CHILD DEVELOPMENT

Child Development, January/February 2018, Volume 89, Number 1, Pages 37–47

The title for this Special Section is **Contemporary Mobile Technology and Child and Adolescent Development**, edited by Zheng Yan and Lennart Hardell

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

Lauren E. Sherman
Temple University

Patricia M. Greenfield, Leanna M. Hernandez, and Mirella Dapretto
University of California, Los Angeles

Mobile social media often feature the ability to "Like" content posted by others. This study examined the effect of Likes on youths' neural and behavioral responses to photographs. High school and college students (N = 61, ages 13–21) viewed theirs and others' Instagram photographs while undergoing functional Magnetic Resonance Imaging (fMRI). Participants more often Liked photographs that appeared to have received many (vs. few) Likes. Popular photographs elicited greater activity in multiple brain regions, including the nucleus accumbens (NAcc), a hub of the brain's reward circuitry. NAcc responsivity increased with age for high school but not college students. When viewing images depicting risk-taking (vs. nonrisky photographs), high school students, but not college students, showed decreased activation of neural regions implicated in cognitive control.

Since the advent of early social networking sites, 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 (Reich, Subrahmanyam, & Espinoza, 2012). Furthermore, many offline social and emotional processes typical of adolescence are also enacted on social media, including peer influence (e.g., Cohen & Prinstein, 2006). Recently, we (Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016) investigated how the quantifiable nature of certain digital interactions might play into adolescent peer influence at the behavioral and neural level. In the current study, we expand upon these findings by examining possible developmental differences between adolescents and young adults.

Although peers can influence one another to positive or negative behaviors, much of the extant literature has focused on peer influence in the context of risky behaviors, a pressing public health concern. The teen years are a time of heightened risktaking relative to childhood (e.g., Steinberg, 2008). However, certain risky behaviors such as binge drinking actually peak during the college years (Esser, 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 (e.g., Willoughby, Good, Adachi, Hamza, & Tavernier, 2013). Nonetheless, the neural

This research was supported, in part, by grants C06-RR012169 and C06-RR015431 from the National Center for Research Resources, by grant S10-OD011939 from the Office of the Director of the National Institutes of Health (NIH), by a National Institute on Drug Abuse National Research Service Award F31-DA038578-01A1 (to Lauren E. Sherman), and by the Brain Mapping Medical Research Organization, Brain Mapping Support Foundation, Pierson- Lovelace Foundation, The Ahmanson Foundation, Capital Group Companies Charitable Foundation, William M. and Linda R. Dietel Philanthropic Fund, and Northstar Fund. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Correspondence concerning this article should be addressed to Lauren E. Sherman, Department of Psychology, Temple University, 1701 N. 13th Street, Weiss Hall, Rm. 714, Philadelphia, PA 19122. Electronic mail may be sent to lauren.sherman@temple.edu.

 0009-3920/2018/8901-0004
DOI: 10.1111/cdev.12838

systems hypothesized to underlie decision making in adolescence do mature considerably during the late teens and early 20s. Executive functions improve throughout this period, likely as a result of pruning and myelination in the frontal and parietal lobes (Luciana, 2013; 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. In particular, the extant literature has demonstrated that the nucleus accumbens (NAcc) shows greater responsivity to monetary reward during the second decade of life, peaking in mid-to-late adolescence (e.g., Braams, van Duijvenvoorde, Peper, & Crone, 2015; Galvan et al., 2006). The increased sensitivity of the NAcc and other subcortical structures in adolescence is thought to be triggered by puberty, but the exact mechanisms are unknown (van Duijvenvoorde, Peters, Braams, & Crone, 2017). The NAcc can be considered a hub of the brain's reward circuitry: it is involved in the subjective experience of reward and pleasure (Berridge & Kringelbach, 2013), including social rewards (e.g., Fareri & Delgado, 2014; Izuma, Saito, & Sadato, 2008), and in motivating goal-directed behavior (Ikemoto & Panksepp, 1999). The NAcc is also involved in the implicit learning of culturally specific cues (Schaefer & Rotte, 2007) and has been implicated in behaviors common in social media environments (Meshi, Tamir, & Heekeren, 2015), such as sharing information (Tamir & Mitchell, 2012) and receiving positive feedback (e.g., Davey, Allen, Harrison, Dwyer, & Yücel, 2010). Further, the level of NAcc response to positive social feedback has been linked to intensity of social media use (Meshi, Morawetz, & Heekeren, 2013).

Indeed, social media easily afford the learning of social norms, as they involve simple, fast, quantifiable measures of peer endorsement (e.g., Likes). Likes provide an opportunity for social proof (Cialdini, 2009), or the use of social comparison with peers to determine appropriate social behavior, but they are unique in that interactions that were previously qualitative are now primarily or exclusively quantitative. Previously, we dubbed Likes and similar features "Quantifiable Social Endorsement (QSE)" (Sherman et al., 2016) and demonstrated that the level of QSE on Instagram photos—that is, the popularity of photographs posted online—affected both behavioral and neural responses to those images. Adolescents were more likely to Like photographs they believed to be popular, and neural responses differed as a function of popularity. 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, and given that resistance to peer influence is found to be higher in the college years than in the earlier teen years (e.g., Steinberg & Monahan, 2007), we tested if neural responses to social media increased throughout adolescence before tapering off or perhaps decreasing in a cohort of young adults. We also investigated how responses to images of risk-taking behavior (e.g., alcohol and drug use) posted online might be different in older, more independent college students. Finally, we were eager to test if our original findings replicated in a new sample. As with our original study, we investigated the role of Likes at both the behavioral and neural level. This approach reflected our desire to understand (a) measurable behavioral outcomes of peer influence on social media and (b) neural processes potentially underlying these effects. We, thus, had several overarching goals for this study:

1. *Replicate prior behavioral and neural findings 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 more likely to Like popular than unpopular Instagram photos. We also hypothesized that college students' neural responses would differ as a function of photo popularity and, in particular, that receiving many (vs. few) Likes on one's own photographs would elicit significant activation in the NAcc.
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.* First, we hypothesized that NAcc activation in response to social reward (i.e., receiving many Likes on one's own photographs) would increase with age in our high school sample, just as NAcc response to monetary reward increases in adolescence (Braams et al., 2015) but that NAcc response would not continue to increase in a college cohort. Second, we previously reported that high school students showed significantly less activation of neural regions considered hubs of the central executive network (CEN) when viewing risky images compared with neutral images

(Sherman et al., 2016), including parts of the dorsomedial prefrontal cortex (dmPFC), lateral prefrontal cortex, and posterior parietal cortex. Given the maturation of executive function in early adulthood, we did not expect that this decreased activation to risky photographs would occur in our college sample; in other words, we expected high school students to show significantly less activation in regions implicated in executive function than college students.

3. *Explore individual differences in neural activity as a function of health-related risky behavior.* Previous research has linked neural responses during a variety of fMRI paradigms to adolescents' tendency to engage in real-world risky behaviors like drinking and smoking. We tested whether neural responses would similarly vary in response to photographs depicting risky behavior. Previous research on adolescent risk-taking has implicated a variety of regions including the NAcc (Galvan, Hare, Voss, Glover, & Casey, 2007), ventromedial prefrontal cortex (Van Leijenhorst et al., 2010) and posterior cingulate cortex (PCC; Saxbe, Del Piero, Immordino-Yang, Kaplan, & Margolin, 2015). Given the distributed nature of previous findings, we used a bottom-up approach for this analysis.

Method

Participants

An adolescent sample of 34 high school students (M_{age} = 16.8, SD_{age} = 1.4, 18 female) was recruited from the Los Angeles community through flyers and message board postings. A young adult sample of 27 university students (M_{age} = 19.9, SD_{age} = 1.1, 17 female) was recruited through flyers posted on campus. Of these participants, two high school and one college participant were excluded from fMRI data analysis due to scanner malfunction or excessive movement. Participants had not been diagnosed with any developmental, psychiatric, or neurological disorder. College participants were all enrolled in the same 4-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 also had entered a qualitatively different developmental stage. Given the unique experiences of emerging adulthood (Arnett, 2000), as well as evidence suggesting that some neural changes may be attributable specifically to higher education (e.g., Bennett & Baird, 2006; Noble, Korgaonkar, Grieve, & Brickman, 2013), we performed all fMRI analyses, including examining age-related trends, separately in our high school and college samples. All participants gave written consent (or, for individuals under 18, written assent and parental consent) and were fully debriefed and compensated monetarily following study procedures. All procedures were approved by the Institutional Review Board of the University of California, Los Angeles.

Procedure

Data were collected between July 2013 and December 2014. Before the MRI scan, participants were asked to submit photographs from their own accounts on the popular photo-sharing app Instagram. They 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 order to establish the size of the "audience," participants were instructed that approximately 50 other individuals had already participated in the study. In reality, participants did not see one another's photographs in the scanner. Rather, they saw their own photographs, as well as a standardized set of photographs selected by the study team from publicly available images on Instagram. They were told that they could see how many "Likes" each photograph had received from other participants. In reality, the number of Likes was manipulated by the study team, as described below.

In the scanner, participants viewed each photograph for 3 s, with the number of Likes ostensibly provided by peers displayed underneath (Figure 1). Participants saw three categories of images. "Risky" photographs depicted alcohol and partying behaviors, smoking paraphernalia, rude gestures, or other 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, and possessions; Hu, Manikonda, & Kambhampati, 2014). Neutral and risky images did not differ in the overall proportion featuring people versus objects only (χ^2 = 0.002, p = .999). Each participant also saw a selection of images he or she had submitted from his/her own Instagram account. 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 and an "unpopular" value. Two versions of the imaging paradigm were created: In Version 1, 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 2, the values were reversed. Similarly, half of each participant's own photographs were assigned many Likes (23–45), and the other half assigned few Likes (0–22). Participants were asked to view the photographs and decide whether to Like each image. Participants could select either Like or Next by pressing buttons on a handheld button box.

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' appraisal of the risks and benefits associated with risky drinking, drug use, and sexual behavior. "Past Experiences" assesses the frequency with which participants engaged in these behaviors in the past 6 months.

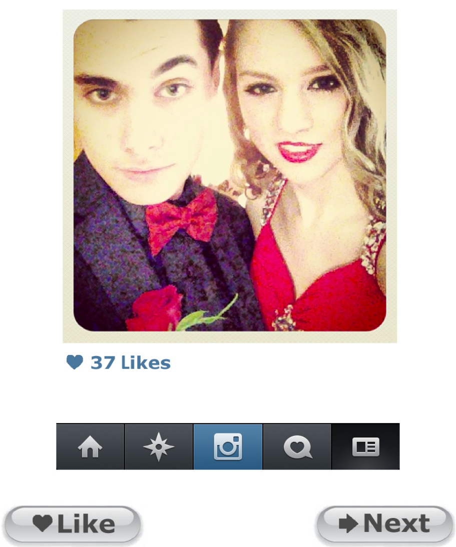

Figure 1. Example of a photograph presented during the Instagram experiment. Participants viewed a series of photographs while in the MRI scanner, depicted in a simplified version of the Instagram user interface (as of 2014). Under each photograph was a blue heart, as well as the number of "Likes" ostensibly 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.

Data Analysis

Behavioral data were analyzed in Stata version 14.1 (StatCorp. 2015. College Station, TX: StatCorp LP.) using a mixed-effects logistic regression (Stata's "melogit" function). Button-press choice for each trial (i.e., selecting Like or Next on each image) was modeled as the binary outcome variable and participant was modeled as a random effect, to determine if participants' likelihood to Like images was predicted by three categorical variables—the popularity of the image (popular, unpopular), the image content (neutral, risky, participant's own), the sample (high school, college)—and all possible interactions.

To test our a priori hypothesis that viewing popular photographs would elicit greater activation in the bilateral NAcc than unpopular photographs, and to compare NAcc findings between samples and across conditions, we used a region of interest (ROI) approach (see Method S1 for more details about the analytic pipeline, including the ROI analysis). We also tested whether NAcc response to receiving social approval (popular > unpopular for participant's own photographs) was correlated with age in our two samples and compared these correlation coefficients using a Fischer's r-to-z transformation. In addition to our ROI analyses, we used a bottom-up approach to investigate effects in other brain regions exhibiting significant task-related activity. Specifically, we modeled contrasts examining the effect of popularity (popular > unpopular and the reverse) for the three types of photograph, and contrasts comparing all neutral photographs to all risky photographs (Method S1).

To examine the relation between task-related neural activity and CARE–R scores, we performed a second bottom-up fMRI analysis with composite scores on the CARE–R modeled at the group level. This analysis involved 57 participants, because one high school participant did not complete the CARE–R. Because age and scores on the CARE–R were correlated (r = .32, p = .02), we included age as a control variable. More details about participant demographics, the fMRI paradigm, data acquisition, and data analysis are available in Method S1.

Results

Goal 1a: Replication of Behavioral Findings

We previously reported that high school participants were more likely to select Like for popular images and Next for unpopular images than expected by chance, as determined by a binomial test. This finding was significant for all three categories of photographs (Sherman et al., 2016). For the present inquiry, we utilized a statistical model that additionally allowed us to (a) model within-subject variability for each participant and (b) report the likelihood of a participant Liking an image given its popularity and type. The full model was significant (χ^2 = 1,437.20, p < .0001). High-school and college students 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 = .30), which suggests that our cohorts did not significantly differ in their tendency to Like popular versus unpopular images; we therefore report behavioral results for the two cohorts combined. Participants were significantly more likely to Like popular images than unpopular images (z = 7.28, p < .001). Although the effect of popularity 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), the effect of popularity was significant for all three types of photograph (all ps < .01). In other words, for each photograph type, participants more frequently "Liked" popular than unpopular photographs. Table 1 presents the probability of participants Liking a photograph, given its popularity and type; Table S1 presents all main and interactive effects, including effects not related to our hypotheses (e.g., main effect of photo type).

Table 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 1b: Replication of fMRI Results for Popularity Effect

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 with few (Sherman et al., 2016). 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, high school and college students did not significantly differ in activation in left or right NAcc for this comparison: left, $t(56)$ = 0.39, p = .70; right, $t(56)$ = 0.251, p = .80. Similarly, the cohorts did not differ in NAcc response when viewing popular (compared with unpopular) risky images, left, $t(56)$ = 1.91, p = .06; right, $t(56)$ = 0.96, p = .34, or neutral images, left, $t(56)$ = 0.97, p = .34; right, $t(56)$ = 0.14, p = .89. In the college cohort, viewing popular risky images was associated with significantly greater activation than unpopular risky images in the left NAcc, $t(25)$ = 2.78, p = .01, but this same comparison in the right NAcc did not reach significance, $t(25)$ = 1.50, p = .146. Viewing popular neutral images (compared with 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 S1 depicts results of the bottom-up analysis comparing popular with unpopular photographs for the three photo categories (neutral, risky, participant's own) in our college sample. When viewing photographs with many likes (popular) compared with few likes (unpopular), college students demonstrated significantly greater activation in several brain regions. The regions differed by photo type but included areas implicated in social cognition (e.g., precuneus, medial prefrontal cortex), reward (NAcc, caudate, orbitofrontal cortex), and visual attention (occipital cortex). College students showed no areas of significant activation when viewing photographs of any type for the opposite contrast (unpopular > popular). When directly comparing our college and high school samples in our bottom-up analysis, we only found a single contrast in which the two cohorts differed significantly in brain responses 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 (Montreal Neurological Institute coordinates of max voxel, x = 6, y = −72, z = 16; Max Z = 3.40, 526 voxels).

Goal 2a: Age Differences in NAcc Responsivity to Social Media

Figure 2 presents the results of the correlational analysis relating age to NAcc response when viewing one's own photographs with many likes compared with 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 correlation coefficients for college and high school students were significantly different in the left NAcc (Z = 2.1, p = .04) though not the right NAcc (Z = 1.27, p = .20).

Goal 2b: Cohort Differences in Neural Responses to Risky Versus Neutral Photographs

High school and college participants differed significantly in their neural responses to risky (compared with neutral) photographs. We previously reported that when high school students viewed risky images (vs. neutral images), they demonstrated significantly less activation in the dmPFC, lateral parietal cortices, and bilateral prefrontal cortices, as well as a portion of the visual cortex (Sherman et al., 2016). Notably, although the college student sample showed a similar decrease in activation in visual and right parietal cortices, we found no significant decreases in frontal areas (Figure 3). Indeed, significant differences between high school and college students were observed in dmPFC (MNI coordinates of max 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.

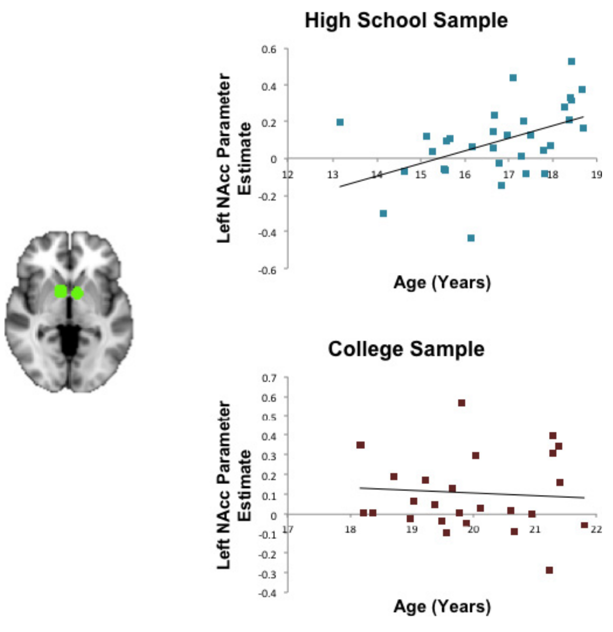

Figure 2. NAcc response to social reward and its relation to age. For participants in the high school cohort, NAcc response to the popular (many likes) > unpopular (few likes) contrast increased linearly with age (left NAcc: r = .47, p = .006). However, for participants in the college cohort, NAcc response was not associated with age (left NAcc: $r = -.07$, p = .72). Responses differed significantly for the high school and college samples in the left NAcc, depicted in the figure. Parameter estimates are reported in percent signal change, determined using an isolated 3-s event with a double-gamma HRF. The NAcc region of interest was selected from an independent sample of young adults completing a Monetary Incentive Delay task (Tamir & Mitchell, 2012).

Goal 3: Correlation Between fMRI Results and Risky Decision Making

Composite scores on the CARE–R ranged from 1.1 to 3.2 (M = 1.8) in our high school sample and 0.9 to 3.7 (M = 2.1) in our college sample, 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. Frequency and appraisal scores were highly correlated, $r(55)$ = .73, p < .001. Frequency scores for college students were higher than those of high school students, $t(55)$ = 2.1, p = .04, but appraisal scores were not significantly different, $t(55)$ = 1.2, p = .24. In our bottom-up correlational analyses with the CARE–R measures, no significant differences were observed between the college and high school groups; however, some significant correlations emerged for only one cohort. Composite CARE–R scores were not significantly related to brain activity when participants viewed their own photographs with many versus few likes or others' neutral photographs with many versus few likes. However, when viewing risky images with many > few likes, high school students with higher composite CARE–R scores showed greater activation in a region of the occipital cortex (MNI coordinates of max voxel, $x = -20$, $y = -74$, z = 4; Max Z = 3.45, 467 voxels; Figure S2, top row). 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 max voxel, $x = -6$, $y = -96$, z = 0; Max Z = 3.78, 598 voxels), as well as the precuneus/PCC (MNI coordinates of max voxel, x = 8, $y = -54$, z = 12; Max Z = 3.14, 321 voxels; Figure S2, middle row). For college students only, higher CARE–R scores were additionally associated with greater activation in the mPFC (MNI coordinates of max voxel, $x = -8$, y = 66, z = 4; Max Z = 3.70, 672 voxels) and superior lateral occipital cortex (MNI coordinates of max voxel, $x = -28$, $y = -76$, z = 50; Max Z = 3.45, 304 voxels; Figure S2, bottom row). We extracted parameter estimates for each of these regions and

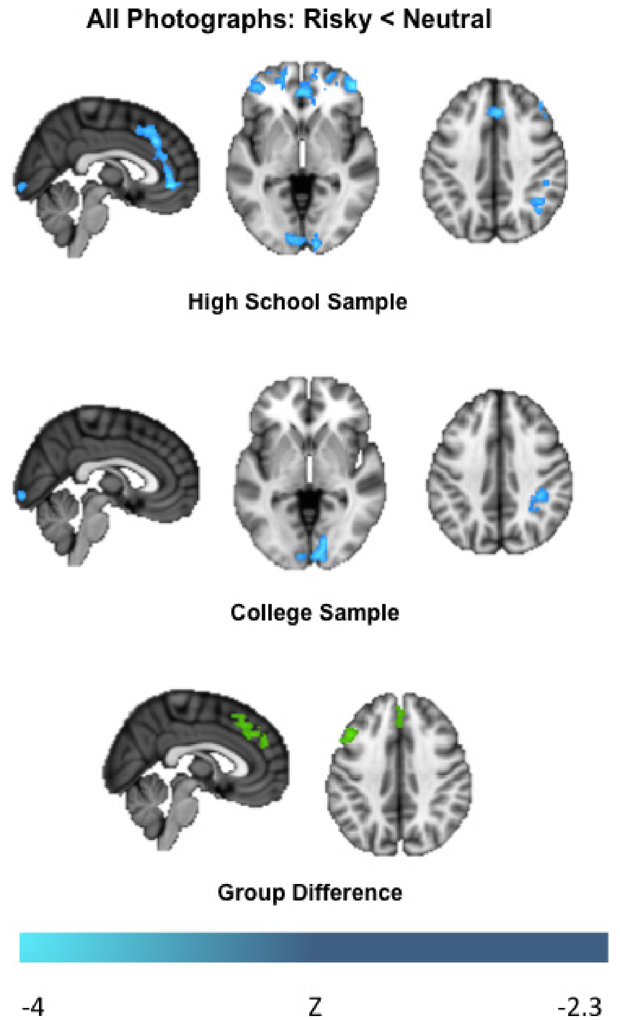

Figure 3. Differences in decreased activation for comparison of risky and neutral photographs. When viewing Instagram photographs depicting risk-taking activities, compared with photographs depicting nonrisky, neutral activities, only high school students showed a significant decrease in activity in frontal regions including the dorsomedial prefrontal cortex (dmPFC) and the dorsolateral prefrontal cortex (dlPFC). The high school and college samples differed significantly in the dmPFC and left dlPFC. All images thresholded at $Z > 2.3$, with cluster correction to maintain $p < .05$.

correlated them to appraisal scores and frequency scores separately on the CARE–R. In all cases, correlations with parameter estimates were higher for appraisal scores than frequency scores, but the correlation coefficients were not significantly different ($p > .05$ for all).

Discussion

The first goal of this study was to extend our prior findings from our sample of high school social media users (Sherman et al., 2016) in a new, college-aged sample. As hypothesized, participants in both cohorts were more likely to Like photographs when they were popular; this effect was especially strong for participants' own photographs. College students, like adolescents, showed significantly greater activation in the NAcc when viewing their own photographs that had received many likes, as compared with few, and showed significantly greater activity in multiple brain regions when viewing popular photographs; however, they showed no areas of greater activity when viewing unpopular photographs compared with popular photographs. Indeed, when comparing popular and unpopular photographs, 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.

In addition to corroborating to our original findings, the observed agreement across the two samples for both behavioral results and NAcc activation suggests that QSE plays a significant role in influencing how young adults perceive and respond to information on social media; in other words, QSE is a mechanism of peer influence, and a potential means by which individuals learn about their social environment, 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. Although the present inquiry used an Instagram-like interface, Likes are a feature of many social media, including Facebook and Twitter; thus, we expect that our findings would generalize to other digital platforms. QSE is not unique to mobile media use; indeed, Likes existed before smartphones were widely used by adolescents. However, all major social media tools are widely used on mobile phones, and Likes play an especially prominent role on Instagram, an tool initially designed for and primarily used on smartphones.

Although this study focused specifically on peer influence, it is possible that nonpeers (e.g., older adults and parents) might have a similar effect, in line with work suggesting overlapping mechanisms between peer and parental influence (Welborn et al., 2016, though see also Telzer, Ichien, & Qu, 2015, for an discussion of differential responses to parents and peers). Of note, we artificially assigned Likes in order to implement our experimental manipulation and to avoid possible image-specific confounds; however, this meant that participants saw the same average number of Likes on their photographs regardless of their own popularity. Given that visual attention is moderated by adolescents' status (e.g., Lansu, Cillessen, & Karremans, 2014), future research should consider how users' own popularity influences their behavioral and neural responses to popular and unpopular images.

Our second and third study goals aimed to characterize age differences 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 around age 16–17 (Braams et al., 2015). Our results indicate that social reward may progress along a similar trajectory as monetary reward. They are also 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 with older adults and younger teens (Lenhart, Madden, Smith, & Macgill, 2007; Madden, Lenhart, Duggan, Cortesi, & Gasser, 2013). Although 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 greater independence from parents but also increased 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 versus neutral images. Unlike high school students, college students did not show a decrease in activity in regions of the dmPFC and lPFC that overlap with the CEN (Sherman et al., 2014). The CEN is frequently activated during tasks involving executive function, including response inhibition and cognitive control, and metrics of CEN connectivity have been found to relate executive function and IQ in youth and adults (e.g., Li & Tian, 2014; Seeley et al., 2007). In other words, high school but not college students showed decreased activity in frontal cognitive control regions when viewing images of risky behaviors. This difference could reflect continued maturation of the frontal cortex into early adulthood (Luciana, 2013; Paus, 2005). Our findings are 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 should be noted that even though college students did not demonstrate decreased activation of regions implicated in cognitive control while viewing risky photographs, they did report higher overall risk taking. This heightened risk taking is not surprising: It is reasonable to assume that factors in their social environment (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 (for further discussion of these factors, see Willoughby et al., 2013). However, our findings highlight the importance of considering the relation between neural and behavioral responses within the larger context of the sociocultural environment, particularly in instances where two distinct developmental cohorts are being compared.

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 and (for college students) mPFC. Our results are in concert with Saxbe and colleagues' (2015) findings that, during a task in which adolescents rated peers' emotions from video, activity in the precuneus, PCC, and mPFC was correlated with adolescents' reported risk taking and their affiliation with risky peers. The precuneus/PCC and mPFC have been associated with social-cognition (e.g., Mars et al., 2012; Zaki & Ochsner, 2009) and self-reference (Northoff et al., 2006). 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 own selves and social activities (though this is only one of many possible interpretations; for example, the mPFC is also implicated in valuation and memory; e.g., Euston, Gruber, & McNaughton, 2012). 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, in the health domain and more generally. 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 health-risk behaviors, we suggest that a social media paradigm be considered in addition to more classic risk-taking paradigms because of the high ecological validity.

Although 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 photographs and subsequent behavior on social media.

References

Arnett, J. J. (2000). Emerging adulthood: A theory of development from the late teens through the twenties. *American Psychologist*, *55*, 469. http://psycnet.apa.org/doi/10.1037/0003-066x.55.5.469

Bennett, C. M., & Baird, A. A. (2006). Anatomical changes in the emerging adult brain: A voxel-based morphometry study. *Human Brain Mapping*, *27*, 766–777. https://doi.org/10.1002/hbm.20218

Berridge, K. C., & Kringelbach, M. L. (2013). Neuroscience of affect: Brain mechanisms of pleasure and displeasure. *Current Opinion in Neurobiology*, *23*, 294–303. https://doi.org/10.1016/j.conb.2013.01.017

Braams, B. R., van Duijvenvoorde, A. C., Peper, J. S., & Crone, E. A. (2015). Longitudinal changes in adolescent risk-taking: A comprehensive study of neural responses to rewards, pubertal development, and risk-taking behavior. *The Journal of Neuroscience*, *35*, 7226–7238. https://doi.org/10.1523/jneurosci.4764-14.2015

Cialdini, R. B. (2009). *Influence: Science and practice*. Boston, MA: Pearson Education.

Cohen, G. L., & Prinstein, M. J. (2006). Peer contagion of aggression and health risk behavior among adolescent males: An experimental investigation of effects on public conduct and private attitudes. *Child Development*, *77*, 967–983. https://doi.org/10.1111/j.1467-8624.2006.00913.x

Davey, C. G., Allen, N. B., Harrison, B. J., Dwyer, D. B., & Yücel, M. (2010). Being liked activates primary reward and midline self-related brain regions. *Human Brain Mapping*, *31*, 660–668. https://doi.org/10.1002/hbm.20895

Esser, M. B. (2014). Prevalence of alcohol dependence among US adult drinkers, 2009–2011. *Preventing Chronic Disease*, *11*, 1–11. https://doi.org/10.5888/pcd11.140329

Euston, D. R., Gruber, A. J., & McNaughton, B. L. (2012). The role of medial prefrontal cortex in memory and decision making. *Neuron*, *76*, 1057–1070. https://doi.org/10.1016/j.neuron.2012.12.002

Fareri, D. S., & Delgado, M. R. (2014). The importance of social rewards and social networks in the human brain. *The Neuroscientist*, *20*, 387–402. https://doi.org/10.1177/1073858414521869

Galvan, A., Hare, T. A., Parra, C. E., Penn, J., Voss, K., Glover, G., & Casey, B. J. (2006). Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. *The Journal of Neuroscience*, *26*, 6885–6892. https://doi.org/10.1523/jneurosci.1062-06.2006

Galvan, A., Hare, T., Voss, H., Glover, G., & Casey, B. J. (2007). Risk-taking and the adolescent brain: Who is at risk? *Developmental Science*, *10*, F8–F14. https://doi.org/10.1111/j.1467-7687.2006.00579.x

Hu, Y., Manikonda, L., & Kambhampati, S. (2014, June). What we Instagram: A first analysis of Instagram photo content and user types. *Proceedings of the 8th International Conference on Weblogs and Social Media*, Ann Arbor, MI.

Ikemoto, S., & Panksepp, J. (1999). The role of nucleus accumbens dopamine in motivated behavior: A unifying interpretation with special reference to reward-seeking. *Brain Research Reviews*, *31*, 6–41. https://doi.org/10.1016/s0165-0173(99)00023-5

Izuma, K., Saito, D. N., & Sadato, N. (2008). Processing of social and monetary rewards in the human striatum. *Neuron*, *58*, 284–294. https://doi.org/10.1016/j.neuron.2008.03.020

Katz, E., Fromme, K., & D'Amico, E. (2000). Effects of outcome expectancies and personality on young adults' illicit drug use, heavy drinking, and risky sexual behavior. *Cognitive Therapy and Research*, *24*, 1–22. https://doi.org/10.1023/a:1005460107337

Lansu, T. A., Cillessen, A. H., & Karremans, J. C. (2014). Adolescents' selective visual attention for high-status peers: The role of perceiver status and gender. *Child Development*, *85*, 421–428. https://doi.org/10.1111/cdev.12139

Lenhart, A. (2015). *Teens, social media & technology overview 2015*. Pew Internet and American Life Project. Retrieved from http://www.pewinternet.org/2007/12/19/teens-and-social-media/, Washington, DC.

Lenhart, A., Madden, M., Smith, A., & Macgill, A. (December 19, 2007). *Teens and social media*. Pew Internet & American Life Project, Retrieved from http://www.pewinternet.org/2007/12/19/teens-and-social-media/

Li, C., & Tian, L. (2014). Association between resting-state coactivation in the parieto-frontal network and intelligence during late childhood and adolescence. *American Journal of Neuroradiology*, *35*, 1150–1156. https://doi.org/10.3174/ajnr.a3850

Luciana, M. (2013). Adolescent brain development in normality and psychopathology. *Development and Psychopathology*, *25*, 1325–1345. https://doi.org/10.1017/s0954579413000643

Madden, M., Lenhart, A., Duggan, M., Cortesi, S., & Gasser, U. (2013). *Teens and technology, 2013*. Retrieved from http://www.pewinternet.org/Reports/2013/Teens-and-Tech/Summary-of-Findings.aspx

Mars, R. B., Neubert, F., Noonan, M. P., Sallet, J., Toni, I., & Rushworth, M. F. S. (2012). On the relationship between the "default mode network" and the "social brain." *Frontiers in Human Neuroscience*, *6*, 189. https://doi.org/10.3389/fnhum.2012.00189.

Meshi, D., Morawetz, C., & Heekeren, H. R. (2013). Nucleus accumbens response to gains in reputation for the self relative to gains for others predicts social media use. *Frontiers in Human Neuroscience*, *7*, 439.

Meshi, D., Tamir, D. I., & Heekeren, H. R. (2015). The emerging neuroscience of social media. *Trends in Cognitive Sciences*, *19*, 771–782. https://doi.org/10.1016/j.tics.2015.09.004

Noble, K. G., Korgaonkar, M. S., Grieve, S. M., & Brickman, A. M. (2013). Higher education is an age-independent predictor of white matter integrity and cognitive control in late adolescence. *Developmental Science*, *16*, 653–664. https://doi.org/10.1111/desc.12077

Northoff, G., Heinzel, A., De Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain—a meta-analysis of imaging studies on the self. *NeuroImage*, *31*, 440–457. https://doi.org/10.1016/j.neuroimage.2005.12.002

Paus, T. (2005). Mapping brain maturation and cognitive development during adolescence. *Trends in Cognitive Sciences*, *9*, 60–68. https://doi.org/10.1016/j.tics.2004.12.008

Reich, S. M., Subrahmanyam, K., & Espinoza, G. (2012). Friending, IMing, and hanging out face-to-face: Overlap in adolescents' online and offline social networks. *Developmental Psychology*, *48*, 356–368. https://doi.org/10.1037/a0026980

Saxbe, D., Del Piero, L., Immordino-Yang, M. H., Kaplan, J., & Margolin, G. (2015). Neural correlates of adolescents' viewing of parents' and peers' emotions: Associations with risk-taking behavior and risky peer affiliations. *Social Neuroscience*, *10*, 592–604. https://doi.org/10.1080/17470919.2015.1022216

Schaefer, M., & Rotte, M. (2007). Favorite brands as cultural objects modulate reward circuit. *NeuroReport*, *18*, 141–145. https://doi.org/10.1097/wnr.0b013e328010ac84

Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., . . . Greicius, M. D. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neuroscience*, *27*, 2349–2356. https://doi.org/10.1523/jneurosci.5587-06.2007

Sherman, L. E., Payton, A. A., Hernandez, L. M., Greenfield, P. M., & Dapretto, M. (2016). The power of the like in adolescence: Effects of peer influence on neural and behavioral responses to social media. *Psychological Science*, *27*, 1027–1035. https://doi.org/10.1177/0956797616645673

Sherman, L. E., Rudie, J. D., Pfeifer, J. H., Masten, C. L., McNealy, K., & Dapretto, M. (2014). Development of the default mode and central executive networks across early adolescence: A longitudinal study. *Developmental Cognitive Neuroscience*, *10*, 148–159. https://doi.org/10.1016/j.dcn.2014.08.002

Shulman, E. P., Smith, A. R., Silva, K., Icenogle, G., Duell, N., Chein, J., & Steinberg, L. (2016). The dual systems model: Review, reappraisal, and reaffirmation. *Developmental Cognitive Neuroscience*, *17*, 103–117. https://doi.org/10.1016/j.dcn.2015.12.010

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review*, *28*, 78–106.

Steinberg, L., & Monahan, K. C. (2007). Age differences in resistance to peer influence. *Developmental Psychology*, *43*, 1531–1543. https://doi.org/10.1016/j.dr.2007.08.002

Tamir, D. I., & Mitchell, J. P. (2012). Disclosing information about the self is intrinsically rewarding. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 8038–8043. https://doi.org/10.1073/pnas.1202129109

Telzer, E. H., Ichien, N. T., & Qu, Y. (2015). Mothers know best: Redirecting adolescent reward sensitivity toward safe behavior during risk taking. *Social Cognitive and Affective Neuroscience*, *10*, 1383–1391. https://doi.org/10.1093/scan/nsv026

van Duijvenvoorde, A. C., Peters, S., Braams, B. R., & Crone, E. A. (2016). What motivates adolescents? Neural responses to rewards and their influence on adolescents' risk taking, learning, and cognitive control. *Neuroscience & Biobehavioral Reviews*, *70*, 135–147.

Van Leijenhorst, L., Moor, B. G., de Macks, Z. A. O., Rombouts, S. A., Westenberg, P. M., & Crone, E. A. (2010). Adolescent risky decision-making: Neurocognitive development of reward and control regions. *NeuroImage*, *51*, 345–355. https://doi.org/10.1016/j.neuroimage.2010.02.038

Welborn, B. L., Lieberman, M. D., Goldenberg, D., Fuligni, A. J., Galván, A., & Telzer, E. H. (2016). Neural mechanisms of social influence in adolescence. *Social Cognitive and Affective Neuroscience*, *11*, 100–109. https://doi.org/10.1093/scan/nsv095

Willoughby, T., Good, M., Adachi, P. J., Hamza, C., & Tavernier, R. (2013). Examining the link between adolescent brain development and risk taking from a social–developmental perspective. *Brain and Cognition*, *83*, 315–323. https://doi.org/10.1016/j.bandc.2013.09.008

Zaki, J., & Ochsner, K. (2009). The need for a cognitive neuroscience of naturalistic social cognition. *Annals of the New York Academy of Sciences*, *1167*(1), 16–30. https://doi.org/10.1111/j.1749-6632.2009.04601.x.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Figure S1. College Students' Neural Responses to Photographs as a Function of the Perceived Popularity of the Photograph

Figure S2. Correlation Between Neural Responses to Risky Photographs and Real-World Risky Behavior and Appraisals

Table S1. Summary of Mixed-Effects Binary Logistic Regression

Table S2. Peak Coordinates of Activation for Regions Obtained From the Random-Effects Contrasts of Popular > Unpopular for Neutral, Risky, and Participants' Own Images for College Student Sample

Table S3. Peak Coordinates of Activation for Regions Obtained From the Random-Effects Contrasts of Risky Images > Neutral Images and Risky Images < Neutral Images for College Student Sample

Method S1. Supplementary Methods