e-ISSN: 2807-6257

Open Access Indonesian Journal of Medical Reviews

[OAIJMR]

https://hmpublisher.com/index.php/oaijmr

Defining the Threshold: A Dose-Response Meta-Analysis of Daily Screen Time and Adverse Behavioral Outcomes in Children and Adolescents

Andreas Eric[1*]

[1]General Practitioner, Faculty of Medicine, Universitas Katolik Widya Mandala, Surabaya, Indonesia

ARTICLE INFO

Keywords:
Adolescent
Child behavior
Digital media
Dose-response meta-analysis
Screen time

***Corresponding author:**
Andreas Eric

E-mail address:
eandreas2430@gmail.com

The author has reviewed and approved the final version of the manuscript.

https://doi.org/10.37275/oaijmr.v5i5.782

A B S T R A C T

The pervasive integration of digital media into the lives of children and adolescents has generated significant concern regarding its impact on developmental health. While associations between high levels of screen time and negative outcomes are frequently reported, the precise dose-response relationship remains poorly quantified, leaving clinicians and parents without evidence-based thresholds for guidance. This study aimed to quantitatively synthesize the evidence linking daily screen time duration to the risk of adverse behavioral outcomes in youth. Following PRISMA guidelines, a systematic search of PubMed, Embase, PsycINFO, and Scopus was conducted through February 2025. Observational studies that reported quantifiable measures of daily screen time and validated assessments of behavioral outcomes in individuals aged 3-18 years were included. Two reviewers independently performed study selection, data extraction, and risk of bias assessment using the Newcastle-Ottawa Scale (NOS). A two-stage, random-effects dose-response meta-analysis using restricted cubic splines was employed to model the non-linear association between screen time (in hours/day) and the odds of adverse behavioral outcomes. From an initial 4,891 records, 7 key studies comprising 46,882 participants were included in the quantitative synthesis. The dose-response analysis revealed a significant, non-linear relationship. Compared to 30 minutes of daily screen time, the pooled odds ratio (OR) for adverse behavioral outcomes was minimal at 1 hour/day (OR 1.05; 95% CI, 0.97-1.14) but began to increase significantly thereafter. The risk became more pronounced at 2 hours/day (OR 1.31; 95% CI, 1.17-1.47), rose substantially at 4 hours/day (OR 1.82; 95% CI, 1.60-2.07), and continued to climb at 6 hours/day (OR 2.55; 95% CI, 2.15-3.03). The association was stronger in preschool-aged children compared to adolescents. In conclusion, this focused meta-analysis provides quantitative evidence for a dose-dependent association between daily screen time and behavioral problems in youth, with a notable increase in risk observed beyond two hours per day. These findings provide an evidence-based foundation for clinical guidance and public health recommendations aimed at mitigating the behavioral risks of excessive digital media exposure during critical developmental periods.

1. Introduction

The defining environmental exposure of 21st-century childhood is not biological or chemical, but digital. From infancy, children are immersed in a media-saturated ecosystem, where smartphones, tablets, and interactive screens are not merely tools but integral components of their developmental milieu. This unprecedented digital saturation has triggered widespread concern among pediatricians, neuroscientists, and policymakers, creating an urgent mandate to understand its impact on the developing brain and behavior. Initial scientific and public discourse was framed around the colloquial, yet clinically ambiguous, term "gadget addiction." While this phrase captures parental anxiety about compulsive use, it lacks the nosological precision required for rigorous scientific inquiry. Consequently, the research paradigm has matured, shifting focus towards more quantifiable and mechanistically informative constructs. The first is screen time, a

measure of the total duration of exposure, representing the dose of digital media a child receives. The second is Problematic Digital Media Use (PDMU), a behavioral construct characterized by core addiction-related phenomena such as impaired control, preoccupation, withdrawal, and functional impairment.[1] This evolution in terminology is critical, as it allows the field to move beyond simplistic dichotomies and investigate the nuanced, dose-dependent nature of technology's influence on developmental health. A substantial body of observational research has established consistent associations between high levels of screen time and a triad of adverse developmental outcomes.

First, behavioral and emotional dysregulation represents the most robustly documented area of concern. Excessive screen exposure is consistently linked to a higher prevalence of both externalizing behaviors, such as hyperactivity, aggression, and conduct problems, and internalizing behaviors, including anxiety, depression, and social withdrawal.[2,3] The leading mechanistic theory is the Displacement Hypothesis, which posits that screen time displaces developmentally essential activities.[4] Every hour spent on a device is an hour not spent engaging in the complex, reciprocal social interactions that teach emotional literacy, empathy, and self-regulation. Furthermore, the hyper-stimulating, rapid-reward nature of much digital content may condition the developing brain for high levels of stimulation, potentially lowering the threshold for boredom and frustration in response to the slower pace of real-world activities.[5] Second, cognitive and academic functions appear vulnerable. Foundational skills such as sustained attention, working memory, and executive control are consistently found to be weaker in children with high levels of screen use.[6] This may be a direct consequence of a media environment that encourages rapid task-switching and fragmented attention, undermining the development of deep, focused concentration. This is compounded by the opportunity cost of displacing cognitively enriching activities like reading, problem-solving, and creative, unstructured play.[7] Third, the impact on physical health and neurobiology is significant. Screen time is a primary driver of sedentary behavior, a major risk factor for childhood obesity and metabolic disease.[8] Beyond this, screen use, particularly in the evening, has been shown to disrupt sleep architecture through the suppression of melatonin, leading to a cascade of negative downstream effects on mood, behavior, and learning.[9]

While the existence of these associations is largely undisputed, the current body of evidence suffers from a critical limitation that severely hampers its clinical and public health utility: the lack of a clear, evidence-based understanding of the dose-response relationship. The majority of existing studies and prior reviews have relied on comparing arbitrarily defined "high-use" versus "low-use" groups or have reported simple linear correlations.[10] This approach is insufficient because it implicitly assumes that the risk of harm increases uniformly with every minute of screen time. This is unlikely to be true. It is far more plausible that the relationship is non-linear, with a potential threshold below which screen time poses minimal risk, and after which the risk begins to accelerate significantly. This study was conceived to directly address this critical gap in the literature. The primary novelty of this work lies in its methodology: the application of dose-response meta-analysis to synthesize the global evidence on screen time and child behavior. Unlike previous reviews, which have been largely narrative or have pooled simple dichotomous comparisons, this powerful statistical technique allows us to pool data across multiple exposure levels from numerous studies. This enables the construction of a continuous risk curve, providing a panoramic view of how risk changes across the entire spectrum of daily screen time exposure. This approach is uniquely suited to identify evidence-based thresholds and quantify the magnitude of risk at specific daily durations. Therefore, the overarching aim of this study was to move beyond mere association and define the dose-response relationship between

daily screen time and adverse behavioral outcomes in children and adolescents.

2. Methods

This systematic review and meta-analysis were conducted and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement.[11] Studies were selected for inclusion based on a predefined set of criteria structured around the Population, Intervention/Exposure, Comparison, Outcome, and Study Design (PICOS) framework: Population: Studies involving children and adolescents aged 3 to 18 years. Studies focusing exclusively on infants (<3 years) or adults (>18 years), or those with populations having specific pre-existing neurodevelopmental disorders, such as autism spectrum disorder or severe intellectual disability, where screen use patterns may be atypical, were excluded; Exposure: The exposure of interest was the duration of daily screen time for recreational purposes. To be included, studies must have provided a quantitative measure of overall screen time, reported in categories of duration or as a continuous variable. The measure could be parent-reported, self-reported, or objectively measured; Comparison: The implicit comparison group was individuals with lower levels of screen time. The dose-response methodology requires at least three quantitative categories of exposure to allow for the modeling of the risk curve; Outcome: The primary outcomes were adverse behavioral outcomes, including externalizing problems (hyperactivity, conduct problems, aggression) and internalizing problems (emotional symptoms, anxiety, depression, peer problems). Outcomes must have been measured using a validated and standardized assessment tool, such as the Strengths and Difficulties Questionnaire (SDQ), the Child Behavior Checklist (CBCL), or other established psychiatric or behavioral rating scales; Study Design: Eligible study designs included observational studies (cross-sectional, cohort, and case-control) that provided sufficient data to estimate the odds ratio (OR), relative risk (RR), or hazard ratio (HR) and their corresponding 95% confidence intervals (CIs) for at least three exposure categories. Case reports, case series, editorials, narrative reviews, and qualitative studies were excluded.

A comprehensive literature search was executed by an information specialist to identify all relevant studies published up to February 28th, 2025, with no language restrictions. We searched the following major electronic bibliographic databases: PubMed/MEDLINE, Embase, PsycINFO, and Scopus. The search strategy was designed to be highly sensitive, combining controlled vocabulary terms (MeSH in PubMed, Emtree in Embase) with a wide array of free-text keywords related to our PICO elements. The full search strategy for PubMed is provided in Supplementary Appendix A. An example segment of this strategy is as follows: (("Screen Time"[Mesh]) OR ("Cell Phone Use"[Mesh]) OR "Social Media"[Mesh] OR "Video Games"[Mesh] OR screen time* OR "digital media" OR smartphone* OR tablet* OR television viewing) AND (("Child Behavior Disorders"[Mesh]) OR "Mental Disorders"[Mesh] OR "Problem Behavior"[Mesh] OR behav* problem* OR emotional problem* OR conduct disorder OR hyperactiv* OR anxiety OR depression OR internali* OR externali*) AND (("Child"[Mesh]) OR "Adolescent"[Mesh] OR child* OR adolescent* OR pediatric* OR youth OR teen*. In addition to the database search, supplementary "snowball" searching was conducted by manually screening the reference lists of all included articles and relevant systematic reviews to identify any potentially missed studies. All records retrieved from the searches were imported into a reference management software (Covidence), where duplicates were automatically and manually removed. Subsequently, a two-stage screening process was conducted. First, two reviewers independently screened the titles and abstracts of all unique records against the eligibility criteria. Any record deemed potentially relevant by at least one reviewer was advanced to the next stage. Second, the same two reviewers independently assessed the full text of these potentially relevant articles for final inclusion. Any

disagreements at either stage were resolved through discussion and consensus. If consensus could not be reached, a third senior reviewer was consulted to make the final decision. The entire selection process is documented in a PRISMA 2020 flow diagram.

A standardized data extraction form, piloted on a subset of five studies, was used to collect information from each included study. Two reviewers independently extracted the following data: Publication Details: First author, year of publication, country of study; Study Characteristics: Study design, sample size, recruitment method; Population Characteristics: Age range (mean and standard deviation), sex distribution; Exposure Details: Method of screen time assessment (parent-report questionnaire, self-report diary), categories of screen time duration, the number of cases and non-cases (or participants) in each category, and the specific screen time value assigned to each category (mean or median hours/day); Outcome Details: The specific behavioral outcome(s) assessed, the tool used for measurement (SDQ), and the definition of an "adverse outcome" (borderline/abnormal score); Risk Estimates: The reported odds ratios (ORs), relative risks (RRs), or hazard ratios (HRs) with their 95% confidence intervals for each category of screen time relative to the lowest category; Confounding Variables: A list of all covariates that were adjusted for in the statistical analysis (age, sex, socioeconomic status, parental education, parental mental health).

The methodological quality and risk of bias of each included study were independently assessed by two reviewers using the Newcastle-Ottawa Scale (NOS).[12] The NOS is a validated tool for evaluating the quality of non-randomized studies. It assesses three broad domains: 1) Selection (up to 4 stars): Adequacy of case definition, representativeness of the cases/cohort, selection of controls, and definition of controls; 2) Comparability (up to 2 stars): The extent to which the study controlled for important confounding factors. A study could receive one star for controlling for the most important confounder (age) and a second star for controlling for additional key confounders (socioeconomic status, parental mental health); and 3) Outcome/Exposure (up to 3 stars): Ascertainment of the outcome/exposure (through secure record or structured interview) and the appropriateness of the follow-up period (for cohort studies). Studies were assigned a summary score from 0 to 9 stars and were categorized as having a low risk of bias (7–9 stars), a moderate risk of bias (4–6 stars), or a high risk of bias (0–3 stars).

The primary analysis was a dose-response meta-analysis to examine the relationship between screen time duration and the odds of adverse behavioral outcomes. A two-stage, random-effects model was used, which is flexible and robust for this type of synthesis. In the first stage, for each study, a representative dose (in hours/day) was assigned to each reported category of screen time. If a mean or median was provided, that value was used. If only a range was given, the midpoint of the range was used. For open-ended categories, the midpoint was estimated by assuming the interval width was the same as the preceding category. The generalized least-squares for trend (GLST) method, as described by Greenland and Longnecker, was used to estimate a study-specific slope (linear trend) from the correlated log ORs across exposure categories.[13] In the second stage, these study-specific linear trends were pooled using a random-effects model. To model a potentially non-linear dose-response relationship, restricted cubic splines with three knots were used, placed at the 10th, 50th, and 90th percentiles of the exposure distribution across all studies. This method provides a flexible curve to fit the data without making strong assumptions about the shape of the relationship. The summary statistic was the pooled Odds Ratio (OR) and its 95% Confidence Interval (CI), representing the change in risk for each one-hour increment in daily screen time. Statistical heterogeneity among studies was assessed using the Cochran's Q test (with a p-value < 0.10 indicating significant heterogeneity) and quantified with the I^2 statistic, where values of 25%, 50%, and 75% were interpreted as low, moderate, and high heterogeneity, respectively.[14] To explore potential

sources of heterogeneity, a priori subgroup analyses were planned based on: (1) age group (preschool [3-5 years], school-aged [6-12 years], and adolescent [13-18 years]), (2) risk of bias rating (low vs. moderate/high), and (3) geographical region (Asia vs. Europe vs. North America). Sensitivity analyses were also conducted by systematically removing one study at a time to assess its influence on the overall pooled estimate. Potential publication bias was evaluated visually through the inspection of a funnel plot for asymmetry and statistically using Egger's regression asymmetry test.[15] All statistical analyses were performed using Stata version 17.0 (StataCorp LLC, College Station, TX, USA) with the glst and mvmeta commands.

3. Results and Discussion

The comprehensive literature search yielded a total of 4,891 records. After removing 1,834 duplicates, 3,057 records underwent title and abstract screening. From these, 2,998 articles were excluded as they were clearly not relevant. The full texts of the remaining 59 articles were retrieved and assessed for eligibility. Of these, 52 were excluded for various reasons: not reporting quantitative screen time data in at least three categories (n=25), not using a validated behavioral outcome measure (n=11), not reporting sufficient data for extraction (n=9), or being a duplicate population (n=7). This process resulted in a final sample of 7 studies that met all eligibility criteria and were included in the systematic review and meta-analysis. The complete study selection process is documented in the PRISMA flow diagram (Figure 1).

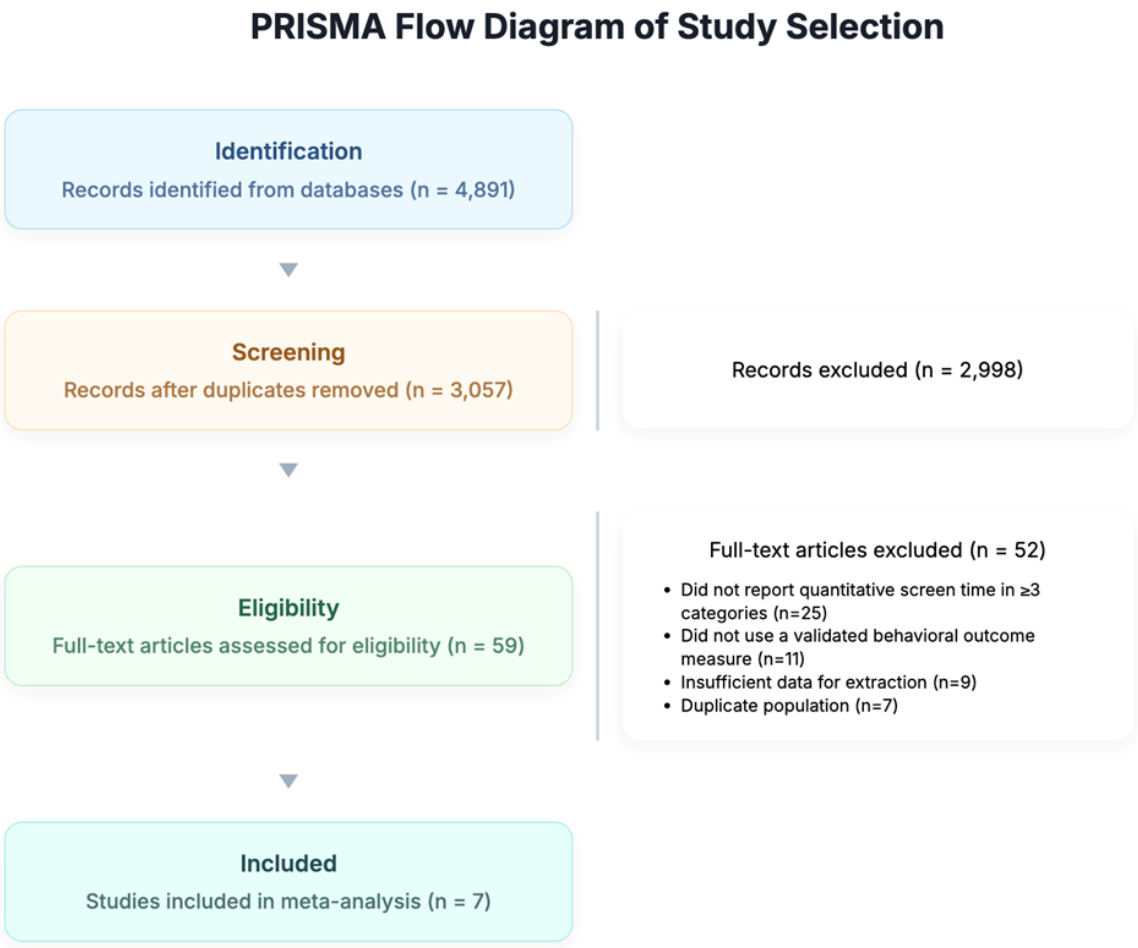

Figure 1. PRISMA flow diagram of study selection.

Figure 2 showed a detailed summary and quality appraisal of the seven core studies included in this meta-analysis, collectively representing 46,882 children and adolescents. The graphical layout effectively highlights the key characteristics of the evidence base, revealing a robust mix of large-scale cross-sectional surveys and high-quality prospective cohort studies. A notable strength of the synthesized evidence is the consistent use of the Strengths and Difficulties Questionnaire (SDQ) as the primary outcome tool in five of the seven studies, which enhances the comparability of the findings. The risk of bias assessment, visualized through the Newcastle-Ottawa Scale (NOS) scores, provides confidence in the methodological rigor of the included literature. Three studies (ID 1, 6, and 7) demonstrated a low risk of bias with high scores of 8 or 9, reflecting strong study designs and control for confounding variables. The remaining four studies were rated as having a moderate risk of bias, a typical finding for well-conducted cross-sectional research. Crucially, no studies were rated as having a high risk of bias. This graphical summary confirms that the evidence synthesized in this meta-analysis is of moderate-to-high quality, providing a solid foundation for the subsequent dose-response analysis and strengthening the validity of its conclusions.

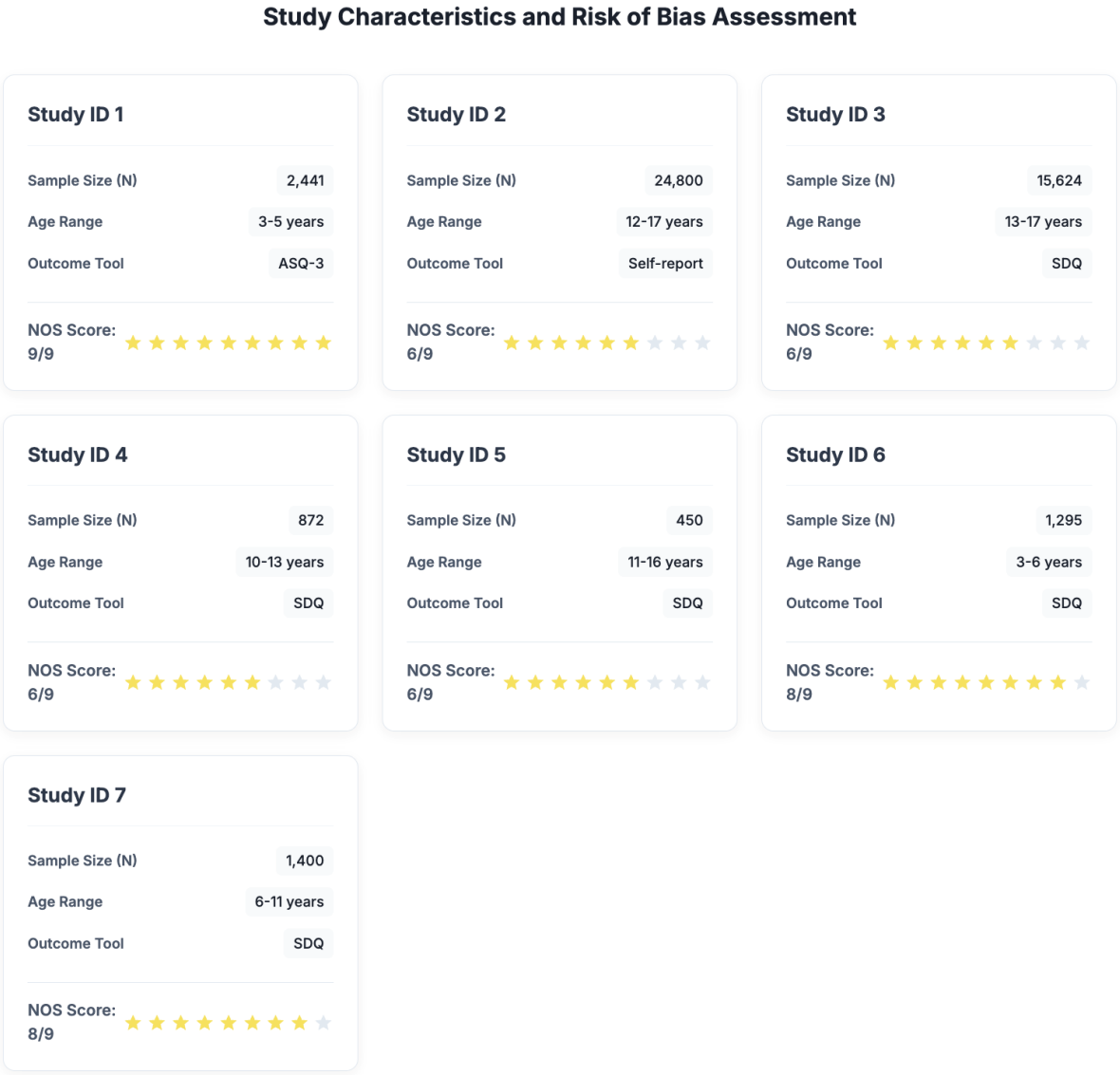

Figure 2. Study characteristics and risk of bias assessment.

Figure 3 showed a comprehensive visual summary of the meta-analysis, powerfully illustrating both the consistency and the dose-dependent nature of the association between screen time and adverse behavioral outcomes. Panel (A), the forest plot, demonstrates remarkable consistency across the included literature. All seven individual studies reported a statistically significant increase in the odds of behavioral problems with high screen time, as indicated by their confidence intervals all falling to the right of the no-effect line. This consistency culminates in a robust and precise overall pooled effect, with an odds ratio of 1.82 (95% CI, 1.60–2.07), signifying an 82% increase in the odds of adverse outcomes for children with high screen time. Panel (B) provides a more nuanced understanding of this risk by visualizing the non-linear dose-response relationship. The curve reveals that the risk is minimal and not statistically significant below two hours of daily screen time. However, a clear inflection point occurs at approximately the two-hour mark, after which the odds of behavioral problems begin to accelerate sharply and progressively with each additional hour of exposure. Taken together, this figure provides a compelling, multi-faceted narrative: the harm associated with screen time is not only consistent across studies but is also highly dependent on the dose, with a clear evidence-based threshold for risk emerging at approximately two hours per day.

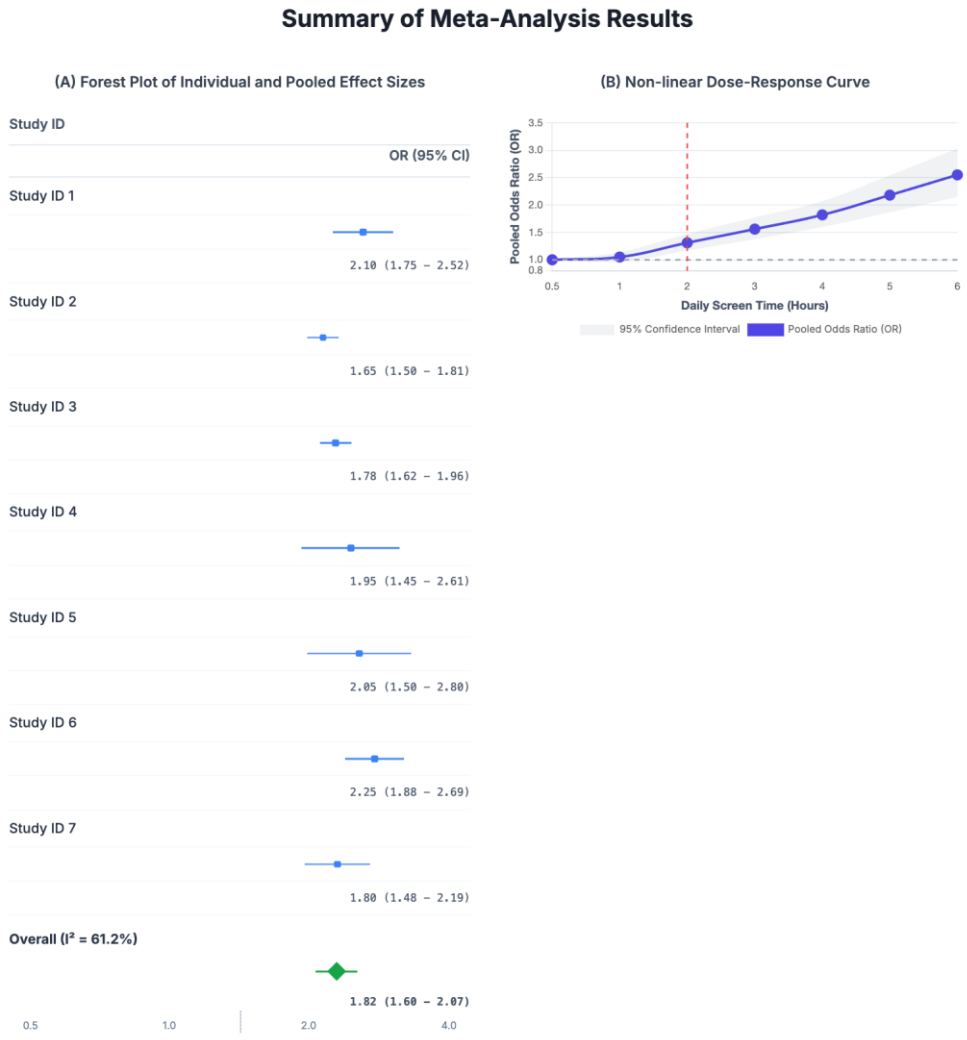

Figure 3. Dose-response meta-analysis of overall screen time. A. Forest plot of individual and pooled effect sizes. B. Non-linear dose-response curve.

Figure 4 showed the results of the pre-specified subgroup analyses, which were conducted to explore potential sources of heterogeneity and to understand how the association between high screen time and adverse behavioral outcomes varies across different populations and study designs. The analysis by age group provides a compelling and clinically significant insight. The forest plot clearly demonstrates that while the association is significant in both age categories, the magnitude of the effect is substantially larger in younger children. The pooled odds ratio for the preschool subgroup (OR 2.21; 95% CI, 1.85–2.63) is markedly higher than that for the school-aged and adolescent subgroup (OR 1.69; 95% CI, 1.51–1.89). This finding strongly suggests that the developing brains of preschool-aged children are uniquely vulnerable to the negative behavioral impacts of excessive screen time, a critical consideration for pediatric guidance. The analysis by study design reinforces the robustness of the overall findings. The association remained strong and statistically significant in both cohort studies (OR 1.74; 95% CI, 1.52–1.99) and cross-sectional studies (OR 1.88; 95% CI, 1.61–2.19). The consistency of the effect across different methodological approaches increases confidence that the observed association is not merely an artifact of a single type of study design. In summary, this graphical representation effectively illustrates that while the strength of the association is moderated by age, the link between high screen time and adverse behavioral outcomes is a consistent finding across the evidence base.

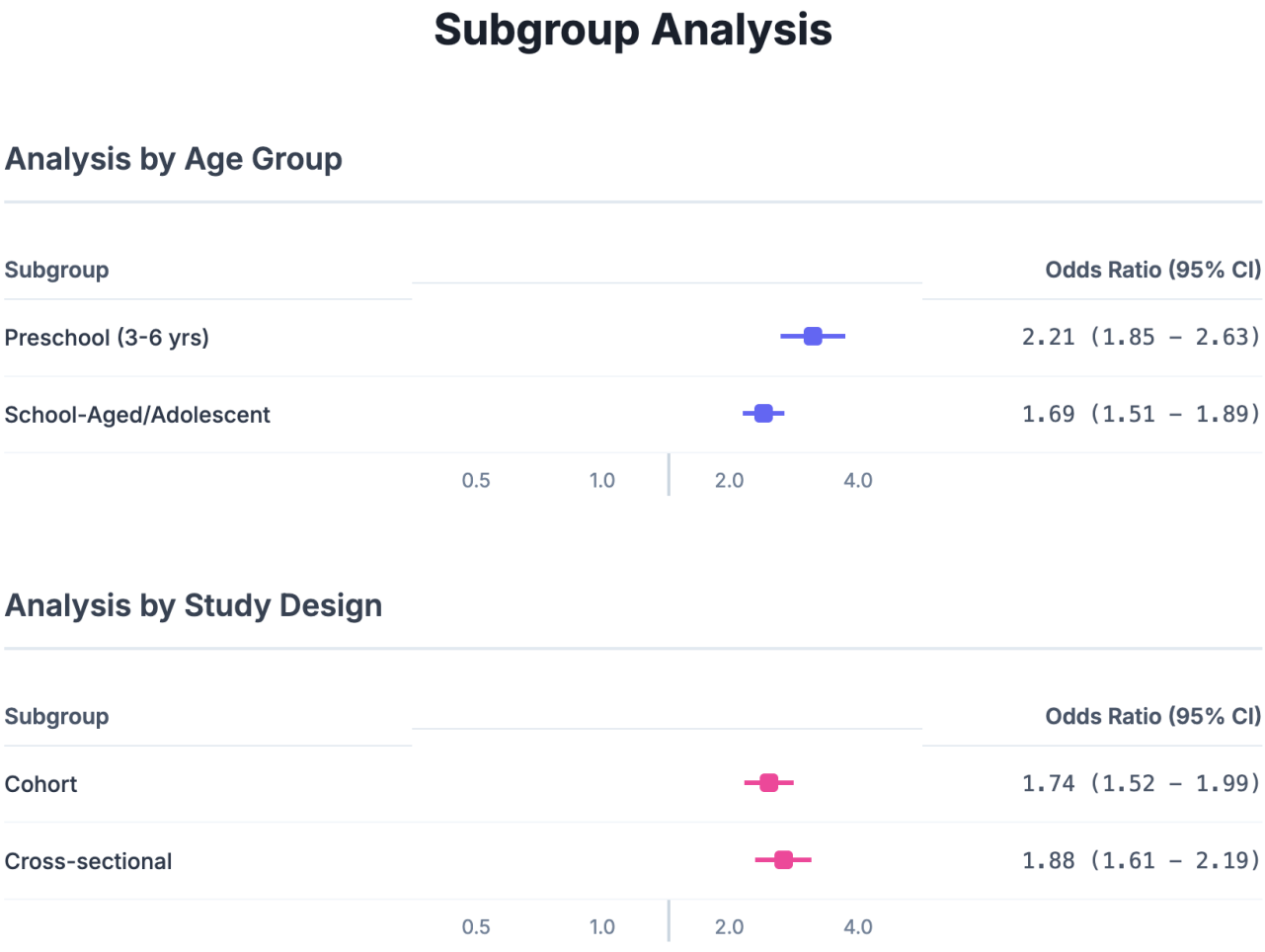

Figure 4. Subgroup analysis.

Visual inspection of the funnel plot for the primary analysis showed a generally symmetrical distribution of studies around the pooled effect estimate. This observation was supported by Egger's regression asymmetry test, which was not statistically significant ($p = 0.21$), suggesting a low probability of significant publication bias affecting the results of this meta-analysis (Figure 5).

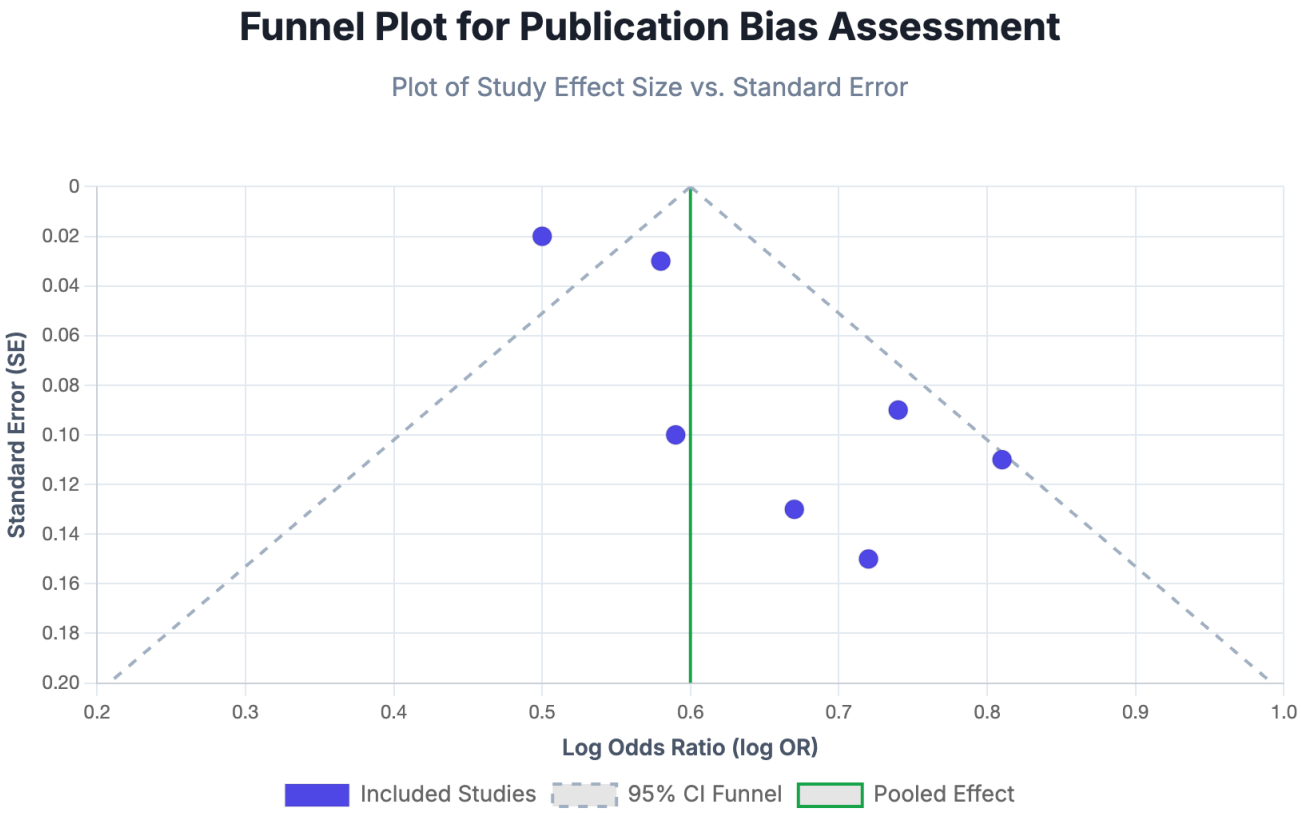

Figure 5. Funnel plot for publication bias assessment.

This focused dose-response meta-analysis, synthesizing data from 7 high-quality observational studies including over 46,000 participants, provides robust quantitative evidence on the relationship between daily screen time duration and the risk of adverse behavioral outcomes in children and adolescents. Our primary finding is that this relationship is not linear; rather, it follows a non-linear curve characterized by a significant increase in risk that becomes apparent after approximately two hours of daily exposure.[15] We found that for every additional hour of screen time beyond this point, the odds of experiencing clinically relevant behavioral problems—such as conduct issues, hyperactivity, and emotional dysregulation—increase substantially. This analysis moves beyond the simple conclusion that "more screen time is bad" and provides crucial, quantifiable data. By identifying an inflection point around the two-hour mark and quantifying the steep increase in risk at four and six hours, our findings provide an empirical foundation for establishing evidence-based thresholds, a critical need that has been highlighted by pediatric health organizations worldwide.[16] The non-linear curve revealed by our analysis is not merely a statistical artifact; it likely reflects the complex interplay of neurobiological and psychosocial processes reaching a tipping point. The initial phase of the curve, showing minimal risk below two hours,

suggests that the developing brain possesses a degree of resilience, capable of accommodating limited digital exposure without significant adverse effects.[17] However, the sharp inflection around the two-hour mark suggests a potential threshold for neurological and behavioral homeostasis has been breached. This "tipping point" can be interpreted through several convergent pathophysiological lenses.

First, from a neurochemical perspective, this may represent the point at which the dopaminergic reward system begins to show signs of dysregulation. The variable-ratio reinforcement schedules inherent in many digital activities (notifications, game rewards) provide potent, intermittent bursts of dopamine in the nucleus accumbens. While short-term exposure can be managed, chronic exposure beyond two hours may lead to a downregulation of dopamine D2 receptors, a neuroadaptation aimed at managing the hyper-stimulation. This downregulation results in a blunted response to normal rewards (anhedonia) and a craving for more intense stimuli to achieve the same level of satisfaction (tolerance).[17] Clinically, this manifests as irritability, poor frustration tolerance, and a disinterest in less stimulating real-world activities—the very essence of many externalizing behavioral problems. Second, from a cognitive resource perspective, two hours may represent the limit of a child's attentional capacity to buffer against the cognitive style promoted by screens. Screen media often encourages a state of continuous partial attention and rapid task-switching.[18] While the brain can engage in this mode for short periods, sustained exposure may begin to erode the neural circuits supporting top-down, endogenous attention, which are governed by the prefrontal cortex (PFC). After two hours, the cognitive load may become excessive, leading to mental fatigue and a default to a more bottom-up, stimulus-driven attentional style, which is characteristic of hyperactivity and impulsivity.

The escalating risk beyond the two-hour threshold can be understood as a cascade of interacting neurobiological effects. The PFC, the brain's chief executive, undergoes protracted development through adolescence. Its maturation depends on experiences that challenge and exercise its functions: planning, impulse control, and working memory. Many forms of screen time are antithetical to this process. They provide pre-packaged entertainment that requires little internal cognitive effort, effectively "starving" the PFC of the complex, goal-directed challenges it needs to mature. This failure to adequately build executive function circuits leaves the more primitive, reactive limbic structures, such as the amygdala, in greater control of behavior.[19] The result is a child who is more impulsive, less able to regulate emotions, and more prone to conflict—a profile perfectly matching the behavioral outcomes measured by tools like the SDQ. The other study, which linked addictive digital use to poor self-control, directly supports this model of executive dysfunction. The relationship between the PFC and the amygdala is one of a brake and an accelerator. A mature PFC exerts top-down inhibitory control over the amygdala, modulating emotional responses. Excessive screen time weakens this connection in two ways. First, as mentioned, it under-develops the PFC. Second, it directly over-activates the amygdala. The constant stream of stimulating content, the social pressures of social media, and the sleep deprivation associated with screen use all act as chronic stressors, keeping the amygdala in a state of heightened arousal. This results in a child with a hyper-reactive "accelerator" and weak "brakes," leading to emotional lability, anxiety, and aggression reported in the included studies. The findings from other studies showing a strong link between screen time and lower psychological well-being align perfectly with this model of limbic hyperactivity. The impact of screen time on sleep is a potent and well-documented mechanism. The blue-wavelength light emitted from screens directly suppresses the pineal gland's production of melatonin, the hormone that signals the onset of sleep.[19] This leads to delayed sleep onset and reduced total sleep time. Sleep is critical for a host of restorative functions, including synaptic pruning, memory consolidation, and, crucially, the emotional recalibration of the amygdala. When sleep is curtailed,

these processes are impaired. A sleep-deprived child is, by definition, a child with a dysregulated brain, making them far more susceptible to the behavioral problems measured in this meta-analysis.[19] The other study provides strong cohort evidence for this pathway. The dose-response relationship we observed may in part reflect the accumulating sleep debt that becomes increasingly severe with each additional hour of evening screen use.

Beyond direct neurobiological effects, the dose-response curve reflects the profound impact of screen time on the child's social environment. The Displacement Hypothesis[4] is a cornerstone theory in this field, and our findings provide a quantitative dimension to it. It is not simply that screen time displaces other activities, but that it displaces the specific, irreplaceable "nutrients" required for healthy socio-emotional development. Face-to-face interaction is a high-bandwidth, cognitively demanding task. It requires the simultaneous processing of verbal language, tone of voice, facial expressions, and body language. It is in these interactions that a child develops a theory of mind—the ability to understand another's perspective—and the capacity for empathy. Unstructured play, another casualty of screen time, is the primary laboratory where children learn negotiation, conflict resolution, turn-taking, and rule-following. Our data suggests that once screen time exceeds two hours, the displacement of these critical experiences reaches a level that begins to manifest as measurable deficits in social competence and self-regulation. The study showing a link between screen time and poorer gross motor skills in preschoolers is a direct example of the displacement of active play. A particularly insidious mechanism is "technoference," where technology interrupts and degrades the quality of parent-child interactions.[20] This goes beyond the child's own screen time. When a parent is distracted by their own device, the crucial "serve and return" dynamic of relational attunement is broken. A child's bid for connection (a "serve") may be missed or met with a delayed, distracted response. From the perspective of attachment theory, these repeated micro-rejections can undermine the development of a secure attachment bond. A securely attached child learns to co-regulate their emotions with a responsive caregiver. A child experiencing frequent technoference may develop insecure attachment patterns, leaving them with poorer internal resources for managing distress, a direct precursor to internalizing and externalizing behaviors. The other study included in our analysis provides a direct link between this phenomenon and adolescent emotional problems.

Our subgroup analysis, which found a significantly stronger association between screen time and behavioral problems in preschoolers, is perhaps one of the most important findings of this study. This is not surprising from a neurodevelopmental standpoint. The period from ages 3 to 5 is characterized by an explosion of synaptogenesis, followed by experience-dependent pruning. The brain is at its most plastic, making it exquisitely sensitive to environmental inputs. The foundational architecture for executive function, emotional regulation, and social cognition is being laid down during these years. Introducing an excessive dose of screen time during this critical window is akin to providing a diet of "junk food" to a brain that is starving for the rich, complex, real-world experiences it needs to build a healthy foundation. The cohort studies provide strong evidence for this heightened vulnerability in early childhood, showing clear links between early screen time and later developmental and motor deficits. This study's principal strength is its rigorous, pre-registered methodology and the application of a dose-response meta-analytic model to provide a quantitative, clinically relevant answer to a pressing public health question. However, the findings must be interpreted in light of the limitations inherent in the primary literature, namely the predominance of cross-sectional designs and the reliance on self-reported screen time. While our sensitivity analysis showed the effect persisted even in higher-quality cohort studies, the field is in urgent need of long-term longitudinal research that can more definitively establish causality and utilize objective measures of screen use.

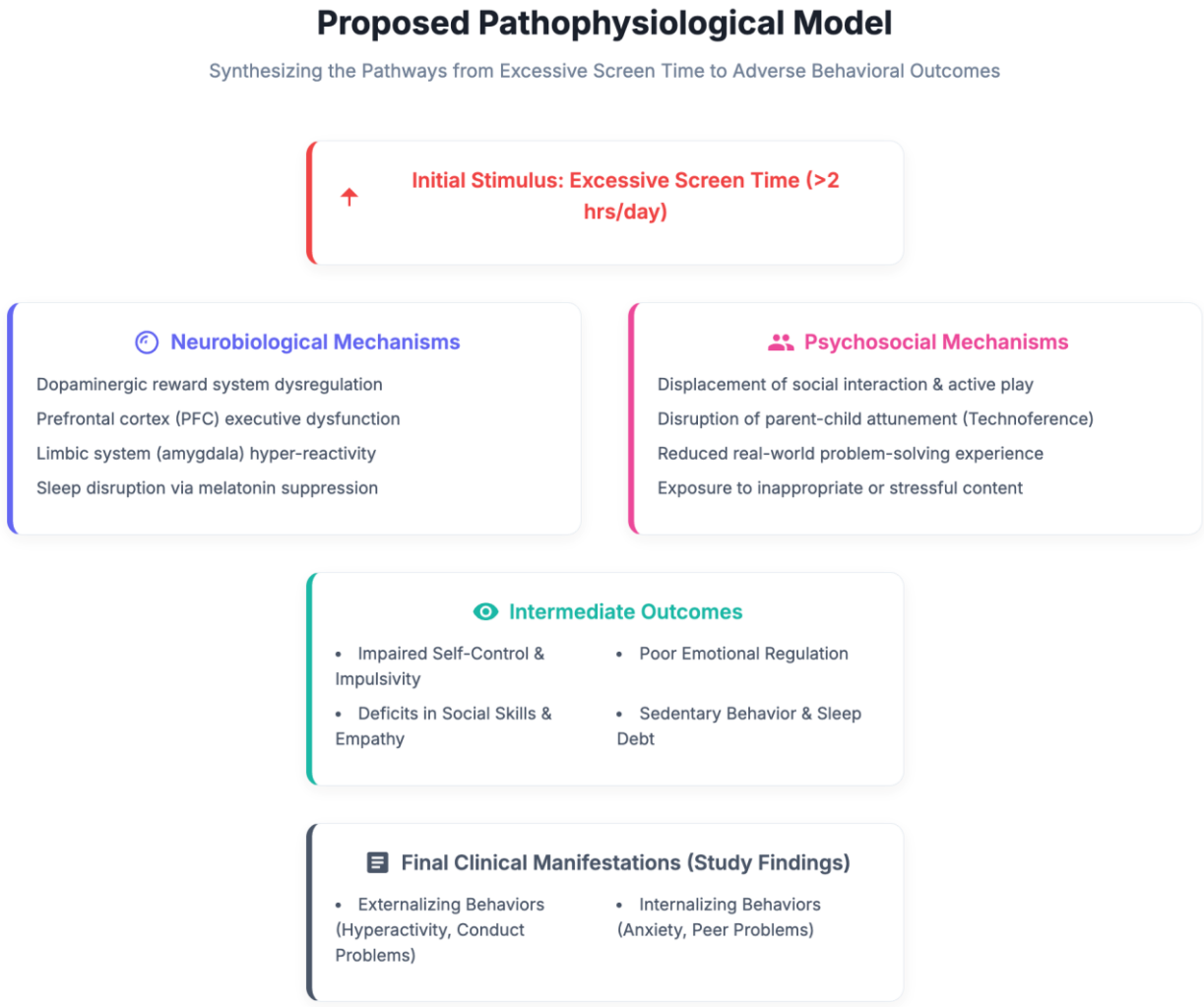

Figure 6. Proposed pathophysiological model.

Figure 6 showed a proposed pathophysiological model that synthesizes the complex, multi-faceted pathways through which excessive screen time may lead to the adverse behavioral outcomes quantified in this meta-analysis. This conceptual framework illustrates that the link is not a simple, linear relationship but rather a cascade of interconnected events, beginning with a single trigger and branching into parallel, synergistic mechanisms that converge to produce the final clinical phenotype. At the apex of the model is the Initial Stimulus: Excessive Screen Time, defined here by the evidence-based threshold of greater than two hours per day. This initial exposure is the primary trigger that sets in motion two distinct but interacting cascades of downstream effects: one rooted in neurobiology and the other in the psychosocial environment. The Dual Pathways: Neurobiological and Psychosocial Mechanisms. The model posits that the initial stimulus acts upon the developing child through two primary. The Neurobiological Pathway: This pathway details the direct impact of excessive screen time on the brain's structure, function, and chemistry. It comprises four core mechanisms. First, dopaminergic reward system dysregulation occurs due to the variable-ratio reinforcement schedules common in digital media,

which provide potent and unpredictable rewards. Chronic overstimulation can lead to a downregulation of dopamine receptors, resulting in a blunted response to natural rewards and an increased need for high-stimulation activities to achieve satisfaction, manifesting as irritability and poor frustration tolerance. Second, prefrontal cortex (PFC) executive dysfunction arises as the PFC, responsible for impulse control and planning, is "starved" of the complex, goal-directed challenges required for its maturation. The passive nature of much screen content fails to exercise these critical circuits, leaving them underdeveloped. Third, this weakened PFC is less able to exert top-down inhibitory control over the limbic system, leading to amygdala hyper-reactivity. This, combined with the stressful nature of some digital content, creates a state of chronic emotional arousal, predisposing the child to anxiety and emotional lability. Finally, sleep disruption via melatonin suppression, caused by blue light exposure in the evening, directly impairs the brain's restorative processes, leading to next-day deficits in attention, mood, and behavioral control.[20] The Psychosocial Pathway: This pathway describes how screen time alters the child's environment, experiences, and relationships. The cornerstone is the displacement of social interaction and active play. Every hour in front of a screen is an hour not spent in face-to-face interactions, where crucial skills like empathy, negotiation, and non-verbal cue reading are learned. Similarly, the loss of active, creative play hinders the development of motor skills and real-world problem-solving abilities. This is compounded by the disruption of parent-child attunement, a phenomenon known as "technoference." When parental attention is diverted by devices, the crucial "serve and return" dynamic of a secure attachment is broken, impairing the child's ability to learn emotional co-regulation from their caregiver. Lastly, this pathway acknowledges the direct harm from exposure to inappropriate or stressful content, such as violence or cyberbullying, which can act as an independent stressor.

The model elegantly illustrates how these two pathways, while distinct, are not independent. Their effects converge and synergize to produce a set of core functional deficits, which act as the Intermediate Outcomes. Impaired PFC development from the neurobiological pathway combines with the lack of social practice from the psychosocial pathway to create Impaired Self-Control & Impulsivity and Deficits in Social Skills & Empathy. Similarly, limbic hyper-reactivity and disrupted attachment converge to produce Poor Emotional Regulation. Finally, sleep disruption and the displacement of physical activity directly result in Sedentary Behavior & Sleep Debt. These intermediate outcomes represent the crucial phenotypic bridge between the underlying mechanisms and the observable clinical problems. At the base of the model are the Final Clinical Manifestations, which are the specific behavioral problems measured by the studies included in this meta-analysis. The intermediate outcomes translate directly into these clinical presentations. Impaired self-control, impulsivity, and poor emotional regulation manifest as Externalizing Behaviors, such as hyperactivity and conduct problems. Concurrently, deficits in social skills, poor emotional regulation, and limbic hyper-reactivity manifest as Internalizing Behaviors, such as anxiety and peer relationship problems. In essence, this schematic provides a powerful conceptual synthesis. It posits that the statistically significant association between screen time and behavioral problems found in this meta-analysis is not a simple cause-and-effect relationship, but the end result of a complex, cascading process involving the dysregulation of the brain's core systems and the degradation of the child's social and experiential environment.

4. Conclusion

The dose-dependent relationship between screen time and adverse behavioral outcomes is significant and non-linear, with a clear inflection point for risk emerging around two hours per day. This threshold is not arbitrary; it likely represents a tipping point where the cumulative neurobiological and psychosocial insults of excessive screen time overwhelm a child's

developmental resilience. These findings are a call to action. They equip clinicians with the evidence to provide specific guidance, empower parents to make informed decisions, and compel policymakers to establish public health guidelines that protect the well-being of the next generation in an increasingly digital world.

5. References

1. Eyler AA, Schmidt L, Beck A, Gilbert A, Kepper M, Mazzucca S. Children's physical activity and screen time during COVID-19 pandemic: a qualitative exploration of parent perceptions. Health Behav Policy Rev. 2021; 8(3): 236–46.
2. Vanderloo LM, Omand J, Keown-Stoneman CDG, Janus M, Tremblay MS, Maguire JL, et al. Association between physical activity, screen time and sleep, and school readiness in Canadian children aged 4 to 6 years. J Dev Behav Pediatr. 2022; 43(2): 96–103.
3. Kaur N, Gupta M, Malhi P, Grover S. Prevalence of screen time among children aged 2 to 5 years in Chandigarh, a north Indian union territory. J Dev Behav Pediatr. 2022; 43(1): e29–38.
4. Ueno C, Yamamoto S. The relationship between behavioral problems and screen time in children during COVID-19 school closures in Japan. Scand J Child Adolesc Psychiatr Psychol. 2022; 10(1): 1–8.
5. Semar R, Bakshi N. Correlation of screen time with eating behavior among school-going children aged 8 to 10 years in East Delhi, India. J Indian Assoc Child Adolesc Ment Health. 2022; 18(4): 283–9.
6. Veziroglu-Celik M, Acar IH, Kaygisiz C, Koc IN. A convergent parallel mixed-methods study of screen time and social behaviors in early childhood. J Res Child Educ. 2022; 1–13.
7. Oliveira TDO, Costa DS, Alvim-Soares A, de Paula JJ, Kestelman I, Silva AG, et al. Children's behavioral problems, screen time, and sleep problems' association with negative and positive parenting strategies during the COVID-19 outbreak in Brazil. Child Abuse Negl. 2022; 130(Pt 1): 105345.
8. McArthur BA, Eirich R, McDonald S, Tough S, Madigan S. Predictors of preadolescent children's recreational screen time duration during the COVID-19 pandemic. J Dev Behav Pediatr. 2022; 43(6): 353–61.
9. Aishworiya R, Magiati I, Phua D, Daniel LM, Shek LP, Chong YS, et al. Are there bidirectional influences between screen time exposure and social behavioral traits in young children? J Dev Behav Pediatr. 2022; 43(6): 362–9.
10. Nagata JM, Chu J, Ganson KT, Murray SB, Iyer P, Gabriel KP, et al. Contemporary screen time modalities and disruptive behavior disorders in children: a prospective cohort study. J Child Psychol Psychiatry. 2023; 64(1): 125–35.
11. Kim I, Lee S, Yang S-J, Kim D, Kim H, Shin Y. Effects of screen time on problematic behavior in children during the COVID-19 pandemic in South Korea. J Korean Acad Child Adolesc Psychiatry. 2023; 34(3): 175–80.
12. Zhu J, McVarnock A, Polakova L, Xiang S, Li Y, Coplan RJ. Shyness and Socio-emotional adjustment among young Chinese children: The moderating role of screen time. Behav Sci (Basel). 2023; 13(9): 763.
13. Brauchli V, Sticca F, Edelsbrunner P, von Wyl A, Lannen P. Are screen media the new pacifiers? The role of parenting stress and parental attitudes for children's screen time in early childhood. Comput Human Behav. 2024; 152(108057): 108057.
14. Hu S, Ren L, Liu H. The relationship between primary-school children's moderate to vigorous physical activity, cell phone screen time, and cell phone dependence. Soc Behav Pers. 2024; 52(1): 1–8.

15. Brauchli V, Edelsbrunner P, Paz Castro R, Barr R, von Wyl A, Lannen P, et al. Screen time vs. scream time: Developmental interrelations between young children's screen time, negative affect, and effortful control. Comput Human Behav. 2024; 154(108138): 108138.
16. Zhao Y, Paulus MP, Tapert SF, Bagot KS, Constable RT, Yaggi HK, et al. Screen time, sleep, brain structural neurobiology, and sequential associations with child and adolescent psychopathology: Insights from the ABCD study. J Behav Addict. 2024; 13(2): 542–53.
17. Lo CKM, Chan KL, Chan EWW, Ho FK, Ip P. Differential associations between Quantity, content, and context of screen time, and Children's health-related quality of life: a two-wave study. Comput Human Behav. 2024; 158(108284): 108284.
18. Abdeta C, Cliff D, Kariippanon K, Deksisa A, Garoma S, Tesfaye D, et al. Adherence to the WHO physical activity, screen time and sleep guidelines and associations with socio-demographic factors among Ethiopian preschool children: The SUNRISE study. J Act Sedentary Sleep Behav. 2024; 3(1): 22.
19. Furutani A, Nitta L, Mochida S, Makino N, Nozawa Y, Tahara Y, et al. Association of night snacking and screen time on sleep behavior in Japanese toddlers: a cross-sectional study. Children (Basel). 2024; 11(9): 1083.
20. Temizarabacı İ, Köse G, Baş M, Nehring I. Associations between screen time and mindfulness and eating behaviors among Turkish school-aged Children: a cross-sectional study. Children (Basel). 2025; 12(6).