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Early Screen Exposure and Neurodevelopment: A Narrative Review of Longitudinal Evidence on Sleep, Brain Structure, and Cognition

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Abstract

Digital devices have become part of children's everyday experiences, raising important questions about how early and repeated screen exposure may influence development. These concerns are particularly relevant during early childhood, when sleep patterns, brain structures, and cognitive abilities are still developing. This narrative review examines evidence on the relationship between screen exposure and neurodevelopment, drawing particularly on longitudinal studies alongside relevant observational research, systematic reviews, meta-analyses, and selected grey literature. Literature was identified through searches of PubMed, Google Scholar, Scopus, ScienceDirect, and the Cochrane Library, with findings synthesized narratively because of differences in study designs, exposure measurements, and developmental outcomes. Across the reviewed literature, greater screen exposure, especially around bedtime, was frequently associated with shorter sleep duration, delayed sleep onset, and poorer sleep quality. Studies also reported associations with language development, attention, and cognitive performance, although these findings were not uniform and appeared to vary with children's ages, the nature of screen use, and caregiver involvement. Evidence concerning brain structure was less conclusive, as relatively few studies directly examined changes in brain volume over time. Taken together, the findings suggest that the developmental implications of screen exposure depend not simply on duration but also on timing and context. However, the largely observational evidence and differences in research methods make it difficult to establish causal relationships. Further longitudinal research is therefore needed to clarify how early screen exposure relates to sleep, brain development, and cognitive growth.

Categories: Neurology, Pediatrics, Healthcare Technology
Keywords: brain volume, cognitive growth, digital devices, early exposure, neurodevelopment, screen time, sleep

Introduction And Background

Digital devices have become so deeply embedded in children's lives that their presence is now difficult to separate from many everyday activities. For young children in particular, this growing exposure has raised important questions about how screen use may relate to their development. Mealtimes, playtime, travel, soothing routines, and, increasingly, bedtime are all accompanied by screens [1]. This means that screen use is no longer merely a lifestyle issue but a developmental one. When children are exposed to digital media too early and too frequently, this exposure occurs during a critical period when the brain is rapidly restructuring, sleep patterns are forming, and the foundations for language, attention, memory, and social learning are being laid [2,3].

For this reason, screen exposure has attracted increasing attention in child health and developmental research. The concern is not simply whether children use digital devices, but how that use fits into their daily experiences. Screen exposure may influence sleep routines, patterns of behavior, interactions with caregivers, and the time available for physical and social activities [3,4]. Although these changes may appear relatively minor when considered individually, their repeated occurrence during early childhood raises questions about their possible developmental implications.

A major challenge in this field is that the discussion often tends to be overly simplistic. Screen use is sometimes viewed as a single, uniform form of exposure, but this is not the case. The experience of a child watching fast-paced entertainment programs alone for long periods is vastly different from that of another child engaging in brief screen use with parents in an interactive setting.

These differences have become more important as children's exposure has expanded beyond television to smartphones, tablets, and other forms of digital media [1,5]. They also make it increasingly difficult to

interpret screen time as a single measure of exposure.

Recent reviews indicate that these concerns are no longer limited to behavioral aspects. Current research now encompasses potential changes in cognitive development, emotional and social functioning, sleep, physical health, and brain-related outcomes [2,6]. This broader perspective is important because the different aspects of neurodevelopment do not occur independently. Sleep, cognitive functioning, emotional regulation, and brain maturation are closely related, and difficulties in one area may have implications for another [3,7]. Understanding these relationships therefore requires attention not only to screen exposure itself but also to the developmental processes with which it may interact.

Among the many widely discussed consequences, there is good reason why sleep stands out. Sleep is not merely a period of rest during childhood; it is an integral part of the developmental process itself. When media use delays bedtime, increases arousal, presents stimulating content before sleep, or replaces routines that promote sleep, the impact may extend far beyond simply reduced sleep duration [8]. Poor sleep quality in children can affect mood, attention, executive function, learning efficiency, and daily behavior. For this reason, sleep is by no means a secondary issue in the debate over screen time. It is one of the most likely pathways through which early exposure to digital devices may have broader effects on neurodevelopment [8].

Another area of growing concern is cognition. In early childhood, children learn through repeated interactions with people, objects, language, and social cues. Development during this stage relies heavily on responsiveness, dialogue, joint attention, and exploratory engagement [2]. If screen use reduces the frequency or quality of these experiences, the effects will manifest not only in behavior but also, over time, in developmental outcomes. Recent studies have linked longer screen exposure to poorer performance on developmental screening measures and broader child health and developmental outcomes [4,9]. These associations do not imply that all forms of screen exposure are harmful, nor do they suggest that screen use exists in isolation from family life. However, this does mean that the impact of early and long-term exposure to digital media on child development warrants further in-depth study.

When the discussion turns to the developing brain, this issue becomes even more pressing. Research in this field has begun to move beyond the widespread concern over “excessive screen time” and toward more biologically grounded questions. Reviews on digital media and brain development indicate that this is not merely a matter of entertainment preferences or parenting styles. It involves the interaction between environmental stimuli and developmental timing [3]. The brains of young children are still forming patterns of connection, regulation, and adaptation. During this period, the quality, timing, and repetition of experiences are all critical. While this does not support alarmist conclusions, there is indeed reason to examine carefully whether excessive or inappropriately timed exposure to digital media might shape developmental trajectories in subtle, cumulative, and clinically significant ways [3,10]. At the same time, this topic must be approached with a balanced perspective. Not every study reaches the same conclusion, nor is every child affected in the same way. Factors such as family background, parental involvement, socioeconomic status, content quality, and the purpose of screen use all complicate the picture [2,5].

These differences make it necessary to examine the available evidence carefully, without assuming that every form of screen exposure has the same developmental implications [6,7].

Despite the growing body of research, important questions remain about how screen exposure during early childhood relates to development over time. Much of the available evidence identifies associations between screen use and particular developmental outcomes, but such findings do not always establish whether exposure preceded the differences observed. This is especially important when considering sleep, brain structure, and cognitive development, as these processes change considerably during childhood and may also influence one another. While cross-sectional studies provide useful information about existing associations, longitudinal investigations offer a clearer opportunity to examine how early exposure relates to later developmental outcomes [4,9]. Even so, the available longitudinal evidence is not equally extensive across these areas, and differences in study populations, exposure measurements, and follow-up periods make comparisons difficult. These limitations leave uncertainty about the persistence of reported associations and the extent to which findings in one developmental domain may help explain changes in another.

Against this background, this narrative review examines the relationship between early screen exposure and neurodevelopment, with particular attention to longitudinal evidence involving children exposed to digital devices between birth and five years of age. The review focuses on three related outcomes: sleep duration and quality, structural measures of brain development, and cognitive or developmental performance. These areas were selected because they reflect different but closely connected dimensions of development. Sleep supports biological regulation, brain structure reflects ongoing processes of neural maturation, and cognitive performance provides an indication of how developmental abilities emerge and change over time [2,3,8]. Although longitudinal investigations remain central to the discussion, evidence from other study designs and older age groups is considered where it provides relevant context.

The study is presented as a narrative review, with its literature identification and selection procedures described with reference to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 reporting principles, rather than as a systematic review. By examining the available evidence across these three areas, the review seeks to clarify what is currently understood, where important uncertainties remain, and which relationships require further longitudinal investigation.

Review

Methods

This study was conducted as a narrative review, with particular attention given to longitudinal evidence on the relationship between early screen exposure and neurodevelopment. This approach was considered appropriate because the existing literature does not examine all aspects of child development in the same way. While some studies follow children over time, others assess screen exposure and developmental outcomes at a particular point or bring together findings from previously published research. These differences are important, especially when considering outcomes such as sleep, brain structure, and cognitive functioning, which may develop or change over different periods. The narrative approach therefore provided an opportunity to examine the available evidence collectively while recognizing the differences in what individual studies could establish. Although longitudinal investigations formed the main focus, findings from other study designs were considered where they contributed to a better understanding of the subject.

A comprehensive literature search was carried out using the databases Google Scholar, the Cochrane Library, PubMed, ScienceDirect, and Scopus over 18 months (from January 3, 2025, to June 2, 2026). Boolean operators (AND, OR) were used in conjunction with keywords such as "screen time," "neurodevelopment," "early exposure," "digital devices," "sleep," "predictive analytics," "brain volume," "cognitive growth," and "longitudinal studies" to narrow and concentrate the outcomes and find pertinent scholarly articles authored in the English language over the previous 20 years.

To improve the clarity and reproducibility of the search process, the search terms were organized around three main concepts: screen exposure, the population of interest, and developmental outcomes. Terms within each concept were combined using OR, while AND was used to connect the different concepts. This arrangement allowed the search to cover several forms of digital exposure alongside outcomes relating to sleep, brain structure, and cognition. The Pubmed search keywords combined were (("screen time"[tiab] OR "screen exposure"[tiab] OR "digital media"[tiab] OR "digital devices"[tiab] OR "screen-based media"[tiab] OR "television viewing"[tiab]) AND (infant*[tiab] OR toddler*[tiab] OR preschool*[tiab] OR child*[tiab] OR adolescen*[tiab]) AND (sleep[tiab] OR neurodevelopment*[tiab] OR "brain volume"[tiab] OR "brain structure"[tiab] OR cognit*[tiab] OR language[tiab] OR attention[tiab])) AND ("2005/07/01"[dp] : "2026/05/31"[dp]) AND english[la]

The same concepts were adapted for the other databases, taking into account differences in their search functions. The following search strategy and terms were used for Scopus: TITLE-ABS-KEY(("screen time" OR "screen exposure" OR "digital media" OR "digital devices" OR "television viewing") AND (infant* OR toddler* OR preschool* OR child* OR adolescen*) AND (sleep OR neurodevelopment* OR "brain volume" OR "brain structure" OR cognit* OR language OR attention)) with publication and language filters of July 2005-May 2026; English.

For Cochrane Library Search Manager, the following was used: #1 ("screen time" OR "screen exposure" OR "digital media" OR "digital devices" OR "television viewing"),ab,kw; #2 (infant* OR toddler* OR preschool* OR child* OR adolescen*),ab,kw; #3 (sleep OR neurodevelopment* OR "brain volume" OR "brain structure" OR cognit* OR language OR attention),ab,kw; #4 #1 AND #2 AND #3

In the case of ScienceDirect, the search terms were ("screen time" OR "screen exposure" OR "digital media" OR "digital devices" OR "television viewing") AND (infant OR toddler OR preschool OR child OR adolescent) AND (sleep OR neurodevelopment OR "brain volume" OR "brain structure" OR cognition OR language OR attention),

For Google Scholar: (1) "screen time" "early childhood" sleep longitudinal; (2) "screen exposure" children "brain structure"; (3) "digital media" children "cognitive development"; (4) "screen time" preschool language longitudinal.

These expressions provided a more consistent basis for identifying relevant literature. However, differences in database coverage and search functions mean that the same expression may not retrieve identical publications across platforms. The strategies presented here are reconstructed expressions and should be verified against the actual searches conducted. Their execution dates, applied restrictions, and retrieval counts must also be documented before they can be used to confirm the reported study-selection figures.

The review prioritized peer-reviewed research, particularly studies that followed children over time and examined developmental outcomes at later assessments. Although longitudinal studies were central to this

review, the available evidence was not equally extensive across all three areas of interest. Research examining screen exposure and sleep was relatively more established, while studies tracking changes in brain structure and cognitive development over time remained more limited. Relying exclusively on longitudinal investigations would therefore have left important aspects of the discussion insufficiently explored. For this reason, the review also considered relevant cross-sectional and repeated cross-sectional studies, systematic reviews, meta-analyses, scoping reviews, and selected grey literature published within the specified period. These sources served different purposes. Cross-sectional studies helped identify patterns of association, while systematic and scoping reviews provided a broader understanding of existing findings, inconsistencies, and gaps in the literature. Grey literature was considered where it offered relevant background or contextual information not adequately captured in peer-reviewed publications. However, these sources were not treated as providing the same level of evidence. Greater emphasis was placed on longitudinal findings when discussing developmental changes over time, while evidence from other study designs was interpreted in light of its methodological limitations. This allowed for a broader examination of the subject without overlooking the differences in what individual studies could reasonably establish.

The selection of publications was guided by their relevance to the objectives of the review, particularly the relationship between screen exposure and sleep, brain structure, or cognitive development. The search covered English-language publications from July 2005 to May 2026, with priority given to research involving children exposed to digital devices between birth and five years of age. Studies involving older children and adolescents were also considered where they provided useful information about developmental changes or possible biological pathways, although their findings were distinguished from evidence obtained directly during early childhood. Longitudinal studies received particular attention because they assessed screen exposure and subsequent outcomes at different points in time. Cross-sectional investigations and evidence syntheses were considered mainly for their supporting contributions, rather than as equivalent evidence of developmental change. Following the initial screening of titles and abstracts, potentially relevant publications were examined in greater detail, while their reference lists were searched for additional literature. Studies addressing unrelated physiological outcomes, informal opinion pieces, and publications without sufficient relevance to the review's objectives were excluded. Selected grey literature was considered for contextual information rather than as primary evidence of neurodevelopmental effects.

Figure *1* presents the identification and selection of publications using a flow diagram informed by PRISMA 2020 reporting principles.

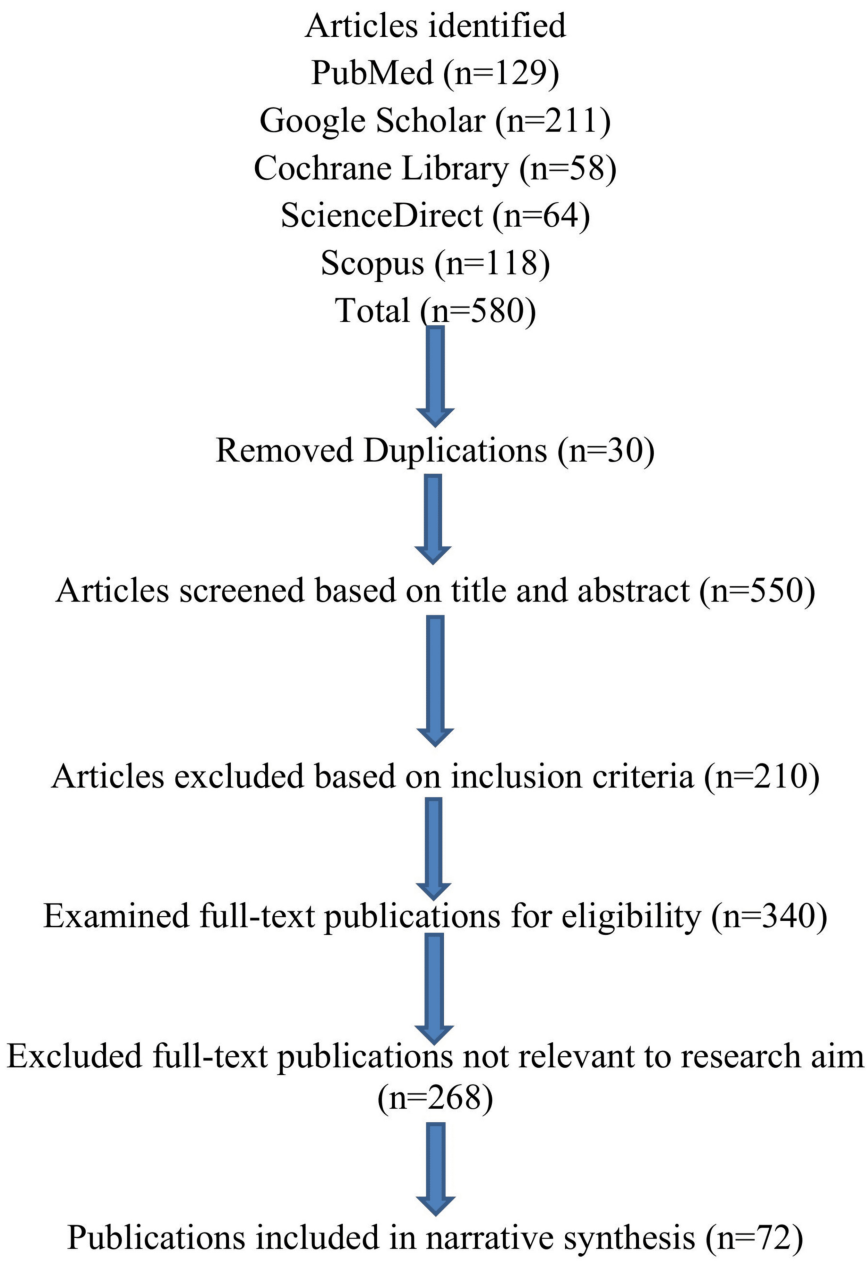

FIGURE 1: A flow chart showing the selection procedure of the study

However, the present study remains a narrative review, and the use of this diagram does not imply that a systematic review or complete PRISMA 2020 assessment was undertaken. The selected publications were examined according to three principal areas: sleep, brain structure, and cognitive development. Greater emphasis was placed on longitudinal findings when considering changes over time, while evidence from other study designs was used to provide additional context and explain areas where the findings remained inconsistent. Differences in participants' ages, exposure measurements, follow-up periods, and developmental outcomes were also considered when interpreting the evidence. Given these methodological differences, no meta-analysis was performed. Instead, the findings were synthesized narratively, with attention to what individual studies could reasonably establish and the limitations affecting their interpretation.

To find pertinent papers on how early exposure to digital devices affects sleep, brain volume, and cognitive growth, an organized review of the available literature was employed.

The literature search across PubMed, Google Scholar, the Cochrane Library, ScienceDirect, and Scopus identified 580 records published between July 2005 and May 2026. Of these, 30 duplicate records were

removed, leaving 550 publications for screening based on their titles and abstracts. At this stage, 210 records were excluded because they did not satisfy the preliminary selection criteria, while 340 publications were retained for full-text assessment. Following a more detailed examination, a further 268 publications were excluded because they did not meet the review's objectives or eligibility requirements. This left 72 publications for the final narrative synthesis. The selection process is summarized in Figure *1*, with the figures for identification, duplicate removal, preliminary screening, full-text assessment, and final inclusion presented separately.

The findings were examined through a narrative synthesis organized around the three principal developmental outcomes: sleep, brain structure, and cognitive development. This approach was considered appropriate because the studies differed in their designs, participants, exposure measurements, and methods of assessing developmental outcomes. Rather than treating the findings as directly comparable, greater attention was given to the direction and consistency of reported associations, particularly where screen exposure was measured before subsequent developmental assessments. Evidence from cross-sectional investigations and systematic reviews was considered alongside longitudinal findings, although differences in methodological strength were taken into account when interpreting their contributions. The synthesis also considered the extent to which study populations represented children exposed during the first five years of life. This made it possible to identify areas where findings appeared relatively consistent and others where the available evidence remained limited or difficult to interpret.

Results

A handful of themes can be employed to expound on how early exposure to digital devices affects sleep, brain volume, and cognitive growth. These themes include (1) definition and overview of neurodevelopment in early childhood; (2) longitudinal study designs in screen time and child development; (3) impact of early screen exposure on sleep duration and quality; (4) association between screen time and sleep disruption in children; (5) effects of screen time on brain volume in developing children; (6) neurobiological mechanisms of screen exposure in brain development; (7) impact of screen time on cognitive growth in early childhood; (8) longitudinal evidence on cognitive development outcomes; and (9) relationship between sleep, brain development, and cognitive outcomes.

Definition of Screen Time in Early Childhood Research

The term “screen time” sounds simple, but its complexity becomes apparent when researchers actually need to define it. At first glance, it seems to refer to the time children spend in front of a screen. But once studies begin comparing different results, this definition starts to blur. Some researchers count only the time spent actively watching or using electronic devices, while others include time spent with the TV playing in the background, family viewing, video calls, gaming, educational apps, and time spent switching between multiple devices [11,12]. This is one reason why, in public discourse, research on “screen time” in early childhood often appears more definitive than its actual methodological approach. Although the term is widely used, the specific forms of engagement it refers to are not always consistent.

Early pediatric media discussions primarily viewed “screen time” as a duration-based concept. The concerns at the time were clear: children were spending increasing amounts of time watching television and engaging with other media, which might crowd out time for sleep, play, reading, and social interaction [13,14]. This framework remains important today, particularly among young children, because time is still one of the easiest variables to measure and one of the most intuitively observable indicators for parents and clinicians. However, duration alone is an incomplete definition. Two children might each spend an hour in front of a screen, but the significance of that hour for their development could be worlds apart. One child might passively consume fast-paced entertainment while eating alone; the other might briefly engage with age-appropriate content alongside a caregiver, who responds, points out objects, and turns the moment into a social interaction. Treating these two scenarios as identical forms of screen time would overlook these crucial differences.

As children’s media environments have expanded, this issue has become increasingly apparent. Screen exposure in early childhood no longer refers solely to watching television in the living room; today, it includes smartphones, tablets, touchscreen apps, streaming content, handheld game consoles, and portable viewing devices that accompany children throughout their day [1,13]. The importance of the device itself is also less significant than it once was. Although televisions, tablets, and smartphones all display visual content, they differ in terms of portability, interactivity, intensity of sensory stimulation, and the potential to disrupt sleep patterns or caregiving moments. For this reason, a valid research definition of “screen time” must go beyond simply asking about “duration” and instead focus on questions such as “what kind of screen exposure occurred, in what context, and at what stage of development” [12,15].

Researchers have responded to this in various ways. A common approach is to define “screen time” as the total duration of daily exposure to screen-based media, typically reported by parents in hours or minutes per day [12,16]. This method remains widely used because it is both practical and allows for efficient data collection in large-scale studies. It is particularly common in cohort studies and population surveys. However, this approach has limitations that cannot be ignored. Parents may be estimating rather than

measuring precisely. They might underreport exposure times they perceive as excessive or overreport content they consider educational. In households where screens are almost always on, they may also struggle to distinguish between their children's direct use and background exposure in the home environment [12]. These issues are by no means trivial, as when measurements of exposure time are imprecise, the associations with developmental outcomes become more difficult to interpret.

Consequently, some studies have attempted to examine screen exposure beyond its total duration. A common distinction is between passive viewing and interactive use, although interactivity does not necessarily mean that a particular digital experience is developmentally beneficial. Educational content may provide opportunities for learning, especially when accompanied by caregiver involvement, while prolonged recreational viewing may offer fewer opportunities for direct social interaction [1,11]. The timing of exposure also matters. Screen use during the day may have different implications from use immediately before bedtime, particularly when the latter interferes with sleep routines. These distinctions are important because two children exposed to screens for the same duration may not necessarily have the same developmental experiences. However, the existing studies do not measure these differences consistently, making it difficult to establish which forms of screen exposure are most strongly associated with particular developmental outcomes.

Screens that replace caregiver interaction, outdoor play, or sleep may have a very different impact on child development than screens used solely for brief communication or guided learning. This does not imply that interactivity automatically makes digital media exposure beneficial; rather, it means that the measures used must align with the specific aspects of child development being examined.

Age-related factors further complicate this definition. During infancy and early childhood, people tend to take a more conservative stance on screen time, as very young children rely heavily on direct interpersonal interactions for language development, emotional regulation, and social learning [1,14]. At this age, even the concept of "use" can be misleading. A child may not actively operate a device but may still be repeatedly exposed to screen media through a television in the background, a video playing nearby, or a device used by an adult in the same room. Although such exposure is difficult to quantify, it may still affect children's attention, parent-child interactions, and daily routines [14]. For preschool-aged children, the scope of the issue expands further. At this stage, researchers must not only consider whether children are exposed to screens but also examine the duration of exposure, the types of devices used, the presence of supervision, and the relationship between screen time and sleep, diet, and learning opportunities [1,16].

This is one reason why pediatric guidelines often define "screen time" from a functional rather than a purely technical perspective. These guidelines do more than simply list devices; they connect screen exposure to the broader context of children's development. Guidelines for young children emphasize that media use should be understood in the context of factors such as age, content quality, caregiver involvement, and whether screen time might replace experiences that are more essential to children's development [1,13,15]. This framework is methodologically valuable because it reminds researchers that screen time is not merely a media variable. In early childhood, it also represents competing patterns of attention, stimulation, daily routines, and interaction.

The World Health Organization recommends no sedentary screen time for infants and one-year-olds, and no more than one hour per day for children aged two to four years [17]. The American Academy of Pediatrics, in its 2026 policy statement, places additional emphasis on the developmental context of children's digital environments, including content quality, commercial design, and caregiver support, and this is different from the old policy statement [2,18]. These recommendations provide practical guidance, although they should not be confused with evidence that screen exposure causes a particular neurodevelopmental outcome.

A review of measurement methods further supports this concern. Byrne et al. found significant variations in the assessment of screen time among children aged 0 to six, including inconsistencies regarding respondents, recall periods, device categories, and whether usage contexts were recorded [14]. Some scales measure only television viewing time; others combine all screen devices into a single total; some ask separately about weekdays and weekends, while others rely on overall estimates. This lack of consistency poses practical difficulties for meta-analyses. When one study defines screen time as exposure to all devices, while another defines it as specific forms of child-initiated use, the actual measurements do not fully align, even if both report "hours per day." This helps explain why researchers in this field often require careful interpretation of study results rather than treating them as fully interchangeable data.

Population data also explains why definitions matter. Estimates of media exposure among young children are influenced by the scope of the data collection. Extensive household surveys indicate that media exposure begins at an early age and may be quite widespread by the preschool years, but the severity of the issue varies depending on the scope of the metrics, whether total exposure time, individual device use, background media, or specific content types are measured [19]. This makes the clarity of definitions more than just a technical preference. It influences prevalence estimates, shapes policy language, and affects parents' perceptions of what constitutes "high-risk use."

Therefore, for research on early childhood, screen time should not be understood as a single, uniform form of exposure but rather as a series of related exposure patterns organized around screen media. Duration remains part of the definition, but duration alone is insufficient. A more comprehensive definition must encompass factors such as device type, content, context, time, interactivity, and developmental age [1,11,12]. Without these elements, the term will struggle to accurately address the questions this paper seeks to answer, particularly in subsequent chapters discussing sleep, brain development, and cognitive growth, as the meaning of "exposure" in these contexts depends largely on how it is initially defined.

Overview of Neurodevelopment in Early Childhood

Early childhood is one of the most active stages of human brain development. During this period, the brain not only grows in size but also undergoes structural reorganization. As children adapt to their environment, neural circuits are constantly formed, strengthened, optimized, and sometimes pruned. This is why early development is often described as being "plastic," though this term can sometimes sound overly abstract. Put simply, this means that the young brain is highly responsive to experience while its structure is still malleable [20,21]. The importance of experiences during this period lies not in the fact that every interaction leaves a distinct imprint, but rather in the rapid pace of development and the ongoing formation of fundamental systems.

One of the most striking features of this stage is the rapid pace of structural change. White matter develops rapidly during early childhood, reflecting increased myelination and improved efficiency in information transmission between different brain regions [21]. This is crucial because early cognitive and behavioral development depends not only on the brain's various regions but also on the smoothness with which connections begin to form between neural networks. The emergence of coordinated processing capabilities supports language development, motor skill development, memory formation, and the formation of early executive functions. These changes do not unfold at the same pace across different brain regions. Certain systems mature earlier, particularly those associated with basic sensory and motor functions, whereas systems involved in more complex regulation, attention, and higher-order learning require more time to develop [22,23].

During this period, brain volume also undergoes significant changes, although volume alone cannot fully serve as a measure of healthy development. Nolvi et al. pointed out that there is a correlation between brain volume in newborns and neural development throughout early childhood; this is important because it suggests that even very early structural differences may influence development over time [24]. This does not mean that brain volume should be regarded as a simple proxy for intelligence or the quality of development. The implication is that brain structures present at birth and during infancy may influence how subsequent developmental factors are experienced. In other words, early brain structure can serve as one of the starting points for a child's development, rather than merely a result of subsequent measurements.

This is one of the reasons why longitudinal studies are so valuable in developmental neuroscience. A single scan or a single developmental assessment can capture only a single moment in an ever-changing process. By modeling sparse longitudinal neurodevelopmental data, Chen et al. directly addressed this issue and demonstrated that early brain development should often be understood as a trajectory rather than a static state [25]. This is particularly important during childhood, as different time points may alter the interpretation of results. A feature that appears delayed at a certain age may return to normal at a later stage. A pattern that initially appears weak may become more pronounced over time. Development is not merely about the state a child is in at a specific moment but rather about the process of change across different periods.

Brain development is also shaped by experiences beyond biological maturation. McLaughlin et al. described how early environmental conditions may influence neural development through different biological and behavioral pathways [26]. This is particularly relevant to the present review, since screen exposure is one of several experiences occurring within a child's broader developmental environment.

The community environment and structural context are equally important. Lewis et al. reviewed the associations between the community environment and brain structure in children and adolescents, demonstrating that neurodevelopment is linked not only to direct interactions within the family but also to broader environmental conditions [27]. Although the review also included older children and adolescents, its findings cannot automatically be extended to early childhood. Nevertheless, it provides useful background for understanding how broader environmental conditions may relate to brain development across different stages.

Child development does not occur in an isolated biological space. Housing quality, safety, resources, stimulation, and environmental stability collectively constitute the environmental context in which neurodevelopment takes place. Therefore, early childhood should be viewed as a critical period characterized by both biological and social development.

Perinatal factors remain crucial. In a study of twins from a nationwide longitudinal survey in Japan, Tamai et

al. found an association between gestational age and children's subsequent health and neurodevelopment [22]. This reminds us that neurodevelopment begins well before birth, and developmental differences observed in childhood may partly reflect prenatal and perinatal conditions. Gestational maturity, delivery circumstances, and early physiological stability collectively form the foundational platform for subsequent development [27]. When examining outcomes in early childhood, these early influences should not be overlooked, as they can both alter baseline developmental levels and affect children's sensitivity to later environmental stimuli.

The same logic applies when tracing later academic and cognitive outcomes back to early brain development. Turesky et al. tracked longitudinal trajectories of brain development from infancy through school age and linked these trajectories to the development of literacy skills [28]. This association is particularly significant because it bridges the gap between structural neurodevelopment and functional outcomes. It demonstrates that early neurodevelopment is not merely a descriptive phenomenon visible on imaging scans; rather, it has practical implications for the skills children use in their future learning. Literacy, language skills, attention, and school readiness do not arise independently of brain development but are shaped by it.

Taken together, these findings help explain why early childhood is an important period for examining the developmental implications of screen exposure. The brain is undergoing rapid structural changes, different regions are maturing at different rates, and experiences continue to shape the organization of neural connections [21,24]. These features do not necessarily mean that screen use alters brain development, but they provide a reason to investigate whether repeated digital exposure is associated with structural differences over time. Longitudinal studies are particularly useful in this regard, since changes observed at one developmental stage may become more apparent, diminish, or take a different form as children grow [23,25].

Longitudinal Study Designs in Screen Time and Child Development

Longitudinal research designs are important in this context because screen exposure is not a one-time event, nor is child development a fixed outcome. Both change over time. A child may initially have limited exposure but later transition to heavy daily use. Sleep quality may deteriorate gradually rather than suddenly. Differences in language, behavior, and developmental performance may not be apparent at the onset of exposure but may become more evident after several months or years. Cross-sectional studies can identify certain associations, but their evidential strength is limited when the central question is whether early screen exposure precedes later developmental changes. It is precisely at this point that longitudinal studies become more valuable [28,29].

One of the most common research methods in this field is the prospective cohort study design. In this research model, researchers follow children at specific developmental stages and conduct an association analysis between screen exposure measured early on and later outcomes. Kracht et al. employed this study design to examine the relationship between screen time among mothers and infants and later growth and development of children [30]. The value of this approach lies in its ability to place the exposure factor chronologically before the outcome, thereby making the direction of the association easier to interpret. Although it does not in itself prove causality, it addresses a major challenge in media research: the difficulty in determining whether screen use influences the development of children or whether children who already exhibit developmental or behavioral differences are more likely to be placed in front of screens.

Another key design feature of this study is the use of repeated developmental assessments across multiple rounds. De Andrade et al. utilized cross-sectional and prospective data to examine the relationship between screen time and neurodevelopment in two Brazilian cohorts separated by 11 years [31]. This design enhanced the interpretability of the findings in two ways. First, it allowed for comparisons between early and later developmental stages within the same broad research framework. Second, it enabled researchers to observe whether the associations remained stable across cohorts exposed to different technological environments. This is crucial because the nature of childhood screen time has changed significantly over the past decade. Cohorts born into television-dominated environments have very different exposure patterns compared to those who have grown up using smartphones and tablets from infancy.

Longitudinal study designs also vary in terms of research intensity. Some large cohort studies collect exposure and outcome data at relatively long intervals, typically once a year or every few years. Other studies employ more frequent repeated measurements over shorter time periods. For example, Parker et al. used an intensive longitudinal study design to explore the feasibility of measuring screen time, activity, and context in households with preschool-aged children [32]. This is methodologically crucial because screen use behavior is often variable at the daily level. Children's screen exposure may vary significantly between weekdays and weekends, days in childcare and days at home, or during routine periods and times of family stress. Consequently, simply estimating "average daily screen time" may obscure important variability. Although high-frequency longitudinal designs are typically smaller in scale and difficult to sustain, they can capture this variability more accurately.

Some longitudinal studies are most persuasive not because they track children over the longest periods, but because they measure the context surrounding screen use more precisely. Hayes et al. examined how children, parenting styles, family, and community factors are associated with screen time among children aged four to seven [33]. This research design helps shift the field's perspective away from viewing screen exposure as an isolated behavior and toward recognizing that media use is an integral part of family life. Parenting styles, family routines, community environments, and social contexts may simultaneously influence both the duration of screen exposure and children's developmental outcomes. From a methodological perspective, this implies that longitudinal studies in this field must not only measure device usage time but also rigorously account for confounding factors.

In research on child development, the issue of confounding factors is particularly critical. A child's developmental trajectory may be influenced by a variety of factors, including socioeconomic status, caregiver education level, sleep habits, childcare settings, parental mental health, preterm birth, and family stimulation. Longitudinal studies are better suited than cross-sectional studies for addressing some of these complexities, provided that their research designs and analyses are sufficiently rigorous to adequately account for these factors. Through the Canadian Early Childhood Study, Kerai et al. used population-level data to link screen time with developmental health [34]. While large population datasets offer greater statistical power and broader representativeness, they also require careful adjustment, as developmental risk factors rarely exist in isolation. In other words, while a study scale can enhance precision, it cannot replace the necessity of careful interpretation.

Repeated-measures designs are particularly useful when research focuses on developmental changes rather than merely the presence or absence of a problem. Nagata et al. tracked changes in screen time, sleep, and physical activity during early adolescence, demonstrating how these behaviors influence one another and co-develop over time [35]. Although the scope of this study extended beyond early childhood, its methodological contributions remain relevant here. It illustrated the benefits of longitudinal media research when media exposure is examined in conjunction with competitive or interactive behaviors, rather than in isolation. Screen use may partially alter developmental trajectories by influencing the behaviors it displaces. If it crowds out sleep, physical activity, social engagement, or language-rich interactions, research designs must be capable of capturing these interrelated developmental trajectories.

Another major advantage of longitudinal studies is their ability to link screen exposure to later functional outcomes that are critical for everyday development. Gath et al. examined the longitudinal associations between screen time and children's language abilities, early learning skills, and peer social functioning [36]. This type of research design is important because it goes beyond broad developmental concerns to delve into specific areas of development. While overall screening scores are useful, analyses of specific outcomes - such as language, early learning, and social functioning - often make research findings more clinically meaningful. Such studies also allow researchers to investigate whether screen exposure is more strongly associated with a particular developmental trajectory.

Nevertheless, the presence of a longitudinal design does not automatically mean that a study provides stronger or more reliable evidence. Much depends on how participants are selected, how exposure and developmental outcomes are measured, and whether other factors that may influence the findings are adequately considered. Selection bias may arise where the children included in a study differ from the wider population, while the loss of participants during follow-up may further affect the representativeness of the findings. Another important limitation concerns the measurement of screen exposure. Many studies rely on parental reports, which are useful for examining large populations but may be affected by recall bias, social desirability, or difficulties in estimating the actual duration and context of screen use [30,32]. Some studies also combine different devices and forms of exposure into a single measure, making it difficult to distinguish between passive viewing, interactive use, or exposure occurring at different times of the day. These limitations become more important when developmental outcomes are also assessed through caregiver reports. Furthermore, factors such as socioeconomic conditions, parental education, family routines, and pre-existing developmental differences may influence both screen exposure and the outcomes observed. Even where statistical adjustments are made, residual confounding cannot always be excluded. No formal study-by-study risk-of-bias scoring was undertaken in this narrative review. The findings must therefore be interpreted with these methodological limitations in mind, particularly when considering the strength of the reported associations.

The importance of developmental differences at baseline is also reflected in longitudinal investigations involving vulnerable populations. Kim et al., for instance, examined growth and neurodevelopmental outcomes among extremely low birth weight infants with congenital abnormalities [37]. Although this investigation did not directly examine screen exposure, it provided useful methodological context by showing why early biological conditions must be considered when interpreting subsequent developmental changes. Children do not necessarily begin from the same developmental baseline, and differences observed during follow-up may reflect several influences operating before or alongside later environmental experiences. For this reason, studies examining screen exposure and neurodevelopment must account for pre-existing developmental conditions wherever possible, rather than attributing subsequent differences to digital media alone.

For this review, the value of longitudinal study designs lies in their ability to link exposure, timing, and developmental trajectories. They help clarify whether early exposure to digital devices precedes later differences in sleep, cognition, or broader developmental functioning; whether these associations persist across multiple assessments; and whether environmental contexts can help explain why screen exposure of the same duration may have different implications across cases [28,29,32]. For this reason, this review relies heavily on evidence from longitudinal studies. Without such evidence, the relevant discussion would likely remain at a descriptive level, but with it, the analysis can move closer to a developmental explanation.

Screen Exposure and Sleep in Children: Duration, Quality, and Timing

Sleep duration and bedtime screen use: One of the earliest and most observable effects of screen exposure in children is its impact on sleep. This is not surprising when considering how sleep develops in early life. During infancy and early childhood, sleep patterns are still being established. Bedtime routines are forming, circadian rhythms are becoming more regulated, and a child's ability to fall asleep depends heavily on environmental cues. When screens are introduced into this process - particularly in the evening - they can influence not only how long a child sleeps but also how easily sleep begins and how restorative it is [36,37].

One of the most straightforward effects is on sleep duration. Early screen exposure is consistently associated with shorter total sleep time, largely due to displacement. Time spent on screens, especially before bed, can delay sleep onset without a corresponding delay in wake time. For children who still need to wake early for school, childcare, or family routines, this results in a net loss of sleep [37,38]. Although this may appear minor - such as a shift of 20 or 30 minutes - it can accumulate over time. In early development, sleep loss is not easily compensated. Even small, repeated reductions in sleep may affect daytime alertness, emotional regulation, attention, and learning efficiency.

The relationship becomes clearer when bedtime screen use is examined directly. Nagata et al., using data from 10,280 adolescents aged 10 to 14 years, found that having a television or internet-connected device in the bedroom was associated with a greater likelihood of difficulty falling or staying asleep (adjusted risk ratio: 1.27; 95% CI: 1.12-1.44) [38]. The association also extended to overall sleep disturbance, although the estimated risk was smaller (adjusted risk ratio: 1.15; 95% CI: 1.06-1.25). These findings are particularly useful in showing that the circumstances surrounding screen use may matter alongside total exposure. However, because the study involved adolescents rather than children in their earliest years, its findings should be interpreted as supporting evidence rather than direct evidence of the same effects during early childhood.

Sleep quality and continuity: Sleep quality is equally important in this context. A child may appear to get enough hours of sleep while still experiencing poor-quality rest. LeBourgeois et al. emphasized that digital media affects not only sleep duration but also timing, latency, and overall quality [39]. Poor sleep quality may involve delayed sleep onset, frequent night waking, lighter sleep, or less restorative sleep patterns. Although such outcomes are often measured through parental reports rather than clinical sleep studies, they remain meaningful indicators of disrupted sleep. Reports of difficulty settling, frequent waking, or persistent tiredness despite adequate time in bed suggest genuine disturbances in sleep quality rather than simple routine inconsistency.

Multiple mechanisms likely contribute to these effects. One is psychological arousal. Screens can be highly engaging, especially when content is fast-paced, interactive, or emotionally stimulating, making it difficult for children to disengage [39]. Another is behavioral conditioning. If screens become associated with winding down, children may come to rely on them as part of their bedtime routine, rather than developing independent self-soothing skills [40]. A third mechanism is biological. Exposure to light from screens, particularly in the evening, may interfere with the physiological processes that support sleep onset [37]. Although this is often discussed in terms of melatonin suppression in older populations, the underlying principle applies to younger children as well: screens can provide signals that delay, rather than promote, sleep.

Evidence from systematic reviews supports these patterns. Han et al. found that electronic media use is associated with poorer sleep quality, while He et al. reported increased risks of adverse sleep outcomes linked to screen time [40,41]. These findings are important because they synthesize results across multiple studies and populations, strengthening the overall reliability of the association. At the same time, variation across studies suggests that factors such as age, content type, and timing of exposure influence the strength of the effect. Despite this variability, the overall trend remains consistent: greater and poorly timed screen exposure is linked to poorer sleep outcomes.

The preschool years are particularly sensitive in this regard. Merín et al. highlight that excessive screen use in preschool children is associated not only with sleep disruption but also with broader behavioral and cognitive effects [42]. Sleep in this age group functions as part of a larger developmental system. Disruption does not remain confined to the night; it affects daytime functioning as well. Children who are poorly rested may become more irritable, less attentive, and harder to regulate, which in turn can influence learning, caregiver interaction, and even future screen use. In some cases, screens may be used more frequently to

manage tired or dysregulated behavior, reinforcing the cycle rather than breaking it.

Earlier foundational work also helps explain why the timing and content of screen exposure deserve attention. Garrison et al., in a study involving preschool children aged three to five years, found that each additional hour of evening media use was associated with a 0.743-point increase in sleep-problem scores (95% CI: 0.373-1.114), after accounting for relevant child and household characteristics [43]. Daytime exposure to violent content was also associated with higher sleep-problem scores, although the estimated increase was smaller (0.398; 95% CI: 0.121-0.676). These findings suggest that the amount of time spent using screens may not fully explain differences in sleep outcomes. When children use screens, and the nature of what they watch, may be equally important considerations.

More recent research also highlights the importance of day-to-day variability. Bourke et al. demonstrated that sleep can vary within individuals depending on daily screen use patterns [44]. This approach captures real-life experiences more accurately than weekly averages. A child's sleep may worsen on days with higher or later screen exposure, even if overall use appears moderate. This suggests that the relationship between screen use and sleep operates not only over long periods but also in short-term fluctuations.

Finally, Silva et al. showed that the relationship between screen use and sleep is not limited to a specific age group or device type [45]. While the context changes across development - from caregiver-managed routines in younger children to more independent device use in older ones - the core pattern remains consistent. Screen exposure close to bedtime tends to disrupt both the timing and quality of sleep.

In this review, the significance of these findings extends beyond the observation that children with greater screen exposure may experience shorter sleep duration. The key point is that early screen exposure can interfere with one of the most critical biological processes in development. Both sleep duration and sleep quality are affected. Children may go to bed later, take longer to fall asleep, experience less restorative sleep, or develop fragmented and screen-dependent routines [36,37,43]. As a result, sleep becomes a central pathway through which screen exposure influences neurodevelopment. Once disrupted, the effects extend beyond the night and into broader aspects of development.

Sleep Onset, Timing, and Circadian Disruption

Beyond its association with sleep duration and quality, screen exposure may also relate to the time children take to fall asleep and the regularity of their sleep schedules. Sleep-onset latency is particularly relevant because a child may spend sufficient time in bed without falling asleep promptly. Evening exposure may contribute to this difficulty through continued stimulation, delayed bedtime routines, or exposure to light at a time when the body is preparing for sleep [8,10]. These changes may also affect the regularity of sleep timing, although direct evidence of circadian rhythm disruption in children during the first five years of life remains limited. For this reason, delayed sleep onset and irregular sleep schedules should be distinguished from confirmed changes in biological circadian regulation.

This broader pattern has been consistently observed in research on media use and sleep. Carter et al. demonstrated that access to and use of portable screen-based devices are associated with adverse sleep outcomes [10]. This finding is particularly important because it shifted attention away from screen time alone toward how screens interfere with sleep behaviors. Portable devices are especially disruptive because they can easily enter the child's personal space. While a television in a shared room can influence bedtime, a smartphone or tablet can be used in bed, remain within reach, and prolong engagement late into the night. This portability fundamentally changes how sleep routines are structured.

Hale and Guan similarly identified a consistent association between screen use and sleep problems in children and adolescents [46]. Their work is valuable because it frames sleep disruption as a pattern rather than a single issue. In reality, sleep problems often occur together, later bedtimes, shorter sleep duration, difficulty falling asleep, and daytime fatigue. As these issues begin to cluster, their clinical significance increases. A child who sleeps later, wakes tired, and struggles with regulation during the day is not simply experiencing a minor routine disruption; this pattern can affect behavior, school performance, emotional stability, and overall family functioning.

The timing of screen exposure plays a critical role in this process. Screen use close to bedtime is particularly disruptive because it directly interferes with the transition into sleep. Martin et al., in their review of interventions targeting children's screen use, identified sleep as a key downstream outcome [47]. This highlights that sleep disruption is not merely a side effect but one of the central pathways through which screen exposure becomes developmentally significant. When a child is cognitively stimulated, emotionally engaged, or resistant to stopping device use, they are less likely to enter bedtime in a calm physiological state. Even after the screen is turned off, sleep onset may remain delayed.

For this reason, bedtime screen use should be considered separately from overall daily exposure. A child may have moderate total screen time but still experience significant sleep disruption if that use occurs at inappropriate times. Ramesh et al. examined screen exposure alongside sleep, behavior, health, and

neurodevelopment in children aged one to five years, highlighting the interconnected nature of these outcomes [12]. In early childhood, sleep disruption rarely exists in isolation. It often extends into mood, attention, activity levels, and caregiver stress. When bedtime becomes prolonged or inconsistent, the effects extend beyond the night and reshape the child's daily routine and family dynamics.

Screen-related sleep disruption may also vary across different groups of children. Cuddihy et al. examined screen use in autistic children and adolescents and found associations with sleep difficulties in this population [48]. These findings are important because they draw attention to differences that may exist between groups of children. Children with autism may experience particular difficulties with sensory regulation, transitions, and sleep routines, which could influence how screen exposure relates to their sleep [46]. However, these findings should not be interpreted as representing the experience of all children during early development. Their relevance to the present review lies mainly in showing that pre-existing developmental conditions may influence the relationship between screen use and sleep, rather than establishing that the same associations occur uniformly across different populations.

The impact of screen use may also extend to the timing of sleep. Evening exposure can interfere with bedtime routines, making it more difficult for children to settle at a consistent hour [37]. Research involving older populations provides some additional context. Twenge et al., for instance, reported an association between greater new-media screen time and shorter self-reported sleep duration among adolescents [49]. Although these findings raise related concerns about screen use and sleep, they should not be taken as direct evidence of circadian disruption in children during the first five years of life.

Zhao et al. provide further insight through their longitudinal analysis of 4,641 participants aged nine to 12 years in the Adolescent Brain Cognitive Development (ABCD) study [50]. Across assessments conducted at baseline and during the following two years, greater screen-media activity was associated with shorter subsequent sleep duration ($\beta = -0.10$; 95% CI: −0.16 to −0.03). Interestingly, the relationship was also observed in the opposite direction, with shorter sleep duration predicting greater subsequent screen-media activity ($\beta = -0.11$; 95% CI: −0.18 to −0.05). This suggests that screen use and sleep may influence one another over time, rather than following a single direction of association. Although the participants were older than the early childhood population emphasized in this review, the findings help illustrate why sleep should be considered alongside screen exposure when examining developmental outcomes.

Evidence from adult populations offers a related perspective, although its relevance to early childhood requires caution. Zhong et al. reported associations between electronic screen use and sleep duration and timing among adults [51]. These findings suggest that the relationship between screen exposure and sleep patterns is not confined to childhood. However, the circumstances surrounding sleep differ across developmental stages, particularly because young children depend more heavily on caregiver-established routines. The adult findings are therefore useful as supporting context, rather than direct evidence of how screen exposure affects sleep regulation during early childhood.

Altogether, the evidence suggests that screen exposure may relate to several aspects of sleep, from its duration and timing to the consistency of bedtime routines [8,10,44]. Although the strength of these associations varies across studies and age groups, their possible implications for development deserve attention, particularly where disrupted sleep becomes a repeated part of a child's daily routine. Table *1* summarizes findings on the impact of early screen exposure on sleep duration and quality from selected studies.

Study	Design; sample	Age at exposure	Exposure measure	Outcome measure	Follow-up	Adjusted finding
Garrison et al., 2011 [43]	Cross-sectional baseline analysis; 612 children	3-5 years	Parent-reported media diary; evening use and content	Children's Sleep Habits Questionnaire	None	Each additional hour of evening media use was associated with a 0.743-point increase in sleep-problem score (95% CI 0.373–1.114).
Nagata et al., 2023 [38]	Cross-sectional ABCD analysis; 10,280 adolescents	10-14 years	Self-reported bedtime screen behaviors and bedroom device access	Sleep disturbance and difficulty falling or staying asleep	None	Having a television or internet-connected device in the bedroom was associated with difficulty falling or staying asleep: adjusted RR 1.27 (95% CI 1.12–1.44).
Zhao et al., 2024 [50]	Longitudinal ABCD analysis; 4,641 participants	9-12 years	Frequency of screen-media activity	Sleep duration and sleep problems	Baseline, year 1 and year 2	Higher screen-media activity predicted shorter subsequent sleep duration: β = −0.10 (95% CI −0.16 to −0.03).

TABLE 1: Summaries of findings on the impact of early screen exposure on sleep duration and quality from selected studies

ABCD: Adolescent Brain Cognitive Development.

Effects of Screen Time on Brain Volume in Developing Children

Brain volume may appear to be a straightforward concept, but in the context of child development it is far more complex than simply assuming that “bigger is better” or “smaller is worse.” During early life, the brain undergoes rapid and uneven change. Different regions develop at different rates, white matter continues to mature over time, and typical development involves both growth and refinement. For this reason, when researchers examine whether screen exposure affects brain volume, the question is more nuanced: whether patterns of digital exposure are associated with measurable differences in brain structure during a period of active development [3,50].

This distinction is important, particularly because the evidence in this area is still developing. While there is substantial research on screen time in relation to behavior and a growing body of work on sleep, fewer studies directly investigate brain volume or structural neurobiology in children. The available evidence is nevertheless useful, particularly where studies have examined screen exposure alongside neuroimaging measures. Such investigations have reported associations with aspects of brain structure, although their populations and methods differ, and relatively little of this evidence directly concerns children exposed during the first five years of life [3,48,50].

One of the more relevant investigations in this area comes from Zhao et al., who examined relationships between screen time, sleep, brain structural neurobiology, and psychopathology using longitudinal data from 4,641 participants aged nine to 12 years in the ABCD study [50]. Their findings identified associations involving screen use, sleep, and structural relationships between brain regions, providing a useful basis for considering how these factors may interact over time. However, the study did not directly examine screen exposure during the first five years of life or establish that digital media caused changes in brain volume. Its findings are therefore important for understanding possible developmental pathways, but their application to early childhood remains limited.

Wu et al. provide a broader perspective by reviewing how early digital experiences shape brain development from infancy through adolescence [5]. Their contribution is important because it situates screen exposure within the context of rapid neural change. The developing brain is highly responsive to its environment, continuously adapting to sensory input, social interaction, language exposure, sleep patterns, and routine. When screen use becomes frequent, prolonged, or poorly timed, it may alter this developmental environment in ways that influence how neural systems organize over time. While this does not necessarily result in obvious changes in total brain size, it does make structural differences biologically plausible.

Christakis et al. extend this argument by examining the effects of early media exposure on cognitive development using both human observational data and experimental studies in mice [52]. This combination is particularly valuable because it allows for exploration of underlying mechanisms, rather than relying solely on association. Their findings support the idea that early media exposure can influence developing neural systems in ways that later affect cognition. In terms of brain volume, this is significant because

structural changes rarely occur in isolation. Differences in volume or regional structure may reflect broader alterations in neural development rather than a single isolated outcome.

Mechanistic explanations are further explored in studies examining neuroinflammation and neurobiological imbalance. Verma et al. investigated the relationship between screen time and neuroinflammatory processes, expanding the discussion beyond simple behavioral associations [53]. Although neuroinflammation is not equivalent to changes in brain volume, it provides insight into potential biological pathways. If screen-related behaviors contribute to stress, disrupted sleep, or excessive sensory stimulation, these factors may influence inflammatory or biochemical processes that, in turn, affect brain development.

Rizzo et al. contribute to this mechanistic perspective by discussing molecular and neurobiological imbalances associated with early use of technological devices [54]. While their focus was not limited to brain volume, this broader approach is important. Although these proposed mechanisms may help explain why researchers are interested in the biological implications of early screen exposure, they should not be confused with direct evidence of changes in brain volume. Their relevance is primarily explanatory, particularly where the underlying structural outcomes have not been measured.

Cai et al. approached the relationship between leisure screen time and neurodevelopmental disorders through Mendelian randomization analyses [55]. This offered a different perspective on questions of confounding and causal inference, which remain important limitations in observational screen-time research. However, the study did not directly assess brain volume. Its relevance to this section is therefore methodological rather than structural, and its findings should not be interpreted as evidence that screen exposure causes anatomical changes in the developing brain.

Takahashi et al. further highlighted the role of individual variability by examining the interaction between screen time and genetic risk for neurodevelopmental disorders [56]. This is significant because it suggested that the effects of screen exposure are not uniform across all children. Genetic predisposition may influence how the brain responds to environmental factors, including digital exposure. As a result, structural outcomes may emerge through interaction between biological vulnerability and environmental input, rather than through a single direct pathway.

Taken together, the evidence supports a cautious but meaningful conclusion. The question is no longer whether screen exposure can relate to brain development, it likely does. The more important questions concern the strength of this relationship, which brain regions may be affected, under what conditions, and through which mechanisms [3,48,52,57]. While direct evidence on brain volume in children remains less developed than evidence on sleep or behavior, the combination of neuroimaging studies, mechanistic research, and work on neurodevelopmental risk makes it increasingly difficult to treat screen exposure as biologically insignificant.

Neurobiological Mechanisms of Screen Exposure in Brain Development

When the focus shifts from whether screen exposure is associated with developmental outcomes to how these effects may occur, the discussion becomes more biologically grounded. The impact on the developing brain is unlikely to result from a single mechanism. Instead, it likely arises from multiple overlapping pathways. Some are direct, such as repeated sensory stimulation and changes in attentional processing, while others are indirect, including sleep disruption, reduced caregiver interaction, altered reward systems, and stress-related biological responses [2,3]. Understanding these mechanisms is important because it moves the discussion beyond simple description and allows for a more meaningful interpretation of how screen exposure may influence development.

One of the most immediate mechanisms is attentional shaping. Digital media typically involves rapidly changing stimuli, frequent novelty, and strong visual or auditory signals. Repeated exposure to this type of input may influence how attention is allocated and sustained in the developing brain. Swing et al. highlight the link between media exposure and attentional difficulties, suggesting that repeated screen-based stimulation may condition children toward shorter attention spans or increased sensitivity to high-intensity input [58]. This does not imply that all media exposure is harmful, but it does emphasize that the nature of the stimulation matters. If children are consistently exposed to fast-paced, externally driven input, slower real-world tasks may become less engaging or harder to maintain attention on.

A closely related mechanism involves experience-dependent plasticity. Brain development depends on repeated interaction with the environment, with frequently used neural pathways strengthening over time and less-used pathways weakening. Hutton et al. emphasized that digital media exposure should be understood within this developmental context [4]. If screen use replaces activities such as conversation, shared attention, physical play, or exploratory learning, the brain is not simply receiving additional stimulation, it is receiving a different type of developmental input. This highlights the importance of displacement as a biological mechanism. The concern is not only what screens provide but also what they may be replacing in the child's environment.

More direct evidence comes from Takeuchi et al., who examined television viewing in relation to regional grey- and white-matter volumes [57]. Their investigation included 276 children and adolescents in the cross-sectional analysis, with 216 participants included in the longitudinal neuroimaging assessment conducted several years later. After accounting for potential confounding factors, the researchers identified positive associations between television-viewing duration and grey-matter volume in particular frontal regions, alongside associations involving other brain areas. They also reported negative associations with verbal intelligence measures. The findings are important because they involve directly measured structural outcomes, rather than relying only on proposed biological explanations. Nevertheless, regional differences in brain volume cannot automatically be interpreted as evidence of developmental impairment, and the study does not establish that screen exposure caused the changes observed.

Further insight into experience-dependent brain plasticity comes from Kühn et al., who examined structural changes following video-game training in young adults [59]. Their findings demonstrated that repeated engagement with a digital activity can be associated with measurable changes in regional grey matter. However, this was an adult training study rather than an investigation of excessive screen exposure in young children. Its contribution to the present discussion is therefore largely mechanistic. It illustrates the brain's capacity to adapt to repeated experiences, while leaving open the question of whether similar processes occur during early childhood and what their developmental significance might be.

Reward processing represents another important pathway. Many forms of digital media are designed to sustain engagement through novelty, feedback, and sensory reward. Clemente-Suárez et al. discussed how digital device use may influence cognitive development in ways that reflect these features [60]. Children do not passively consume media; they interact with it, anticipate it, and return to it repeatedly. Over time, this may shape motivational systems, making highly stimulating digital experiences more appealing than slower, less immediately rewarding activities that are nonetheless important for development. This shift does not need to be extreme to be meaningful, it may gradually influence attention, self-regulation, and learning preferences.

Christakis emphasizes that media exposure in early childhood should be understood from a developmental perspective rather than a purely behavioral one [61]. This is particularly relevant when considering critical periods. During infancy and early childhood, neural systems involved in language, social interaction, and regulation depend heavily on responsive human interaction. While screens provide visual and auditory input, they typically lack the timing, reciprocity, and adaptability of caregiver interaction. The issue is not the absence of stimulation but the mismatch between the type of input provided and the needs of the developing brain.

Anderson and Subrahmanyam further clarify this by highlighting that not all screen exposure is neurologically equivalent [62]. Different types of media-interactive, educational, passive, or overstimulating-place different demands on the brain. This distinction is important because brain development is influenced not only by how much exposure occurs but also by the type of cognitive processing it requires. A child engaged in fast-paced, reward-driven interaction is engaging different neural systems than one involved in slow, language-rich, reciprocal communication.

Another key mechanism operates through sleep. As discussed in earlier sections, screen exposure can delay sleep onset and reduce sleep quality, both of which are critical for brain development [2,48]. Sleep supports processes such as memory consolidation, emotional regulation, and neural restoration. When sleep is disrupted, these processes may be affected, making sleep a central indirect pathway linking screen exposure to neurodevelopmental outcomes.

Stress-related and neuroinflammatory processes have also been discussed as possible pathways through which screen exposure might relate to neurodevelopment. Verma et al. explore these biological mechanisms, particularly in relation to prolonged screen use and its potential physiological implications [53]. However, the evidence remains limited, especially when considering direct measurements of neuroinflammatory changes in young children. For this reason, these pathways are better understood as possible explanations requiring further investigation, rather than established mechanisms through which screen exposure alters early brain development.

Taken together, these mechanisms suggest that screen exposure may influence brain development through several interconnected pathways, including attentional conditioning, displacement of developmentally rich experiences, reward-system reinforcement, and sleep-related biological effects [2,57,50]. Importantly, none of these mechanisms requires the assumption that screens directly “damage” the brain. A more accurate interpretation is that the developing brain adapts to repeated patterns of input and experience. When digital exposure becomes excessive, poorly timed, or developmentally mismatched, these adaptations may not support optimal neurodevelopment. Table *2* compares findings from different study designs on the neurobiological mechanisms of screen exposure in brain development.

Study	Design; sample	Age at exposure	Exposure measure	Outcome measure	Follow-up	Adjusted finding
Takeuchi et al., 2015 [57]	Cross-sectional and longitudinal MRI analyses; 276 at baseline, 216 in longitudinal analyses	Approximately 6-18 years	Television-viewing duration	Regional grey- and white-matter volumes; verbal IQ	Several years; exact interval to verify	Adjusted analyses identified regional volume associations, including frontal grey matter. A numerical coefficient with CI has not yet been verified.
Zhao et al., 2024 [50]	Longitudinal ABCD analysis; 4,641 participants	9-12 years	Frequency of screen-media activity	Thalamus–prefrontal cortex–brainstem structural covariation and behavioral outcomes	Baseline, year 1, and year 2	Indirect effect linking baseline structural covariation with later screen-media activity through externalizing behavior: 0.032 (95% CI 0.003–0.067). This is not an estimate of brain-volume change caused by screen exposure.

TABLE 2: Findings from different study designs on the neurobiological mechanisms of screen exposure in brain development

ABCD: Adolescent Brain Cognitive Development.

Impact of Screen Time on Cognitive Growth in Early Childhood

Cognitive development in early childhood is not driven by information alone. It emerges through interaction, repetition, attention, language exposure, play, and the gradual ability to process and apply experience. For this reason, the impact of screen time on cognition cannot be reduced to a simple question of whether children are "learning from screens" or "being harmed by them." A more meaningful question is what kind of cognitive environment screens create, what experiences they may replace, and whether they support or interfere with the developmental processes most critical at this stage [1,2].

This issue is particularly important because early cognitive development relies heavily on direct human interaction. Young children do not learn in the same way as older individuals. Their learning depends on shared attention, turn-taking, imitation, emotional feedback, and repeated engagement with people and objects in their environment [51]. When screen exposure becomes frequent, especially in passive or solitary forms, it may reduce opportunities for these types of interactions. While the effects may not be immediately visible, they can accumulate over time and influence developmental trajectories.

Research has already linked screen exposure to broader cognitive and academic outcomes. For example, Adelantado-Renau et al. found that higher levels of screen media use are associated with poorer academic performance in children and adolescents [63]. Although this finding extends beyond early childhood, it remains relevant. In younger children, the effects are less likely to appear as academic grades and more likely to manifest in areas such as language development, school readiness, attention, and early executive functioning.

Language development provides one of the clearest examples of how screen exposure may influence cognition. Massaroni et al. emphasized that language acquisition depended on interactive, responsive communication rather than passive exposure to words [64]. Children benefit most when language is directed toward them, adapted to their responses, and embedded within shared activities. While screens can present language, they typically lack the reciprocity and timing of real interaction. As a result, they do not provide the same developmental support for language growth.

Shah et al. further illustrated this point by examining television exposure alongside parent-child conversation during shared viewing and its relationship to curiosity in kindergarten-aged children [65]. Their findings highlight that the impact of screens is not determined by exposure alone but also by context. When parents actively engage with children during screen use, the experience becomes more interactive and cognitively stimulating. This does not eliminate developmental concerns, but it suggests that one key pathway through which screen exposure affects cognition is by either limiting or supporting meaningful interaction.

Attention is another critical component of early cognitive development. During this stage, children gradually develop the ability to sustain attention, selectively focus, and engage with tasks that are not immediately stimulating. Jourdren et al. highlighted that screen exposure may influence these processes

[66]. Fast-paced digital content often relies on novelty and rapid changes, which can repeatedly draw attention outward. Over time, this may make slower, real-world tasks - such as reading, problem-solving, or structured learning - more difficult to sustain. This underscores the importance of not only how much screen time children have but also the nature of the content they engage with.

Executive function is also central to this discussion. Maeneja et al. showed that executive functions - including working memory, inhibitory control, and cognitive flexibility - begin developing early in childhood [67]. These skills are foundational for later learning and behavior. If digital environments consistently encourage immediate responses, rapid shifts in attention, or reduced tolerance for delay, they may shape how these regulatory processes develop over time. Although the evidence is still evolving, the concern aligns with established knowledge of early neurocognitive development.

Memory development is similarly interconnected with other developmental processes. Nastaran highlighted how screen exposure relates not only to memory but also to language, sleep, and interaction in early childhood (Dissertation: Nastaran N. How Early Screen Exposure Shapes Language Development, Memory, Sleep, and Interaction in Infants: A Systematic Review; 2023). Memory does not develop in isolation. A child who experiences disrupted sleep, reduced interaction, or increased passive engagement may not only process information differently but also consolidate learning less effectively. This reinforces the idea that cognitive development is cumulative and shaped by multiple interacting factors.

Long-term research also suggests links between early screen exposure and later educational outcomes. Hancox et al. found that television viewing in childhood was associated with later educational achievement [68]. Although this study predates the current digital environment, its relevance remains. It shows that concerns about screen-related displacement of learning experiences are not new. What has changed is the intensity, accessibility, and personal nature of modern digital media.

Njiru and Odundo expanded the discussion by examining screen use in different cultural and socioeconomic contexts [69]. Their work highlighted that while patterns of exposure may vary globally, the underlying developmental questions remain consistent. As screen use becomes more widespread, attention increasingly focuses on its potential impact on thinking, learning, communication, and self-regulation across diverse settings.

Importantly, earlier sections of this review have shown that screen exposure can influence sleep and may relate to brain development. These connections are directly relevant to cognition. A child who sleeps poorly may struggle with attention and learning, while a child whose routine is dominated by passive screen use may receive less language input and fewer opportunities for active problem-solving [8,37]. Thus, the cognitive impact of screen exposure is unlikely to result from a single mechanism. Instead, it likely emerges through multiple interconnected pathways, including reduced interaction, altered attention patterns, disrupted sleep, and the displacement of cognitively enriching experiences.

For this reason, the impact of screen time on cognitive growth in early childhood should not be framed narrowly in terms of intelligence. It is better understood as a question about developmental conditions. Does the child's environment provide sustained interaction, rich language input, consistent routines, and adequate sleep? Or is a significant portion of that environment shaped by screen exposure that is passive, overstimulating, or poorly timed? The evidence does not support extreme conclusions, but it does support a cautious approach. Cognitive development depends on patterns of experience, and screen exposure becomes important when it begins to reshape those patterns in meaningful ways.

Longitudinal Evidence on Cognitive Development Outcomes

One of the key strengths of longitudinal evidence in this area is that it allows cognitive development to be examined as an ongoing process rather than a single snapshot. Cross-sectional studies can show that children with higher screen exposure often perform differently on cognitive or developmental measures, but they cannot determine whether the exposure preceded the outcome, whether the pattern persists over time, or whether it reflects underlying factors such as temperament, family routines, or baseline developmental differences. Longitudinal studies address these limitations by following children over time and assessing whether early screen exposure predicts later cognitive performance [4,9].

This distinction is important because cognitive development unfolds gradually. A child may appear typical at one stage but later show slower progress in areas such as language, school readiness, or attention as developmental demands increase. For this reason, longitudinal research is more informative than single time-point comparisons when examining screen-related developmental risk. It allows researchers to assess whether associations persist, strengthen, or weaken over time, and whether certain developmental periods are particularly sensitive to exposure [68,69].

Zheng et al. provide a strong example of this approach by examining the relationship between screen time, sleep, extracurricular activities, and cognitive development within a longitudinal framework [70]. This study is particularly valuable because it does not treat cognition as something influenced by screens in isolation.

Instead, it situates screen exposure within a broader set of daily activities that shape development. This is important methodologically, as screen time often has indirect effects by displacing other activities. If increased screen use reduces time spent on sleep, reading, play, or structured interaction, then cognitive outcomes may reflect these broader developmental trade-offs rather than a simple direct media effect. Longitudinal designs are especially useful for capturing these patterns over time.

Yamamoto et al. provided more direct longitudinal evidence from early childhood through their analysis of 57,980 children enrolled in the Japan Environment and Children's Study [71]. The researchers examined television and DVD viewing at ages one, two, and three years alongside performance on developmental screening measures. Greater screen exposure at age one was associated with lower developmental scores at age two (β = −0.05; 95% CI: −0.06 to −0.04), while exposure at age two was similarly associated with poorer performance at age three (β = −0.08; 95% CI: −0.09 to −0.06). Although these associations were relatively modest, they are important because exposure and developmental performance were assessed at different stages rather than at a single point in time. The findings therefore support further consideration of how screen use during the earliest years relates to subsequent development, without establishing that exposure alone was responsible for the differences observed.

The findings from individual longitudinal studies also need to be considered alongside evidence obtained from broader reviews. Teague et al., through their systematic review and meta-analysis, examined associations between digital media use and different aspects of child health and development [4]. Their findings provide a broader perspective, although the studies included in such analyses do not necessarily measure screen exposure or developmental outcomes in the same way. This distinction becomes important when comparing the longitudinal findings of Madigan et al. and Yamamoto et al., both of whom reported associations between greater early screen exposure and lower subsequent developmental performance [11,71]. While these findings point in a similar direction, they were obtained from different populations and exposure measurements, making their estimated effects not entirely interchangeable. The agreement between studies therefore strengthens the need to investigate these relationships, but it does not eliminate the possibility that family circumstances, measurement differences, or other developmental factors may have contributed to the associations observed.

Nagata et al., using prospective ABCD data, also identified links between screen time and mental health outcomes [17]. Although this study is not focused exclusively on cognition, it remains relevant because cognitive development in childhood is closely tied to emotional and behavioral functioning. Skills such as attention, learning, and self-regulation are deeply interconnected with mental health. Longitudinal evidence linking screen exposure to psychosocial outcomes therefore helps explain why cognitive effects may emerge gradually, rather than appearing immediately.

Miura and Tanimoto highlighted an important limitation in interpreting longitudinal evidence: variability in how studies define screen exposure and developmental outcomes [18]. This is a critical issue, as conclusions depend heavily on how exposure is measured at baseline and how outcomes are assessed later. Measures based solely on total screen time may overlook differences in content, context, or timing, while broad developmental screening tools may detect general delays without identifying specific cognitive domains. Although longitudinal designs are stronger than cross-sectional approaches, their validity still depends on careful and consistent measurement.

Further evidence comes from Madigan et al., who followed 2,441 children across developmental assessments at 24, 36, and 60 months [11]. Their analysis found that greater screen time at 24 months was associated with poorer developmental screening performance at 36 months (β = −0.06; 95% CI: −0.10 to −0.01). A similar association was observed between screen exposure at 36 months and developmental performance at 60 months (β = −0.08; 95% CI: −0.13 to −0.02). These findings are significant because they place screen exposure before the subsequent developmental assessment, providing a clearer picture of the temporal relationship. However, the estimated associations were small, and the developmental screening measures covered several domains rather than providing a direct assessment of intelligence alone. This distinction matters when interpreting the broader implications of early screen exposure for cognitive growth.

Another strength of longitudinal research is its ability to distinguish between temporary fluctuations and persistent patterns. Child development is not linear, and short-term changes-such as a week of poor sleep, family stress, or increased screen use-may affect behavior without producing lasting developmental consequences. Longitudinal designs make it possible to determine whether observed associations persist over time or resolve as conditions change [68,69]. This is why studies with repeated assessments are generally more informative than those relying on a single baseline and outcome.

Developmental timing is another key consideration. Evidence increasingly suggests that earlier exposure may have stronger effects than later exposure, not because older children are unaffected, but because early cognitive development depends heavily on interaction and routine during sensitive periods [4,69]. This makes toddlerhood and the preschool years particularly important in research on cognitive outcomes. A child with high screen exposure at age two may not simply be showing a preference for screens but may be developing within a context that alters sleep, interaction, language input, and attentional experience during

a critical stage.

Overall, the longitudinal evidence suggests that early screen exposure may be associated with later differences in developmental and cognitive performance, although the strength of these associations varies across studies. The findings reported by Madigan et al. and Yamamoto et al., for instance, indicate relatively small associations between greater screen exposure and subsequent developmental scores [11,71]. These results remain important because exposure and developmental outcomes were assessed at different points in time, but their magnitude should not be overlooked when considering their practical significance. Furthermore, differences in exposure measurement, developmental assessment, and statistical adjustment make it difficult to compare the estimates directly or interpret them as evidence of a uniform developmental effect. The value of longitudinal research therefore lies not only in identifying associations over time, but also in helping to understand their consistency, strength, and possible explanations. These findings support continued investigation without establishing that early screen exposure inevitably leads to long-term cognitive impairment. Table *3* summarizes and compares longitudinal evidence on cognitive development outcomes from selected longitudinal studies.

Study	Design; sample	Age at exposure	Exposure measure	Outcome measure	Follow-up	Adjusted finding
Madigan et al., 2019 [11]	Three-wave longitudinal cohort; 2,441 children	24 and 36 months	Parent-reported screen time	Developmental screening performance	Assessments at 24, 36 and 60 months	Higher screen time at 24 months predicted lower developmental scores at 36 months: β = −0.06 (95% CI −0.10 to −0.01); at 36 months it predicted lower scores at 60 months: β = −0.08 (95% CI −0.13 to −0.02).
Yamamoto et al., 2023 [71]	Longitudinal birth cohort; 57,980 children	1 and 2 years	Television/DVD viewing duration	Ages and Stages Questionnaire, third edition (ASQ-3)	Assessments at 1, 2 and 3 years	Greater viewing time predicted lower subsequent developmental scores at age 2: β = −0.05 (95% CI −0.06 to −0.04); and age 3: β = −0.08 (95% CI −0.09 to −0.06).
Gath et al., 2026 [36]	Prospective longitudinal cohort; 6,281 children	2-4.5 years	Daily screen exposure	Language, educational skills and peer functioning	Outcomes at 4.5 and 8 years	For direct screen use at age 2, covariate-adjusted standardized language scores at age 4.5 were 0.15 for 0 h/day versus −0.06 for 2 h/day (difference −0.21). These are adjusted mean scores, not a regression coefficient; Table 7 does not give a 95% CI for this contrast.

TABLE 3: Comparison of the longitudinal evidence on cognitive development outcomes from selected longitudinal studies

Comparative Summary of Principal Longitudinal Studies

The longitudinal investigations reviewed in this study differed considerably in their populations, exposure measurements, and developmental outcomes. Some followed children from infancy through the preschool years, while others examined older participants across later stages of development. These differences are important because findings obtained during adolescence may not necessarily reflect the same processes occurring during early childhood. Table *4* brings together selected longitudinal investigations to illustrate their principal characteristics and findings, while recognizing that the strength of evidence varies across the studies.

Study	Country and sample size	Age at exposure	Follow-up period	Screen exposure measure	Outcomes assessed	Principal findings
Madigan et al., 2019 [11]	Canada; 2,441 children	24 and 36 months	Assessments at 24, 36, and 60 months	Parent-reported weekly screen time	Developmental screening performance	Greater screen time at 24 and 36 months was associated with lower subsequent developmental scores (β = −0.06 and −0.08, respectively).
Yamamoto et al., 2023 [71]	Japan; 57,980 children	1 and 2 years	Assessments at 1, 2, and 3 years	Television/DVD viewing duration	Developmental performance measured using ASQ-3	Greater viewing time was associated with lower subsequent developmental scores at ages 2 and 3 years (β = −0.05 and −0.08, respectively).
Gath et al., 2026 [36]	New Zealand; 6,281 children	2-4.5 years	Outcomes assessed at 4.5 and 8 years	Daily screen exposure	Language, early educational skills, and peer relationships	Higher screen exposure was associated with poorer language and educational performance and greater peer difficulties, although adjustment for family circumstances reduced the associations.
Zhao et al., 2024 [50]	United States; 4,641 participants	9-12 years	Baseline, year 1, and year 2	Frequency of screen-media activity	Sleep, brain structural covariation, and psychopathology	Greater screen-media activity predicted shorter subsequent sleep duration (β = −0.10; 95% CI: −0.16 to −0.03). The structural analyses examined covariation rather than direct changes in brain volume.

TABLE 4: Comparative summary of selected longitudinal studies on screen exposure and developmental outcomes

ASQ-3: Ages and Stages Questionnaire, Third Edition; β: standardized regression coefficient; CI: confidence interval.

These findings show that longitudinal evidence is more directly available for developmental screening and cognitive outcomes during early childhood than for changes in brain structure. Studies involving older participants provide additional information about possible developmental pathways, but their findings should not be interpreted as direct evidence of the same relationships among children exposed before the age of five.

Relationship Between Sleep, Brain Development, and Cognitive Outcomes

In developmental research, sleep, brain development, and cognitive outcomes tend to be considered separately. However, in reality, each of these elements is inherently related to the other two. In particular, early childhood sleep cannot be viewed as merely an activity inserted between wakefulness phases. Rather, sleep is an integral aspect of development during this period. During sleep, children continue organizing their brains, which directly influences subsequent memory formation, learning, and attention abilities [2,37]. Thus, by disrupting sleep, screen exposure can also influence further brain development and cognitive growth indirectly.

The first way of doing so would be by changing brain development by affecting sleep. Sleep is considered to be one of the most important regulators of development since it is crucial for memory consolidation, emotional and attention regulation, as well as restoration of previously activated brain networks [37]. Disruption in sleeping patterns can lead to poor nighttime behavior and affect subsequent functioning during the daytime; however, sleep can play an even more critical role by potentially disturbing the process of brain development over time.

That is why it is essential to consider the possible influence of screen exposure on brain development during sleep. According to several reviews, such as the works done by Han et al. and He et al., there is a strong relationship between screen exposure and poor sleep outcomes, including decreased sleep quality and general sleep problems [38,41]. As soon as the relationship between screen exposure and sleep disturbance is confirmed, it is necessary to identify whether the latter influences the process of brain development or any subsequent cognitive issues.

It is precisely this relationship that is explained by Zhao et al. by discussing the influence of screen time on sleep, brain structure and function, and potential psychopathology in children as part of the ABCD study

[50]. The significance of the authors' contribution lies in establishing the connection between the three mentioned aspects in a manner that shows the role of sleep within a certain developmental sequence. Rather than establishing a single causal sequence, the findings suggest that screen exposure, sleep-related measures, brain structure, and subsequent emotional or behavioural outcomes may be connected through several developmental pathways.

It is true that the described process does not indicate the exact pathways through which screen exposure may be linked to the mentioned developmental outcomes for each individual. However, by considering sleep as an influential factor in this sequence, it is possible to understand the role it may play in the entire system. It becomes clear that it is essential not to look at screen exposure or its negative consequences individually but see it as a process through which sleep gets affected and that, in turn, impacts further development.

This relationship deserves particular attention during childhood, when white matter maturation and the organization of neural networks are still taking place [3,21,23]. Sleep disruption may alter some of the conditions under which these developmental processes occur, although this does not necessarily mean that measurable structural changes will follow. The available evidence remains insufficient to determine how consistently screen-related sleep disturbances are associated with later changes in brain structure. Nevertheless, sleep remains an important consideration when examining the broader relationship between early screen exposure and neurodevelopment.

As a natural consequence, cognitive outcomes get affected since they are dependent on children's ability to pay attention, interact with peers and teachers, retain new knowledge, etc. [37,64]. In such a case, cognitive problems resulting from increased screen exposure cannot be related only to its content or inability to interact with other children. Instead, they might depend largely on the quality of sleep, which determines how effectively the brain functions in subsequent days.

One additional factor that is important in discussing this relation is the demonstration of longitudinal changes in screen use, sleep disturbances, and activity patterns in children provided by Nagata et al. [35]. This study is significant due to demonstrating that sleep is a component of developmental routines, alongside physical activity, school workload, etc. Consequently, where screen exposure is associated with differences in sleep and activity patterns, these relationships may need to be considered alongside other factors when interpreting subsequent cognitive outcomes.

Sticca et al. made similar assumptions about screen time and provided them from the perspective of developmental psychology, rather than media studies [9]. Such an approach can be helpful in addressing the topic in this paper by considering screen exposure as a reorganized set of developmental variables affecting each other over time. Thus, it leads to the need for reconsidering the relationship between screen use, cognitive functions, brain development, and overall child's sleep, which cannot help being influenced by all mentioned aspects.

Additionally, it might be reasonable to note that the described relationships might be bidirectional, depending on the characteristics of each child. Namely, for instance, a child experiencing certain problems with brain development or behavior regulation is highly unlikely to achieve good sleep and may experience cognitive difficulties during the next day. At the same time, this kind of child may be more predisposed to receiving media exposure due to practical reasons [2,48].

It is evident that it makes it challenging to identify the precise directionality and mechanisms in these relationships; however, it helps to consider their realism. Indeed, in real-world situations, sleep and cognitive function are likely to be interrelated. Moreover, brain development and media use also cannot but interact and affect the processes in one another. Hence, considering such interactions is an important task when analyzing a particular problem, in this case, the one of screen exposure's influence.

Considering the described features of this relationship, it is safe to say that it needs to be analyzed from the position of a whole developmental system. Specifically, it becomes especially evident that screen exposure may be harmful once it begins influencing children's sleep. The reason is simple-sleep is crucial for brain development and cognitive functioning [37,48]. Therefore, by understanding that, it is possible to explain the complexity of the relationship's nature.

Conclusions

The evidence reviewed suggests that early screen exposure is associated with several aspects of child development, although these relationships are not equally established across the outcomes examined. Findings concerning sleep appear relatively more consistent, particularly where greater or poorly timed screen exposure is associated with shorter sleep duration, delayed sleep onset, and poorer sleep quality. Longitudinal studies have also reported associations between screen use and later differences in language, attention, and developmental performance. However, these findings vary across studies, and their interpretation is complicated by differences in exposure measurement, family circumstances, and other developmental influences. Evidence concerning structural brain development remains less conclusive,

particularly because relatively few investigations have directly examined brain-volume changes following exposure during the first five years of life. For this reason, the available findings do not establish that early screen exposure causes structural brain alterations or long-term cognitive impairment. Rather, they suggest that the duration, timing, content, and context of screen use are important considerations when examining its possible developmental implications.

Overall, because of the diverse study design and findings, conclusions should be considered with caution. The lack of a quantitative scoring technique for quality assessment in this research makes it more challenging to determine the validity or weight of particular assertions. Properly constructed prospective investigations are required to produce more accurate and trustworthy results.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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