Association of Habitual Checking Behaviors on Social Media With Longitudinal Functional Brain Development

Maria T. Maza, BS; Kara A. Fox, MA; Seh-Joo Kwon, BS; Jessica E. Flannery, PhD; Kristen A. Lindquist, PhD; Mitchell J. Prinstein, PhD; Eva H. Telzer, PhD

IMPORTANCE Social media platforms provide adolescents with unprecedented opportunities for social interactions during a critical developmental period when the brain is especially sensitive to social feedback.

OBJECTIVE To explore how adolescents' frequency of checking behaviors on social media platforms is associated with longitudinal changes in functional brain development across adolescence.

DESIGN, SETTING, AND PARTICIPANTS A 3-year longitudinal cohort study of functional magnetic resonance imaging (fMRI) among sixth- and seventh-grade students recruited from 3 public middle schools in rural North Carolina.

EXPOSURES At wave 1, participants reported the frequency at which they checked Facebook, Instagram, and Snapchat.

MAIN OUTCOME OR MEASURE Neural response to the Social Incentive Delay task when anticipating receiving social feedback, measured annually using fMRI for 3 years. Participants saw a cue that indicated whether the social feedback (adolescent faces with emotional expressions) would be a reward, punishment, or neutral; after a delay, a target appeared and students responded by pressing a button as quickly as possible; a display of social feedback depended on trial type and reaction time.

RESULTS Of 178 participants recruited at age 12 years, 169 participants (mean [SD] age, 12.89 [0.58] years; range, 11.93-14.52 years; 91 [53.8%] female; 38 [22.5%] Black, 60 [35.5%] Latinx, 50 [29.6%] White, 15 [8.9%] multiracial) met the inclusion criteria. Participants with habitual social media checking behaviors showed lower neural sensitivity to social anticipation at age 12 years compared with those with nonhabitual checking behaviors in the left amygdala, posterior insula (PI), and ventral striatum (VS; β, −0.22; 95% CI, −0.33 to −0.11), right amygdala (β, −0.19; 95% CI, −0.30 to −0.08), right anterior insula (AI; β, −0.23; 95% CI, −0.37 to −0.09), and left dorsolateral prefrontal cortex (DLPFC; β, −0.29; 95% CI, −0.44 to −0.14). Among those with habitual checking behaviors, there were longitudinal increases in the left amygdala/PI/VS (β, 0.11; 95% CI, 0.04 to 0.18), right amygdala (β, 0.09; 95% CI, 0.02 to 0.16), right AI (β, 0.15; 95% CI, 0.02 to 0.20), and left DLPFC (β, 0.19; 95% CI, 0.05 to 0.25) during social anticipation, whereas among those with nonhabitual checking behaviors, longitudinal decreases were seen in the left amygdala/PI/VS (β, −0.12; 95% CI, −0.19 to −0.06), right amygdala (β, −0.10; 95% CI, −0.17 to −0.03), right AI (β, −0.13; 95% CI, −0.22 to −0.04), and left DLPFC (β, −0.10, 95% CI, −0.22 to −0.03).

CONCLUSIONS AND RELEVANCE The results of this cohort study suggest that social media checking behaviors in early adolescence may be associated with changes in the brain’s sensitivity to social rewards and punishments. Further research examining long-term associations between social media use, adolescent neural development, and psychological adjustment is needed to understand the effects of a ubiquitous influence on development for today's adolescents.
n the span of a generation, social media has dramatically changed the landscape of adolescent development, providing unprecedented opportunities for social interactions around the clock. Social media provides a constant and unpredictable stream of social inputs to adolescents during a critical developmental period when the brain becomes especially sensitive to social rewards and punishments. Motivated by the anticipation of this social feedback, adolescents’ constant, habitual checking of social media may alter neural development, significantly changing the ways in which the adolescent brain responds to its environment.

Social media allows immediate access to social information at any time it is desired and is designed to hold users’ engagement by maximizing social rewards. “Likes,” notifications, and messages arrive unpredictably on a maximally powerful variable reinforcement schedule, conditioning individuals to check social media habitually in anticipation of this social feedback. With 78% of 13- to 17-year-olds reporting checking their devices at least hourly and 46% checking “almost constantly,” adolescents may be uniquely vulnerable to habitual checking behaviors.

The brain undergoes significant structural and functional reorganization during adolescence. Neural regions involved in motivational relevance (eg, the ventral striatum; VS) and affective salience (eg, the amygdala and insula) become hyperactive, orienting teens to rewarding stimuli in their environment, particularly from peers. Adolescents’ habitual checking of social media may be exacerbating an already enhanced neural response to the anticipation of salient social feedback. Additionally, the motivational salience of social contexts may undermine adolescents’ ability to engage in cognitive control and, subsequently, to regulate their behaviors.

Consequently, repeated exposure to digital social rewards (eg, notifications or likes) may increase neural reactivity to reward-related cues, reducing adolescents’ ability to resist urges to check social media.

The current study aimed to examine whether social media use is associated with longitudinal changes in functional brain development across adolescence, a developmental period characterized by peak social media use and heightened neural sensitivity to social feedback from peers. We hypothesized that checking social media habitually would make adolescents increasingly hypersensitive to social feedback anticipation and thus would be associated with longitudinal increases in neural activation, particularly within regions comprising the motivational (eg, VS), affective salience (eg, insula and amygdala), and cognitive control (eg, dorsolateral prefrontal cortex; DLPFC) networks. Conversely, we hypothesized that nonhabitual checking would be associated with longitudinal decreases in neural activation in the same brain regions. Given the limited research exploring longitudinal neural activation in relation to social media behaviors, we conducted exploratory whole-brain analyses to determine which brain regions showed the greatest differences in neural activation longitudinally. To our knowledge, results from this study would provide the first insight into how habitual social media behaviors may be altering adolescent brain development.

**Key Points**

**Question** Is adolescents’ frequency of checking behaviors on 3 social media platforms (Facebook, Instagram, Snapchat) associated with longitudinal changes in functional brain development across adolescence?

**Findings** In this cohort study of 169 sixth- and seventh-grade students, participants who engaged in habitual checking behaviors showed a distinct neurodevelopmental trajectory within regions of the brain comprising the affective salience, motivational, and cognitive control networks in response to anticipating social rewards and punishments compared with those who engaged in nonhabitual checking behaviors.

**Meaning** These results suggest that habitual checking of social media in early adolescence may be longitudinally associated with changes in neural sensitivity to anticipation of social rewards and punishments, which could have implications for psychological adjustment.

**Methods**

**Participants** Participants were recruited from a larger, school-based study of 873 sixth- and seventh-grade students from 3 public rural middle schools in North Carolina to participate in a longitudinal functional magnetic resonance imaging (fMRI) study. We recruited 2 cohorts of participants at 12 to 13 years of age across 2 years of the study, leading to a sample size of 178 adolescents (148 students for cohort 1 and 30 for cohort 2). Of the recruited participants for cohort 1, 5 met exclusion criteria after consenting to the study and thus were excluded and not invited back for later waves (see the eMethods in the Supplement for exclusion criteria). Across all waves, 25 participants completed 1 time point, 36 completed 2 time points, and 112 completed 3 time points. All participants provided written informed consent or assent, and the University’s Institutional Review Board approved all aspects of the study. Race and ethnicity were self-reported by participants. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline. For more information on study procedures, see the eMethods in the Supplement.

**Self-reported Social Media Use** Participants reported frequency of checking at wave 1 only. For 3 popular social media platforms (Facebook, Instagram, and Snapchat), participants were asked how many times per day they checked each platform, with answers grouped into 8 numerical score categories (1, <1 time per day; 2, 1 time per day; 3, 2-3 times per day; 4, 4-5 times per day; 5, 6-10 times per day; 6, 11-15 times per day; 7, 16-20 times per day; 8, >20 times per day). We recoded participants’ scores to create an ordinal scale that captured social media checking frequency across a meaningful distribution that could be assessed quantitatively. A score of 1 was recoded to 0 and a score of 2 was recoded to 1. Scores between 3 and 7 were recoded to the average of the range of scores.
number of times checked; for example, if participants selected 6 for their Facebook use (ie, checked Facebook between 11 and 15 times per day), then their score was recoded to the average of 11 and 15 times, which in this case was 13 times checked. Reported scores of 8 (ie, checked >20 times per day) were recoded to 20 times checked. For each participant, the recoded checking behaviors on the 3 social media platforms were summed to create a total social media checking score that ranged from 0 to 54 (mean [SD] checking behaviors per day, 11.85 [15.39]).

Social Incentive Delay Task
At each wave, participants attended a brain imaging session during which they completed the Social Incentive Delay task while undergoing fMRI to measure neural responses when anticipating receiving social rewards and avoiding social punishments. On each trial, participants saw a cue (for 500 milliseconds) indicating whether the potential social feedback would be a reward, punishment, or neutral. After a variable delay (mean delay, 2000 milliseconds; range, 480-3900 milliseconds), a target appeared (for 300 milliseconds), at which point participants were instructed to respond by pressing a button as quickly as possible. The display of social feedback (for 1450 milliseconds) depended on the trial type and participants’ reaction time. In the social reward condition, happy faces were the outcome of a fast response (hit), and blurred faces were the outcome of a slow response (miss). In the social punishment condition, a hit earned a blurred face, and a miss earned an angry face. In the control condition, a blurred face was always the outcome for both hits and misses. Trials were presented in an event-related design, with reward, punishment, and neutral trials randomly ordered. Participants completed 2 rounds of the task, totaling 116 trials (48 reward, 48 punishment, and 20 neutral trials).

Task difficulty was standardized to a hit rate of approximately 50% for all participants by adjusting target duration to individual reaction times. Age-matched adolescent faces with emotional expressions of 24 ethnically diverse people (12 female) were used as reward and punishment stimuli. Photographs were taken from the National Institute of Mental Health male; 38 [22.5%] Black, 60 [35.5%] Latinx, 50 [29.6%] White, 12 [7.2%] non-Hispanic or Latinx, and 6 [3.6%] categorized as other. A2-sided < .05 family-wise error corrected would be achieved with a voxelwise threshold of P < .001 and a minimum cluster size of 80 voxels. A 2-sided P < .01 indicated statistical significance.

To explore any significant whole-brain interactions and plot the trajectories, we extracted parameter estimates from significant clusters. Parameter estimates were fitted into a conditional linear trajectory model whereby these post hoc analyses allowed us to unpack the significant 3-way interaction between age, condition, and social media checking behavior. For plotting purposes, we categorized the total social media checking scores as high (15+; habitual), moderate (1-15), and low (0; nonhabitual). This allowed us to test whether trajectories of neural response differed as a function of anticipation type and amount of social media checking.

Results
After exclusions, the final sample size was 169 (mean [SD] age, 12.89 [0.58] years; range, 11.93-14.52 years; 91 [53.8%] female; 38 [22.5%] Black, 60 [35.5%] Latinx, 50 [29.6%] White, 15 [8.9%] multiracial [2 or more racial categories identified other Hispanic or Latinx], and 6 [3.6%] categorized as other [American Indian or Alaska Native, Asian, and Native Hawaiian...
or other Pacific Islander) collected across 3 waves; 136 participants completed wave 1 (mean [SD] age, 12.80 [0.52] years; range, 11.9-14.5 years; 71 [52.2%] female), 131 participants completed wave 2 (mean [SD] age, 13.7 [0.59] years; range, 12.4-15.4 years; 68 [51.9%] female), and 124 participants completed wave 3 (mean [SD] age, 14.70 [0.60] years; range, 13.4-16.3 years; 61 [49.2%] female). The mean (SD) time between waves 1 and 2 was 49.8 (3.9) weeks, and that between waves 2 and 3 was 52.9 (6.9) weeks. Retention was 81.1% from waves 1 to 2 and 85.3% from waves 2 to 3. Adolescents reported checking behaviors on 3 social media platforms at wave 1 only. For descriptive statistics regarding checking behaviors on all 3 platforms, see the eFigure in the Supplement. Checking behaviors within the 3 apps were recoded and summed for a total social media checking score, which ranged from 0 to 54 mean (SD) score, 11.85 (15.39).

Using 3dLMEr to model longitudinal whole-brain changes in sensitivity to social anticipation, there was not a 3-way interaction between type of social anticipation, age, and social media checking behavior, so we collapsed social reward and social punishment. We found significant 2-way interactions between age and social media checking behaviors in several regions, including the posterior insula (PI; x, 34; y, 6; z, −4), the left amygdala (x, −26; y, −2; z, −12), the VS (x, −24; y, 14; z, −4), the right amygdala (x, 22; y, 4; z, −18), anterior insula (AI; x, 36; y, 22; z, −4), and the DLPFC (x, 42; y, −42; z, 28) (Table). Of particular interest were the left amygdala extending into the PI and VS (Figure 1A), the right amygdala (Figure 2A), right AI (Figure 3A), and left DLPFC (Figure 4A). Significant 2-way interactions between age and social media checking behaviors were found in similar brain regions when receiving social feedback (eTable in the Supplement).

We extracted parameter estimates from each participant at each wave from the significant clusters in order to unpack the 2-way interaction. We ran post hoc conditional linear growth models to compare the trajectories of adolescents who engaged in low (nonhabitual; n = 79), moderate (n = 34), or high (habitual; n = 56) social media checking behaviors. Participants with high (habitual) checking behaviors showed a lower neural sensitivity to social anticipation at age 12 years (ie, the intercept) compared with those with low (nonhabitual) checking behaviors in the left amygdala/PI/VS ($\beta$, −0.22; 95% CI, −0.33 to −0.11 [Figure 1B]), right amygdala ($\beta$, −0.19; 95% CI, −0.30 to −0.08 [Figure 2B]), right AI ($\beta$, −0.23; 95% CI, −0.37 to −0.09 [Figure 3B]), and left DLPFC ($\beta$, −0.29; 95% CI, −0.44 to −0.14 [Figure 4B]). Here, $\beta$ values refer to the main result of checking behavior at age 12 years where negative values indicate lower neural activation with higher checking behavior.

Developmentally, participants with high checking behaviors at age 12 years showed longitudinal increases (ie, the linear slope) in neural sensitivity in the left amygdala/PI/VS ($\beta$, 0.11; 95% CI, 0.04 to 0.18 [Figure 1B]), right amygdala ($\beta$, 0.09; 95% CI, 0.02 to 0.16 [Figure 2B]), right AI ($\beta$, 0.15; 95% CI, 0.02 to 0.20 [Figure 3B]), and left DLPFC ($\beta$, 0.19; 95% CI, 0.05 to 0.25 [Figure 4B]). Participants with low checking behaviors showed significant longitudinal decreases in neural sensitivity in the left amygdala/PI/VS ($\beta$, −0.12; 95% CI, −0.19 to −0.06 [Figure 1B]), right amygdala ($\beta$, −0.10; 95% CI, −0.17 to −0.03 [Figure 2B]), right AI ($\beta$, −0.13; 95% CI, −0.22 to −0.04 [Figure 3B]), and small decreases in the left DLPFC ($\beta$, −0.10; 95% CI, −0.22 to −0.03 [Figure 4B]). Here, $\beta$ represents the age-related change in neural activation for each group. Results suggest that trajectories of neural sensitivity to anticipation of social feedback for habitual and nonhabitual checkers are inversely related.

### Discussion

This cohort study examined whether early adolescents’ frequency of checking behaviors on 3 popular social media platforms (Facebook, Instagram, and Snapchat) was associated with trajectories of functional brain development across adolescence. Adolescents who engaged in high (habitual) checking behaviors showed distinct neural trajectories when anticipating social feedback compared with those who engaged in

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Abbreviation: MNI, Montreal Neurological Institute.

$^a$ Values are the MNI coordinates to regions of the brain that changed significantly over age.

$^b$ Clusters that survived cluster-extent threshold correction when modeling longitudinal whole-brain changes in sensitivity to social anticipation as a function of social media checking behaviors, assessed using the 3dLMEr program (AFNI). Multiple brain regions may lie within the same brain cluster.
moderate or low (nonhabitual) checking behaviors, suggesting that habitual social media checking early in adolescence is associated with divergent brain development over time.

We found that 12-year-old adolescents showed different neural patterns based on their social media checking behavior. While participants with habitual checking behaviors demonstrated hypoactivation of the amygdala, PI, VS, and DLPFC in response to anticipation of social feedback, those with non-habitual behaviors demonstrated hyperactivation in these same brain regions. Interestingly, these patterns diverged...
Figure 4. Functional Activation in the Left Dorsolateral Prefrontal Cortex (DLPFC) During the Anticipation of Social Feedback

A. DLPFC activation

B. Conditional linear growth model

Consequently, adolescents would experience an increased dopaminergic release in response to social feedback and rewards, which further encourages high-reward behaviors. Indeed, compared with children and adults, adolescents show higher activation in the reward system when receiving rewards.10-12,24,26 In contrast, the hyporesponsive theory posits that adolescent reward-seeking behaviors may be associated with a deficit in the activity of brain regions associated with motivation.10,33 This theory argues that repeated exposure to a social reward downregulates dopamine receptors and production, which results in decreased sensitivity of reward circuits. Studies34,35 suggest that, as adolescents experience fewer or less intense positive feelings from previously rewarding stimuli, they are driven to pursue new appetitive reinforcements through increases in reward-seeking behaviors, which increases activity in dopamine-related circuitry. Indeed, relative to adults, adolescents show less engagement of the VS in anticipation of rewards.30,36 While for some individuals with habitual checking behaviors, an initial hyposensitivity to potential social rewards and punishments followed by hypersensitivity may contribute to checking behaviors on social media becoming compulsive and problematic, for others, this change in sensitivity may reflect an adaptive behavior that allows them to better navigate their increasingly digital environment.

Limitations

This study has limitations. Notably, because differences in neural trajectories already existed between participants with habitual and nonhabitual checking behaviors at the start of the study, it is difficult to determine whether social media use prior to data collection caused these distinct neural trajectories or preexisting differences in neural activation placed some youth at risk for more habitual checking behaviors. Future studies should explore the neurodevelopmental trajectories of social feedback responsiveness from an earlier age to uncover causal pathways behind this association. Moreover, examination of social media checking behaviors across time is needed to further elucidate associations with development. Finally, future work should examine functional connectivity to explore how...
affectional salience, motivational, and cognitive control networks coactivate and function at a network level.

Conclusions

Adolescent social media use has proliferated extensively in the past decade. This longitudinal cohort study suggests that social media behaviors in early adolescence may be associated with changes in adolescents’ neural development, specifically neural sensitivity to potential social feedback. Further research examining long-term prospective associations between social media use, adolescent neural development, and psychological adjustment is needed to understand the effects of a ubiquitous influence on development for today’s adolescents.

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Concept and design: Maza, Fox, Flannery, Lindquist, Prinstein, Telzer.

Acquisition, analysis, or interpretation of data: All authors.

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Statistical analysis: Maza, Fox, Flannery, Lindquist, Prinstein, Telzer.

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Obtained funding: Lindquist, Prinstein, Telzer.

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