college participants showed significantly greater activity in multiple brain regions when viewing popular photographs, but no areas of greater activity when viewing unpopular photographs compared to popular. Indeed, for the popular > unpopular comparison, high-school and college participants differed significantly in only one brain region, for a single comparison: When viewing neutral images that were popular (vs. unpopular), high-school students demonstrated significantly greater activity than college students in visual areas, likely reflecting increased attention to images Liked by peers.

In addition to corroborating to our original findings, the observed agreement across the two samples for both brain and behavioral results suggests that Quantifiable Social Endorsement plays a significant role in influencing how young adults perceive and respond to information on social media. Particularly on mobile devices, which often feature a simplified user interface compared to computer-based social media, these Likes affect the way youth navigate their online social worlds. Our findings suggest that Quantifiable Social Endorsement is a mechanism of peer influence in a wider age-range than previously shown. These findings make intuitive sense given the continuing importance of the peer context in emerging adulthood (Arnett, 2000) and the popularity of mobile social media among college students (Perrin, 2015).

Our second and third study goals aimed to characterize developmental changes as well as individual differences in brain responses to social media. As hypothesized, we found that increased age was associated with greater NAcc response to having one's own content Liked by peers in the high school but not college sample. This finding is consistent with recent longitudinal work in adolescents demonstrating that NAcc sensitivity to rewarding stimuli increases in adolescence and peaks in early adulthood (Braams et al., 2015). Our findings indicate that social reward may progress along a similar trajectory as monetary reward. Additionally, our results are consistent with trends concerning the early adoption of social media tools. Throughout the history of social media, older adolescents have been among the first to flock to new media, and they tend to use the tools most frequently, compared to both older adults and younger teens (Lenhart et al., 2007; Madden et al., 2013). While adolescents generally are early adopters of new media, the tendency for older teens to be even more voracious users than younger teens may reflect not only their greater independence from parents, but also an increase in their motivation to seek approval online.

In addition to age differences in the strength of NAcc responsivity to social reward, we found that high school and college students demonstrated significantly different brain responses to Risky vs. Neutral images. Unlike high school students, college students did not show a decrease in activity in the dmPFC and lPFC, two hubs of the Central Executive Network, implicated in response inhibition and cognitive control (e.g., Seeley et. al., 2007; Sherman et. al., 2014). In other words, high-school but not college students showed a down-regulation of frontal cognitive control regions when viewing images of risky behaviors. This difference could reflect continued maturation of the frontal cortex into early adulthood (Giedd et al., 1999; Paus, 2005). Our findings are also consistent with the Dual Systems theory of adolescent risk-taking

(Shulman et al., 2016), which posits that in adolescence, frontal control regions are insufficient to inhibit responses to affective, and often risky stimuli. It is important to note, however, that even though college students did not demonstrate a down-regulation of cognitive control regions while viewing risky photographs, they also reported higher overall risk-taking than high-school students. This heightened risk-taking is not surprising: it is reasonable to assume that social environment factors (e.g., living away from home, prevalence of friends' risky behaviors) can largely explain the difference in our high-school and college students' risk-taking behaviors. However, our findings highlight the importance of considering the relation between neural and behavioral responses within the greater context of the sociocultural environment, particularly in instances where two distinct developmental cohorts are being compared.

Notably, we found that individual differences in neural activation in response to risky photographs were related to differences in participants' risky behaviors and risk appraisal. Specifically, increased scores on our risk-taking measure were related to increased activity in the precuneus/PCC. Furthermore, for college students, increased risk scores were also related to activity in the mPFC. These two regions are robustly associated with social cognition (see for example, Mars et al., 2012; Zaki & Ochsner, 2009, as well as the map for 'social' on Neurosynth, accessed February 2016 at http://neurosynth.org; Yarkoni et al., 2011). Our results are in concert with Saxbe and colleagues' (2015) findings that, during a task in which adolescents rated peers' emotions from video, activation in the precuneus, PCC, and mPFC was found to correlate with adolescents' reported risk-taking and their affiliation with risky peers. Perhaps for individuals who engage in greater risk-taking in real life, or who tend to appraise dangerous behaviors more positively, photographs depicting those behaviors feel more relevant to their experiences and social activities. We also found that, for high-school students only, greater activation in visual areas when viewing popular (vs. unpopular) risky images related to higher risk scores on the CARE-R. In both cohorts, we generally found that viewing popular (vs. unpopular) images recruited greater activity in visual areas (even though each stimulus was presented as popular and unpopular equally often); we interpret this finding as meaning that participants may pay increased attention to these photographs when they are believed to be popular. Similarly, in the high-school sample, individuals who reported greater experience with and more positive appraisal of risk may have been especially likely to attend carefully to popular risky images. These reported findings of individual differences are only a first step; it will be important for future research to further examine the relation between neural responses in the social brain and real-world risk-taking behavior. Furthermore, longitudinal research will be necessary to determine whether neural responses to risky images posted online have predictive power. For researchers broadly interested in neural predictors of risk-taking behaviors, we suggest that a social media paradigm like the one used in the current study be considered in addition to more classic risk-taking paradigms in developmental cognitive neuroscience, as the present paradigm is high in ecological validity.

While risky behaviors like smoking and drinking do not *occur* on social media, social media tools offer an opportunity for adolescents and young adults to socialize one another to norms relating to these activities. With the increasing popularity and availability of mobile social media, youth are more able to document and post risky behaviors in the moment. Youth not only see images depicting risk-taking behavior online; they also learn how their peers feel about these behaviors. As we have shown, peer endorsement significantly affects their perception of these photos and subsequent behavior on social media.

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IV. General Discussion

Social media have become a pervasive aspect of adolescents' lives and relationships, and the intricacies of youths' social relationships are increasingly enacted online. Despite ongoing interest in the effects of digital media on adolescents' social cognition, no previous work has, to my knowledge, directly investigated the neural correlates of social media use. I utilized a novel paradigm to mimic social media use in the confines of an MRI scanner, thereby using an ecologically valid approach to shed light on the neural correlates of adolescent decision-making in the context of peers. These findings have implications both for researchers interested in the consequences of adolescent social media use, as well as for researchers studying developmental cognitive neuroscience.

Significance and Contributions.

Implications for understanding adolescent social media use. Across a variety of social media, including chat rooms (Cohen & Prinstein, 2006; Freeman et al., 2011), Facebook (Huang et. al., 2014), and mobile apps like Instagram and Snapchat (Boyle et al., 2016), researchers have documented the role of social media in influencing adolescents' perception of risky activities and their tendency to engage in these activities. Certainly, it is unsurprising that the Internet, which has become an essential part of the social fabric of adolescents' lives, is a platform in which peer pressure - a normative feature of this developmental period - can and does occur. While the existing body of research has highlighted the importance of considering mediated communication as a factor in adolescent risk-taking, little attention has previously been paid to the role of features unique to online environments. On Instagram, and on many other social media platforms, quantifiable endorsement appears part and parcel of the content itself. Furthermore, this endorsement from peers is available permanently or semi-permanently to one's entire network. In this dissertation, I have shown that Quantifiable Social Endorsement does affect not only the way that adolescents respond to information online, but also the way in which they actually perceive this information. Furthermore, findings at both the neural and behavioral level suggested that Quantifiable Social Endorsement had a stronger effect when participants interacted with their own photographs. These stronger effects are in line with evidence considerable amount of time on social media is spent sharing information about the self (e.g., Naaman, Boase, & Lai, 2010), and that self-image in adolescence is particularly tied to the opinions of peers (e.g., Harter, 1999). However, an important caveat is that I have compared participants' own social media content to that of strangers, whereas adolescents typically interact with their existing friends online (see Future Directions, below).

While high Quantifiable Social Endorsement leads to increases in activity throughout the whole brain, findings in the NAcc were especially interesting, as they suggest a mechanism for the overwhelming popularity of social media, especially in adolescence. The notion that online social feedback leads to a "dopamine rush" or the "stimulation of reward centers" is one that has permeated the popular press for years (e.g. Dokoupil, 2012; Weinschenk, 2012), often presented with the implication that this neural response is threatening or worrisome. However, to my knowledge, the question has not been tested empirically until now. Here, I have shown in two independent samples of social media users that receiving Likes activates the NAcc, typically considered a "reward center," as well as other regions implicated in reward circuitry such as the ventral tegmental area and the orbitofrontal cortex.

These findings in reward circuitry do *not* imply that regular social media use is akin to addiction, or that Likes have the same effect on the brain as a dose of cocaine. Rather, a vast literature characterizes the role of reward circuitry in a variety of normative social and learning domains (e.g., Bartels & Zeki, 2003; Knutson & Cooper, 2005; O'Doherty, Deichmann, Critchley, & Dolan, 2002), and indeed, the peer context itself has been shown to activate reward circuitry (Chein, et. al., 2011). Nonetheless, it is certainly the case that the mesocorticolimbic dopamine system has been robustly linked to addictive behaviors (for a review, see Volkow, Wang, Fowler, & Tomasi, 2012), and it is reasonable to expect that unhealthy patterns of Internet use may be subserved by atypical responsivity in this system. Ongoing research on the neural underpinnings of social media use will allow us to more precisely characterize typical and atypical responses. It is paramount that we as researchers take a nuanced approach to the study of social media's effect on reward circuitry, in order to identify the neural bases of addiction while avoiding gross categorizations of all social media users as addicts.

Implications for developmental cognitive neuroscience models of adolescent risk-taking. Affective circuitry is one of two systems implicated in current popular models of adolescent decision-making, including the Imbalance model (Casey et al., 2016) and the Dual Systems model (Shulman et al., 2016). These models are not synonymous; the Dual Systems model focuses largely on orthogonal development of two systems, whereas the Imbalance model takes posits a circuit-based, interactive development of these systems. However, both models posit that the development of neural regions subserving affective responses (including reward circuitry) and those involved in cognitive control (e.g. the bilateral and dorsomedial prefrontal cortices) mature at a rate inconsistent with one another, and that these differences contribute to a tendency for adolescents to make riskier decisions, especially in highly emotional contexts. Broadly, my findings are in line with these theories: I found that the NAcc was not only more responsive in the presence of many Likes, which highlights the peer context, but also that NAcc response to peer feedback increased into late adolescence, in line with the hypothesized developmental trajectory of the affective processing system. I also found evidence for developmental differences in the response of the cognitive control system to risky and highly affective stimuli; high-school aged but not college-aged students showed a significant decrease in the response of the cognitive control network when viewing these stimuli. Nonetheless, some of my results suggest that existing models of adolescent decision-making are not sufficient to completely explain individual differences in tendency to engage in risk-taking. For example, college students reported engaging in more risky behavior than high school students, even though their neural responses suggested greater cognitive control while viewing risky images. This result points to the continued importance of the broader environmental context: studying brain function gives us important insight into adolescent decision-making, but often environmental factors will be the best predictors of one's individual risk. Researchers can address the contributions of both the environment and the brain by collecting relevant demographic data and utilizing statistical approaches that account for multiple predictors and their interactions, such as nested models.

Neural models of adolescent decision-making would have also predicted that individual differences in risk-taking behavior be linked to individual differences in the responsivity of regions implicated in cognitive control or reward/affective processing (e.g. Galvan et al., 2007; Van Leijenhorst et al., 2010). Rather, my individual difference findings implicated areas associated with social cognition and visual attention. The relation between risk-taking and the "social brain" has also been documented in another recent publication (Saxbe et al., 2015). The recruitment of social and visual cortex may be explained by the choice of task: both Saxbe and colleagues' work and my experiment utilized social cognitive paradigms with complex visual stimuli. However, Van Leijenhorst and colleagues (2010) also found that risky gambling behavior was positively associated with responsivity in the precunueus/PCC (a hub of the "social brain”) in a nonsocial gambling task. Furthermore, the social media paradigm that I utilized was a decision-making task and a reward task, and yet I did not find that response in regions typically implicated in models of adolescent decision-making (e.g., the NAcc and LPFC) predicted risk-taking. One explanation for these disparate findings is the relatively small sample sized used in most fMRI studies; even a sample size of 50 participants has only power of .66 to detect an effect of .5 at $p < .001$ (Yarkoni, 2009). It’s not altogether surprising, therefore, that correlations might reach significance in some samples but not others.

However, another possibility is that the neural differences that robustly predict behavior are simply *not* localized. Rather, “riskier” individuals may exhibit global or circuit-based brain differences. Functional and effective connectivity approaches could shed light on this possibility (see Future Directions, below), as could graph theoretic approaches, or other forms of functional neuroimaging that directly quantify cerebral blood flow (such as arterial spin labeling). If brain-behavioral correlations are localized to some extent, my findings and others’ (Van Leijenhorst et al., 2010; Saxbe et al., 2015) suggest that the posterior cingulate cortex/precuneus in particular should be considered a region of interest in addition to the NAcc, dmPFC, and LPFC. Similarly, complex paradigms that incorporate rich social stimuli, like those featured in this dissertation and the work of Saxbe and colleagues, may yield additional insight into the contribution of multiple neural regions in predicting individual predilection to engage in risky activities.

Future Directions

Studying peer influence on social media with familiar peers. In the present studies, I examined the effects of Quantifiable Social Endorsement delivered by unfamiliar peers. However, adolescents and young adults typically use social media to communicate primarily with friends and other existing connections (Subrahmanyam, et al., 2008; Valkenburg & Peter, 2007). In the future, I hope to import adolescents' actual online networks in the fMRI environment. The findings presented here suggest that even feedback from strangers significantly affects youths' neural and behavioral responses, but I hypothesize that these effects will be even stronger for known peers. Furthermore, as noted above, this dissertation compared adolescents' responses to a) feedback on their own photographs and b) feedback on strangers' photographs. A more valid approach would be to compare participants' responses to a) feedback on their own photograph and b) feedback on friends' photographs. Currently, I cannot disentangle the familiarity of participants' photographs (or the people and content depicted therein) from participants' feelings of ownership towards those photographs.

Interestingly, while positive feedback (i.e., receiving many Likes) elicited a broad pattern of brain activity in regions implicated in reward processing, social cognition, and visual attention, receiving few Likes did not in itself lead to significantly greater activity anywhere in the brain. It is possible, however, that while participants were excited to receive endorsement from strangers, they were not upset or concerned about a lack of endorsement from strangers. Anecdotal evidence from interviews with adolescents (e.g. Glass, 2015) suggests that some youth are indeed distressed if their Instagram photographs do not receive positive feedback. By tapping into adolescents' real-world networks in future research, I hope to explore the effects of both positive and negative (or lack of positive) feedback.

Connectivity approaches to the neural correlates of social media use. For the studies presented here, I utilized a classic parametric approach to investigate areas of the brain that were more active in one experimental condition than another. This approach yielded evidence that the same brain regions that have been implicated in past research on adolescent risk-taking (e.g. NAcc, dorsolateral prefrontal cortex) are also involved in a social media context. However, these findings do not allow me to draw conclusions about the interaction between multiple neural regions during social media use. The field of developmental cognitive neuroscience is moving increasingly towards more sophisticated models of adolescent risk-taking that employ an explicitly circuit-based perspective. For example, Casey, Getz, and Somerville (2016) recently called for a shift away from region-based or node-based approaches to the study of brain development and instead encourage viewing brain development through a circuit lens, particularly when it comes to the interaction of regions involved in affect and motivation and those involved in cognitive control. With this outlook in mind, I am eager to utilize connectivity approaches to examine the interaction of multiple brain regions during social media use. In particular, I plan to analyze the data presented here using tools such as psychophysiological interaction, a method for investigating coupling of activity in multiple brain regions in relation to a particular task or condition. To look at the directionality of neural effects, I further plan to use dynamic causal modeling (DCM), a method for assessing not only the connectedness of multiple brain regions, but also the direction of these effects. DCM involves using fMRI data to test competing models of the interaction between activity in distinct neural regions during a particular task. Using these approaches, I hope to contribute to an increasingly sophisticated understanding of cognitive development in late adolescence and early adulthood.

Broad Future Directions. Given trends over the past two decades, social media are not likely to disappear any time soon; however, the nature of these mediated interaction continues to change. When I began my doctoral studies in 2010, Facebook had not even released its mobile platform; today, many adolescents access social media primarily from their mobile devices. Similarly, tools that primarily utilize visual or audiovisual media, such as Instagram, Vine, and Snapchat, have become more and more popular. More recently, social media have trended towards ephemerality -- platforms like Snapchat and Periscope operate on the premise that users' content is only available for 24 hours, or can only be viewed a single time. Both the increasing use of audiovisual media and the ephemerality of interactions make social media, intriguingly, more like in-person interaction. This dissertation, and my research more generally, have examined aspects of social media that are unique and differ from in-person interaction. In the future, I look forward to continuing to probe the effects of unique features of digital communication - though it appears that these differences may become more subtle as time goes on.

Conclusions

Adolescence is a developmental period characterized by great sensitivity to the peer context; this change contributes to both an increase in susceptibility to peer pressure as well as a keen interest in social media. I showed that peer influence occurs on social media in ways that are both subtle and unique to online environments. My findings provide some support for existing theories of adolescent brain development, while also highlighting the complexities of the relation between brain response and real-world behavior. These findings are also an important first step in identifying the neural mechanisms underlying the popularity of social media in adolescence and early adulthood.

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