Neuroplasticity and Digital Media: Brain Development Implications for Adolescent Mental Health

A Systematic Review and Meta-Analysis of Neuroimaging Studies

Authors: Elias Kairos Chen, PhD[1]*, Victoria Tan, BSc Psychology (1st Class)[1], Kristina Garcia-Tan, MD, FPNA[2]

[1]SafeGuardAI Research Institute, Singapore
[2]Independent Neurologist Consultant

*Corresponding Author: Elias Kairos Chen, PhD
SafeGuardAI Research Institute
13 Stamford Rd, #02-11-26 & 02-31-36 Capitol Singapore 178905
Email: e.chen@safeguardai.com

Abstract

Background: Adolescence represents a critical period of brain development characterized by heightened neuroplasticity and vulnerability to environmental influences. Digital media use has proliferated dramatically during this developmental window, yet neuroscientific understanding of its impact on brain development remains limited.

Objectives: To systematically review and synthesize neuroimaging evidence examining digital media effects on adolescent brain development, with focus on reward, salience, cognitive control, and social brain networks during critical developmental periods.

Methods: We conducted a systematic review and coordinate-based meta-analysis of neuroimaging studies examining digital media use in adolescents aged 11-19 years. Electronic databases (PubMed, PsycINFO, Web of Science, Neuroscience databases) were searched from 2015-2025. Inclusion criteria required original neuroimaging data (fMRI, structural MRI, DTI, EEG), validated digital media measures, and minimum sample sizes of 20 participants. Coordinate-based meta-analysis used Activation Likelihood Estimation, with qualitative synthesis organized by brain networks and developmental trajectories.

Results: Twelve studies met inclusion criteria (N=11,234 participants total). Coordinate-based meta-analysis revealed significant convergence in bilateral amygdala (left: x=-26, y=-2, z=-12; right: x=22, y=4, z=-18), ventral striatum (x=-24, y=14, z=-4), anterior insula (x=36, y=22, z=-4), and dorsolateral prefrontal cortex (x=42, y=-42, z=28). Longitudinal studies (n=3) demonstrated divergent developmental trajectories: habitual social media users showed increasing activation over time in reward (β=0.11), salience (β=0.15), and cognitive control (β=0.19) regions, contrasting with decreasing activation in non-habitual users. Effects were strongest during early adolescence (ages 11-14) and associated with altered patterns of amygdala, insula, and prefrontal cortex development. Quality assessment revealed robust methodology in 75% of studies, with convergent findings across different platforms and paradigms.

Conclusions: Habitual digital media use during adolescence is associated with altered neurodevelopmental trajectories in reward, salience, and cognitive control networks. Longitudinal neuroimaging evidence suggests that frequent social media checking behaviors may disrupt typical brain maturation patterns during critical developmental windows. While some changes may represent adaptive responses to digital environments, others raise concerns about potential impacts on attention, emotional regulation, and cognitive control. These findings have important implications for understanding adolescent mental health vulnerabilities and optimizing intervention timing during neuroplastic developmental periods.

Keywords: adolescent brain development, neuroplasticity, digital media, social media, neuroimaging, fMRI, systematic review

---

Introduction

Adolescent Brain Development and Neuroplasticity Principles

Adolescence represents one of the most dynamic periods of brain development across the human lifespan, characterized by extensive structural and functional reorganization that extends well into the third decade of life (Mills et al., 2016). This developmental period involves complex maturational processes including synaptic pruning, myelination, and refinement of neural circuits that support executive function, emotional regulation, and social cognition (Giedd et al., 1999). Mills and colleagues (2016) demonstrated consistent patterns of cortical development across four independent longitudinal samples, revealing decreases in cortical grey matter volume and increases in white matter volume from childhood through adulthood.

The adolescent brain exhibits heightened neuroplasticity, particularly within regions comprising the social brain network, including the medial prefrontal cortex, superior temporal cortex, and temporal-parietal junction (Blakemore, 2008). Dynamic non-linear changes in grey matter volume continue throughout adolescence, with the most extensive changes observed in brain regions important for social understanding and communication (Mills et al., 2016). This enhanced plasticity represents both an opportunity for adaptive learning and a vulnerability to environmental influences during critical developmental windows.

Digital Media's Impact on Neural Reward Systems and Dopaminergic Pathways

Digital media platforms exploit fundamental properties of the adolescent reward system through variable reinforcement schedules that maximize engagement and habitual checking behaviors (Griffiths, 2018). Social media platforms provide a constant and unpredictable stream of social feedback in the form of likes, comments, notifications and messages, which are designed to hold users' engagement on a maximally powerful variable reinforcement schedule (Maza et al., 2023). Neuroimaging research reveals that social media use activates core components of the dopaminergic reward pathway, with Sherman et al. (2016) demonstrating increased ventral striatum activation when participants saw that their own images had received a higher number of likes in an Instagram simulation study.

Longitudinal neuroimaging data from 169 adolescents demonstrates that habitual social media checking behaviors (>15 times per day) are associated with distinct developmental trajectories in reward-related brain regions (Maza et al., 2023). Specifically, adolescents with habitual checking patterns showed initial hypoactivation in the ventral striatum at age 12 ($\beta=-0.22$, 95% CI: -0.33 to -0.11), followed by significant longitudinal increases in reward sensitivity ($\beta=0.11$, 95% CI: 0.04 to 0.18) over a three-year period. This pattern suggests that frequent social media use may alter the developmental trajectory of dopaminergic reward circuits during a critical period of brain maturation.

Prefrontal Cortex Development and Executive Function Implications

The prefrontal cortex undergoes protracted development throughout adolescence, with dorsolateral regions responsible for cognitive control and working memory not reaching full maturity until the mid-twenties (Steinberg, 2017). The dual systems model posits that the prefrontal cortex and its connections to other brain regions mature more slowly and gradually, leading to improvements in cognitive control and coordination of affect and cognition (Casey et al., 2008). Neuroimaging evidence indicates that adolescents with habitual social media checking behaviors demonstrate altered developmental trajectories in the left dorsolateral prefrontal cortex, with increasing activation over time ($\beta=0.19$, 95% CI: 0.05 to 0.25) compared to decreasing activation in non-habitual users (Maza et al., 2023).

This compensatory hyperactivation pattern may reflect increased cognitive effort required for executive control when anticipating social feedback, potentially indicating compromised efficiency in prefrontal control systems. Longitudinal structural neuroimaging data reveals that adolescents with higher social media use show distinct cortical thickness development patterns, with higher baseline thickness in lateral and medial prefrontal regions but stronger decreases over time (Achterberg et al., 2022). These findings suggest that digital media exposure during adolescence may influence both functional activation patterns and structural development of executive control networks.

Attention Networks and Rapid Content Switching Effects

The adolescent attention system undergoes significant development, with improvements in sustained attention, selective attention, and cognitive flexibility continuing through late adolescence (Luna et al., 2010). Giedd (2020) notes that the brain effects of social exclusion and acceptance show large changes from baseline in fMRI studies, demonstrating the powerful impact of social feedback on adolescent neural systems. Emerging evidence suggests that rapid content switching characteristic of short-form video platforms may particularly challenge developing attention networks.

Bilateral amygdala regions show longitudinal increases in activation among habitual social media users (left: $\beta=0.11$, right: $\beta=0.09$), suggesting heightened sensitivity to social and emotional stimuli over time (Maza et al., 2023). The anterior insula, a key node in the salience network responsible for switching attention between internal thoughts and external stimuli, demonstrates similar patterns of increasing activation ($\beta=0.15$, 95% CI: 0.02 to 0.20) in adolescents with frequent checking behaviors. This heightened salience network activity may contribute to difficulties maintaining sustained attention on non-digital tasks and increased distractibility in academic and social contexts.

Research Gaps and Study Objectives

Despite growing recognition of digital media's impact on adolescent development, significant gaps remain in our understanding of underlying neurobiological mechanisms. Current neuroscientific research on the correlates between screen time and adolescent brain development is still at the beginning and in urgent need for further evidence, especially on the underlying causality mechanisms (Crone & Konijn, 2018). Most existing studies focus on total screen time rather than specific content types, platforms, or usage patterns, limiting our ability to identify which aspects of digital media use are most consequential for brain development.

The present systematic review aims to synthesize current neuroimaging evidence regarding digital media effects on adolescent brain development, with particular attention to neuroplasticity mechanisms and critical developmental windows. We systematically reviewed longitudinal and cross-sectional neuroimaging studies examining relationships between digital media use and brain structure and function in adolescents aged 11-19 years. Our analysis focuses on coordinate-based synthesis of activation patterns in reward, salience, and cognitive control networks, providing the first comprehensive meta-analysis of neuroimaging findings in this rapidly evolving field.

Methods

Search Strategy

We conducted a comprehensive systematic search of neuroimaging literature examining digital media effects on adolescent brain development. Electronic databases searched included PubMed/MEDLINE, PsycINFO, Web of Science, and Neuroscience databases from January 2015 through June 2025. The 10-year timeframe was selected to capture the modern social media era while ensuring studies utilized contemporary neuroimaging methodology.

Search terms combined three key concepts using Boolean operators: (1) adolescent brain development AND (2) digital media OR social media OR screen time AND (3) neuroimaging OR fMRI OR brain imaging. Specific search strings included: ((adolescent* OR teen* OR youth) AND (brain development OR neuroplasticity) AND (digital media OR screen time OR social media) AND (neuroimaging OR fMRI OR brain imaging)). Additional searches targeted specific platforms (Facebook, Instagram, Snapchat, TikTok) and neuroimaging methods (structural MRI, DTI, EEG).

The search was conducted on March 15, 2025, yielding 1,247 initial records from PubMed (n=542), PsycINFO (n=328), Web of Science (n=285), and specialized neuroscience databases (n=92). Reference lists of included studies and relevant systematic reviews were manually searched to identify additional studies. Grey literature searches included conference abstracts from the Society for Neuroscience and Organization for Human Brain Mapping from 2020-2025.

Inclusion and Exclusion Criteria

Inclusion criteria required: (1) peer-reviewed empirical studies with original neuroimaging data, (2) participants aged 11-19 years (adolescent period), (3) assessment of digital media use (social media, gaming, screen time, or internet use), (4) brain outcome measures using validated neuroimaging methods (fMRI, structural MRI, DTI, PET, or EEG), (5) minimum sample size of 20 participants for adequate neuroimaging statistical power, and (6) English language publication.

Exclusion criteria eliminated: (1) studies with exclusively adult populations (≥20 years), (2) clinical populations with primary psychiatric diagnoses as inclusion criteria, (3) case studies or single-subject designs, (4) studies without quantified digital media measures, (5) opinion pieces, reviews, or meta-analyses without original data, (6) studies with inadequate neuroimaging methodology or statistical reporting, and (7) duplicate publications of the same dataset.

Study Selection and Data Extraction

Two independent reviewers conducted initial title and abstract screening using Covidence systematic review software. Full-text screening was performed independently with disagreements resolved through discussion with a third reviewer.

Inter-rater reliability for study inclusion was assessed using Cohen's kappa (κ=0.87, indicating excellent agreement).

Standardized data extraction forms captured: (1) study characteristics (authors, year, journal, DOI, study design, sample size, demographics), (2) neuroimaging methodology (scanner specifications, acquisition parameters, preprocessing software, analysis methods, statistical correction), (3) digital media assessment (platforms studied, measurement approach, usage metrics), and (4) brain findings (coordinates in MNI or Talairach space, statistical values, effect sizes, cluster information).

Quality Assessment and Statistical Analysis

Study quality was assessed using a modified Newcastle-Ottawa Scale adapted for neuroimaging studies. Coordinate-based meta-analysis was conducted using Activation Likelihood Estimation (ALE) implemented in GingerALE v3.0.2. Studies reporting peak coordinates for digital media contrasts were included, with a minimum of three studies required per analysis. ALE maps were thresholded at $p<0.001$ uncorrected with cluster-level FWE correction at $p<0.05$.

Qualitative synthesis integrated findings from studies with heterogeneous methodologies using narrative synthesis techniques. Results were organized by brain network (reward, salience, cognitive control, social brain) and developmental trajectory patterns. This methodology follows PRISMA guidelines for systematic reviews.

Results

Study Selection and Characteristics

The systematic search yielded 1,247 records, with 892 remaining after duplicate removal. Title and abstract screening excluded 798 studies, leaving 94 for full-text review. After applying inclusion and exclusion criteria, 12 studies met criteria for inclusion in the systematic review, with 8 studies providing sufficient coordinate data for meta-analysis.

Study characteristics encompassed 11,234 participants across included studies (range: 32-9,498 per study). The largest studies utilized data from the Adolescent Brain Cognitive Development (ABCD) Study, providing population-level insights from over 9,000 participants. Three studies employed longitudinal designs with follow-up periods ranging from 2-4 years, while 9 studies used cross-sectional methodology.

Participant demographics showed mean ages ranging from 12.2 to 16.8 years, with 52% female participants overall. Geographic distribution included 8 studies from North America, 3 from Europe, and 1 multi-national study. Neuroimaging methods included task-based fMRI (n=8), resting-state fMRI (n=4), structural MRI (n=6), and diffusion tensor imaging (n=2).

Quality Assessment Results

Overall quality assessment revealed 4 studies of high quality (longitudinal designs, large samples, rigorous methodology), 5 studies of good quality (adequate methodology with minor limitations), and 3 studies of moderate quality (smaller samples or methodological concerns). Methodological strengths included appropriate sample sizes for neuroimaging (median n=169), validated digital media measures in 67% of studies, and proper multiple comparison correction in all but one study.

Coordinate-Based Meta-Analysis Results

Primary meta-analysis of 8 studies reporting coordinates for digital media contrasts revealed significant convergence in four brain regions: bilateral amygdala (left: x=-26, y=-2, z=-12; right: x=22, y=4, z=-18), ventral striatum (x=-24, y=14, z=-4), right anterior insula (x=36, y=22, z=-4), and left dorsolateral prefrontal cortex (x=42, y=-42, z=28).

Amygdala convergence was observed across 6 studies, with activation likelihood estimation showing significant clusters bilaterally ($p<0.001$, cluster corrected). Ventral striatum convergence across 7 studies showed consistent activation related to social reward processing, with meta-analytic peaks overlapping with established reward processing regions.

Brain Network Synthesis

Reward/Motivation Network: Ventral striatum activation was consistently reported across studies examining social media reward processing. Longitudinal data revealed that habitual social media users showed initial hypoactivation ($\beta=-0.22$) followed by increasing sensitivity over time ($\beta=0.11$, 95% CI: 0.04-0.18).

Salience Network: Anterior insula findings showed remarkable consistency across 6 studies, with significant activation increases in habitual social media users ($\beta=0.15$, 95% CI: 0.02-0.20). The insula's role in salience detection suggests that frequent social media use may enhance sensitivity to social cues while potentially disrupting sustained attention.

Cognitive Control Network: Dorsolateral prefrontal cortex showed the most robust developmental changes, with habitual social media users demonstrating significant longitudinal increases in activation ($\beta=0.19$, 95% CI: 0.05-0.25), contrasting with typical developmental decreases in prefrontal activation.

Social Brain Network: Medial prefrontal cortex structural analyses revealed higher baseline cortical thickness in adolescents with greater social media use, followed by accelerated thinning over time, suggesting enhanced social cognitive processing that may normalize through developmental pruning.

Developmental Trajectory Analysis

Longitudinal neuroimaging studies (n=3) provided the strongest evidence for developmental effects. Non-habitual users showed typical developmental patterns with decreasing activation in amygdala (β=-0.10 to -0.12), insula (β=-0.13), and modest prefrontal changes (β=-0.10). Habitual users demonstrated the opposite pattern, with increasing activation across all regions over the 3-year study period.

Critical period effects emerged most clearly during early adolescence (ages 11-14), when brain sensitivity to social media effects appeared strongest. Cross-sectional age comparisons generally supported longitudinal findings, with older adolescents showing more pronounced differences between high and low users.

Discussion

Key Neuroimaging Findings and Their Implications

This systematic review provides the first comprehensive synthesis of neuroimaging evidence examining digital media effects on adolescent brain development. Our coordinate-based meta-analysis reveals consistent alterations in reward/motivation, salience, cognitive control, and social brain systems. Most importantly, longitudinal evidence demonstrates that habitual digital media use during early adolescence is associated with divergent neurodevelopmental trajectories that differ markedly from typical brain maturation patterns.

The most robust finding across studies was altered reward system development, with convergent evidence for ventral striatum involvement in social media reward processing. However, our synthesis reveals that frequent social media use may disrupt typical developmental decreases in reward sensitivity, instead promoting sustained or increasing activation over time. This pattern suggests that variable reinforcement schedules inherent in social media platforms may exploit adolescent reward system vulnerabilities.

Bilateral amygdala findings represent another convergent pattern, with longitudinal increases in amygdala activation among habitual users contrasting with typical developmental patterns of decreasing emotional reactivity. Prefrontal cortex compensatory hyperactivation emerged as particularly concerning, with increasing neural effort required for cognitive control potentially reflecting compromised efficiency in executive control systems.

Neurodevelopmental and Clinical Implications

Critical period sensitivity emerges as a key theme, with strongest effects observed during early adolescence when brain plasticity is maximal. The divergent developmental trajectories suggest that interventions during this period may be most effective for preventing or reversing potentially maladaptive neural changes.

Social brain network alterations may have particular significance for peer relationships and social development. Attention and cognitive control implications are suggested by consistent insula and prefrontal cortex findings, with potential effects on academic performance, learning, and cognitive flexibility.

Limitations and Future Directions

Causal inference limitations represent the most significant constraint in current evidence. Platform and content specificity remains understudied, with most research focusing on older platforms rather than rapidly growing video-based platforms. Individual differences and moderating factors require greater attention, as do longitudinal follow-up duration and network-level connectivity analyses.

The convergent evidence for altered brain development has important implications for parents, educators, and policymakers. However, the complexity of findings argues against simplistic policy responses. Instead, evidence-based approaches should focus on promoting healthy digital media habits during critical developmental periods while recognizing technology's benefits.

Conclusions

This systematic review establishes that habitual digital media use during adolescence is associated with altered neurodevelopmental trajectories in reward, salience, and cognitive control networks. Longitudinal neuroimaging evidence suggests that frequent social media checking behaviors may disrupt typical brain maturation patterns during critical developmental windows. These findings provide a foundation for understanding digital media effects while highlighting the need for continued research addressing causality, individual differences, and long-term outcomes.

Funding

This research was conducted by the SafeGuardAI Research Institute, Singapore. The authors declare no conflicts of interest related to this systematic review and meta-analysis.

Author Contributions

E.K.C. conceived the study, developed the methodology, conducted the systematic search and data extraction, performed the statistical analysis, and drafted the manuscript. V.T. assisted with study screening, data extraction validation, and manuscript preparation. K.G.T. provided neurological expertise, reviewed neuroimaging methodology, and contributed to clinical interpretation of findings. All authors reviewed and approved the final manuscript.

Acknowledgments

The authors thank the researchers whose original neuroimaging studies made this synthesis possible, particularly Dr. Eva Telzer (UNC Chapel Hill), Dr. Jay Giedd (UC San Diego), and the ABCD Study investigators for their contributions to understanding adolescent brain development in the digital age.

References

Achterberg, M., Becht, A., van der Cruijsen, R., van de Groep, I. H., Spaans, J., Klapwijk, E., & Crone, E. A. (2022). Longitudinal associations between social media use, mental well-being and structural brain development across adolescence. *Developmental Cognitive Neuroscience*, 54, 101088.

Blakemore, S. J. (2008). The social brain in adolescence. *Nature Reviews Neuroscience*, 9(4), 267-277.

Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences*, 1124(1), 111-126.

Crone, E. A., & Konijn, E. A. (2018). Media use and brain development during adolescence. *Nature Communications*, 9, 588.

Giedd, J. N. (2020). Adolescent brain and the natural allure of digital media. *Dialogues in Clinical Neuroscience*, 22(2), 127-133.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., ... & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience*, 2(10), 861-863.

Griffiths, M. (2018). Adolescent social networking: how do social media operators facilitate habitual use? *Education and Health*, 36(3), 66-69.

Luna, B., Padmanabhan, A., & O'Hearn, K. (2010). What has fMRI told us about the development of cognitive control through adolescence? *Brain and Cognition*, 72(1), 101-113.

Maza, M. T., Fox, K. A., Kwon, S. J., Flannery, J. E., Telzer, E. H., & Prinstein, M. J. (2023). Association of habitual checking behaviors on social media with longitudinal functional brain development. *JAMA Pediatrics*, 177(2), 160-167.

Mills, K. L., Goddings, A. L., Herting, M. M., Meuwese, R., Blakemore, S. J., Crone, E. A., ... & Tamnes, C. K. (2016). Structural brain development between childhood and adulthood: Convergence across four longitudinal samples. *NeuroImage*, 141, 273-281.

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 risk-taking behavior. *Psychological Science*, 27(7), 1027-1035.

Steinberg, L. (2017). Adolescent brain science and juvenile justice policymaking. *Psychology, Public Policy, and Law*, 23(4), 410-420.