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How Early Screen Exposure Shapes Language Development, Memory,
Sleep, and Interaction in Infants: A Systematic Review

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Abstract

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Abstract

Screen use in infancy is increasing, raising concerns about its effects on 1) language, 2) memory, and 3) sleep development. The last chapter of this thesis reviews the literature after theoretically reviewing the main stages of language development in infancy and the main factors that affect it. The review examines empirical research on screen exposure and newborn development. An accurate screening procedure identified 39 papers from Scopus, ScienceDirect, PubMed, and other relevant scientific databases to provide an in-depth analysis of the subject. The studies show that high screen exposure has a negative affect on infants development. 1) by decreasing parent-infant verbal interactions, conversational turns, lowering the joint attention experiences, and infant-directed speech exposure, which all help learning new words and gestures and are also crucial for phonological processing, which studies using EEG and fMRI confirmed lower neural network activity in language processing areas during the screen exposure. 2) Due to the distraction of attention and decrease in social interactions, it brings difficulty for the infants to memorise and process the language inputs, and this could lead to a further detrimental outcome concerning their ability for problem-solving. 3) The screen exposure before bedtime can affect infants' sleep patterns by interfering with melatonin production and circadian rhythms, which results in delayed sleep onset, reduced sleep quality, and shortened overall sleep duration, and this poorer sleep efficiency results in poorer memory consolidation and cognitive performance. Studies indicate that interactive, parent-mediated screen experiences, such as age-appropriate, slow-paced, and language-rich content alongside co-viewing and active parent engagement, could reduce negative effects because of the importance of real-world interactions and direct human contact in shaping cognitive and language development, which screen-based learning could not replace. This study highlights the need for evidence-based guidance on infant screen use and calls for parental education and government legislation to minimise the exposure while enhancing positive social interactions. Also, future research is needed on longitudinal studies for assessing the long-term cognitive and neurological outcomes to minimise the negative effects of early screen exposure on three developmental trajectories. language; sleep; memory; language.

Keywords: infant, screen exposure, language, sleep, memory

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Chapter 1: language and memory development

1.1 Language development before birth

Before infants take their first breath, they have already begun their language journey. This preparation does not appear suddenly at birth; instead, it is shaped by months of auditory experience while the infant is still in the womb. Even though a developing foetus is shielded from the outside world, the womb is far from silent; mother's heartbeat, digestion, and external sounds all combine in a rhythmic symphony, but one sound stands out: the mother's voice. Gerhardt et al. (1990) found that the mother's voice is the initial auditory stimulus for the foetus, with low-frequency components like rhythm, intonation, and stress pattern, which, passing through the amniotic fluid, the foetal auditory system detects rhythmic speech by 26 weeks of gestation, and they may understand pitch and intonation by 28 weeks (Draganova et al., 2007). This early exposure serves as the foundational stage of language acquisition, as it helps shape the foetal auditory system's sensitivity to speech rhythms, intonation, and pitch, which enables them to recognise and even prefer the voice of their mother (DeCasper and Fifer, 1980).

All these show that language acquisition occurs before birth, and to find out how much foetuses process and remember language, researchers have examined whether they can actively distinguish auditory stimuli. Draganova et al. (2007) conducted a longitudinal magnetoencephalographic (MEG) investigation on 18 pregnant women in the third trimester, and they played two sounds: a standard tone (500 Hz) and a deviant tone (750 Hz), which happened in 12% of trials, and by recordings of foetal brain activity, they discovered that a neural response was demonstrated by 66% of foetuses at 28 weeks of gestation in response to the deviant stimuli, and at birth, this reaction had increased to 89% of infants, and that prenatal research indicates that foetuses

actively encode and distinguish between auditory stimuli, which shows that the brain foundation for language processing is already formed.

This early exposure to speech rhythms has long-term consequences after birth. DeCasper and Fifer (1980) conducted a classic experiment in which they assessed ten newborns (less than three days old) by using a non-nutritive sucking paradigm, and the infants had the opportunity to choose whether they heard their mother's voice or the voice of another person. Interestingly, they not only recognise their mother's voice but also actively prefer it; they adjusted their sucking pattern to hear their mother's sound more frequently. Therefore, prenatal auditory experience influences postnatal bonding and language learning and supports developing language from birth.

Additionally, neuroimaging studies provide more evidence. Dehaene-Lambertz et al. (2002) used functional magnetic resonance imaging (fMRI) to investigate how the infant's brain responds to native (familiar) and non-native (unfamiliar) stimuli, and the findings proved left-sided activation in the superior temporal and angular gyri, which are the language processing regions. Moreover, Byers-Heinlein et al. (2010) studied monolingual and bilingual newborns (less than five days old) by using a high-amplitude sucking (HAS) technique and found that monolingual infants preferred their native language, but bilingual newborns did not show a clear preference for one of the languages they had been exposed to in utero, but they preferred both. Apart from identifying speech patterns, they can detect variations in prosody (the rhythm and melody of speech). This is pointed out by Martinez-Alvarez et al. (2022). They placed 25 neonates (1-5 days) to hear four-word-long utterances delivered in two ways: in natural speech and in a time-reversed speech that violated the expected French rhythm. This study by NIRS showed that newborns have larger haemodynamic responses in the right temporal and parietal areas while hearing prosodic violations, so infants actively analyse speech structure and detect prosodic patterns and linguistic regularities from birth.

In the early stages of life, linguistic memory is also evident by using functional near-infrared spectroscopy. Benavides-Varela et al. (2011) investigated whether or not neonates aged one to five days could remember words after a short pause. In this experiment, newborns were first exposed to a familiar bisyllabic word before being tested after two minutes of stillness, music, or another word. Notably, they recognised

familiar words after silence or music, but not when a new word was introduced, which shows retroactive interference affects early language memory. Similarly, Kuhl et al. (2014) investigated how newborns process speech sounds using EEG. They found that by three months of age, sensorimotor mechanisms, which are the interconnected processes that link sensory perception (hearing speech sounds) with motor functions (preparing articulatory movements for speech production), shape speech discrimination: Early speech processing is multimodal; it combines auditory perception and motor representations and supports language processing before birth. Placed together, the foetal brain is already listening, interpreting, and encoding linguistic patterns in the womb, and at birth they are active learners with sophisticated auditory skills who are ready to recognise and engage with the languages that they were already exposed to before birth.

1.2 Language skills development

1.2.1 Intentional and Non-verbal Language Development

The complex and dynamic process of language acquisition includes verbal and nonverbal communication. Infants communicate with their parents and their environment through interactions characterised by sounds, gestures, and facial expressions after birth. They are not born as naturally communicative; their early behaviours, such as crying, fussing, and smiling, serve as cues for carers to interpret their needs but lack intentionality. Intentionality is the fundamental feature of communication as described by Austin (1962) and Grice (1957, 1969), developing gradually over time; while infants can influence their listeners, their actions are initially not performed with the deliberate intent to communicate (Bates, Camaioni, & Volterra, 1975). However, carers has a crucial role to distinguish these behaviours to guess the infant's needs and provide appropriate responses, their communication development includes three phases by Bates and colleagues (1975): the perlocutionary, illocutionary, and locutionary phases. During the perlocutionary phase, which spans from birth to 10 months, infants have effects on their carers without intending to communicate. For example, a child might fuss or cry while reaching for an object, leading the carer to

figure out their desire and provide their need; even though the behaviour achieves a result, it is not driven by communicative intent. This differs with the illocutionary phase, which begins around 10 months. At this stage, infants recognise that their behaviours can influence others and begin using it intentionally to get responses. At this age they now vocalise or gesture to actively ask for help, rather than only fussing. Research also suggests that intentionality may emerge even earlier in some behaviours, such as a 6-month-old crying intentionally to gain attention and stopping once attention is obtained (Oller, 2000). The illocutionary phase also includes protodeclaratives, when infants point to an object to catch their carer's attention until it is recognised, and this phase begins around 12 months, in this phase infants using language as a tool for the communication, and their early words are often tied to specific contexts, like saying "Mm" with a pointing gesture to ask for something or using "bam" during block play as part of the activity rather than as a symbolic representation. Thus, over time, infants develop their ability to use language referentially, gradually moving from context-specific expressions to symbolic communication.

Even before they can speak, their brains show greater activity in response to speech-like stimuli, which indicates infants have neural networks for social and linguistic communication, by using Near-Infrared Spectroscopy (NIRS) that was confirmed by Benavides-Varela et al. (2012), which states that preverbal social interactions activate brain networks involved in language processing. The transition from preverbal interaction to verbal language acquisition is associated with gestures, which are among the earliest non-verbal behaviours. However, they are not random movements but purposeful signals that help infants structure their interactions with their world. Researchers classify gestures into five primary categories; each of them helps in its own way for the development of cognitive and language abilities.

To start, pointing, reaching, and showing are all part of the first category, which is called deictic gestures, and occur between the ages of 7 and 16 months; therefore, even before infants are able to vocally refer to things, these gestures are early communicative tools used to direct the attention of the carer to the object they need. Even the absence of pointing before 14 months has been associated with developmental deficits in social and linguistic growth, emphasising its importance as a predictor of subsequent language abilities (Liszkowski et al., 2004). As they grow, they learn the conventional gestures, which are socially shared movements such as waving

goodbye, shaking the head for "no," and nodding for "yes.". Unlike deictic gestures, which are used to draw attention to something, the conventional gestures are used to communicate and are part of cultural norms that need to be learnt through social interaction and with the help of carers (Baldwin, 1995). In the more complicated category is referential gestures; babies express things or actions with symbolic movements, so infants might place an empty hand to their mouth to indicate eating or flap their hands to symbolise a bird, and when they use referential gestures, they are more likely to move quickly to spoken labels for things and actions, and that is why these gestures are closely related to vocabulary acquisition and scaffold early language acquisition, which is supported by studies of Iverson & Goldin-Meadow (2005) that discovered infants who used referential gestures at 12 months developed a greater vocabulary by 24 months. Add to them, iconic gestures are referential gestures that resemble their referents, for example, a child pretending to turn a steering wheel to indicate driving or rubbing their arms to signal cold, which shows an emerging ability to use representational thought in communication and start to comprehend and use symbols before they can completely express words, mirroring developments in cognitive development. The beat gestures category is another significant but sometimes overlooked category that emphasises prosody, rhythm, and discourse structure. They are rhythmic motions that follow speech, compared to other gestures that express specific meanings, for example, a child tapping their fingers or moving their hands up and down while telling a story. Regardless of the fact that beat gestures often appear later, during the toddler and preschool years, they are beneficial to children's narrative abilities because they help children in structuring and expressing significant language parts throughout speech in an engaging and comprehensible way.

Gestures are not just a coexistence with verbal communication; instead, they actively support language development by enhancing an infant's ability to communicate when they are still in the process of learning verbal language. Infants begin to combine gestures and vocalisations at 12 months, which reflects their early grammatical structure. For example, when they say "big" and point to a dog, they show an adjective-noun pairing that indicates syntactic development. The study of Golden-Meadow (2005) found that by the age of two, infants who began using gesture-word pairs during their first year were more likely to develop sentences that were longer and more grammatically complex. Gestures and language acquisition are

associated with joint attention (the infant's ability to share focus with a carer on an object or event, using eye gaze, pointing, or vocalisations to coordinate attention) is a crucial mechanism that enhances word learning, social communication, and cognitive development. It typically occurs around 6 to 12 months, when Infants frequently engage in joint attention interactions they can have more opportunities to connect words with objects and actions, and this opportunity help them to have greater vocabulary growth compared to those have not (Trevarthen & Hubley, 1978), even when they frequently share their focus with carers tend to have stronger social skills, better turn-taking abilities, and improved processing of conversational cues (Mundy & Gomes, 1998; Carpenter, Nagell, & Tomasello, 1998) which shows joint attention not only help language development but also supports social and cognitive development.

Research indicates that early joint attention behaviours at 12 months predict social competence and communication skills by 30 months (Smith et al., 2009). Furthermore, the quality of joint attention interaction affects the language outcomes. Parents who actively label and name objects, encourage infants' vocalisations by adding meaning to them, and engage in responsive dialogue by turn-taking like a conversation help their infants to have richer linguistic input, enhance speech processing, and support the development of their conversational skills, which results in greater language outcomes (Adamson, Bakeman, Deckner, & Nelson, 2012).

Consequently, gestures and joint attention are mechanisms that are extremely tied together and responsible for the learning and social interactions development. While gestures are an early tool for expressing meaning, joint attention helps to acquire the essential linguistic input from social interactions, which makes them significant factors for later language proficiency and cognitive development. Xu et al. (2009), by using functional magnetic resonance imaging (fMRI), found that both modalities activate a common neural system, particularly in the left inferior frontal gyrus (Broca's area) and the posterior superior temporal sulcus, regions traditionally associated with language processing, and this overlap indicates a shared neural basis for gesture and speech, highlighting their association in communication. Moreover, Benavides-Varela et al. (2012), by using functional near-infrared spectroscopy (fNIRS), confirmed the same findings by finding a significant neural activity in right frontal, left temporal, and right parietal regions, areas associated with memory retrieval, speech perception, and language processing. Notably, these regions are engaged during gestural

communication, which confirms the idea that language and gestures share a common neural foundation from birth.

These findings confirm that gestures and spoken language are highly interconnected at the behavioural and neural levels, even supporting the claim that gestural communication is a fundamental key of human language development. Therefore, the process of shifting from nonverbal to verbal communication in infants is extremely dynamic and multimodal; it is not just a straightforward change from gestures to words; it means when they start speaking, they do not stop using gestures; instead, gestures stay as an important support of their communication, helping their early syntax, reinforcing meaning, and improving their ability to tell stories. Add to this, using deictic, conventional, referential, and iconic gestures shapes the foundation for their verbal communication, and the use of joint attention and social referencing helps them to boost linguistic input. However, the combination of neuroscientific and developmental research shows that language is more than just a spoken phenomenon; it is a rich, embodied, and interacting process that allows for a more thorough understanding of how infants explore their environments by recognising a combination between gestures, gaze, and voice and being able to create meaning through many channels of expression.

1.2.2 Verbal development: From early sounds to conversations

The transition from reflexive sounds to meaningful speech is a complex, multi-stage process affected by biological development, sensory experiences, and social interaction. Crying is the first form of linguistic expression, but infants don't start making speech-like sounds until they can control their respiratory and vocal mechanisms, and these vocalisations improve gradually, resulting in cooing, babbling, first words, and, finally, structured conversations. Each stage of verbal development builds on the previous one, shaping the phonetic, prosodic, and syntactic characteristics of spoken language (Otto, 2018).

Infants between six and eight weeks old begin their cooing stage, which is characterised by the production of prolonged vowel-like sounds such as "ooo" and "ahh." And these

vocalisations might seem to be repetitive, but they are critical for phoneme discrimination; they help the infant to practice controlling airflow and vocal tract movements. By 16 weeks, these cooing sounds become more socially involved and are followed by smiling, showing the first use of vocal expression in a social and emotional context. Also, they are able to communicate actively with their parents by verbal play and facial expressions. Between 16 and 30 weeks, they play with various vowel and consonant-like sounds as part of their vocal exploration to explore and test their articulations. Following these vocalisations, infants start producing semi-structured syllables like "maaaa" and "gaaa," which are known as marginal babble, which change speech development by showing improved neuromuscular control over articulation and the ability to organise phonemes in a speech-like way, even though they lack linguistic meaning.

And around six months, they usually start with canonical babbling, which is known by repetitive consonant-vowel (CV) syllables such as 'ba-ba-ba' and 'da-da-da' (Nazzi et al., 1998). In contrast to earlier marginal babbling, which involves less defined phonetic patterns, canonical babbling includes more stable, rhythmic, and speech-like sounds, and this stage helps infants to enhance the coordination between their auditory and motor mechanisms and allows them to recognise sounds that they frequently hear in their environment (Oller & Eilers, 1988). However, the start of canonical babbling varies by individual; for example, while many infants begin this stage around six months, others may begin sooner or later. Notably, infants with hearing impairments frequently face considerable delays in this stage. Eilers and Oller (1994) observed that infants with hearing impairment did not produce canonical syllables until 11 months of age, while all typically developing infants did so by 10 months. Their babbling becomes more complicated at nine months when newborns start combining different syllables like "ba-da" or "ka-do.". This stage is known as variegated babbling. It introduces prosodic elements such as speech rhythm, stress, and intonation, which make infant vocalisations sound language-like. Importantly, variegated babbling builds the foundation for first-word production as infants build their speech motor control and phonemic organisation to match the sounds they frequently hear in their environment. Research suggests that the complexity of babbling at this stage predicts the emergence of first words (Oller, 2000; Vihman, 1996). Carer responsiveness, such as turn-taking

and contingent feedback, boosts these vocal patterns, gradually shaping them into meaningful words (Goldstein & Schwade, 2008).

However, by the end of this stage, infants are not only experimenting with sound combinations but also developing the phonological structures necessary for early word production and more meaningful speech. As they get closer to their first birthday, they reach the stage of jargon babbling (or pre-lexical speech), which is followed by the formation of protowords (consonant word-like vocalisations that have specific meanings); for instance, when referring to a bottle, a baby may say "baba" repeatedly, even though the pronunciation differs from the adult form. However, these protowords, which are frequently associated with gestures, serve as a link between babble and real words, showing how newborns frequently develop their phonological representations in response to carer feedback and social interactions (Vihman & McCune, 1994). So by this age, around 12 to 14 months, usually most infants might say their first words, representing the start of verbal communication (Mandel, Jusczyk & Pisoni, 1995); their words are initially very context-dependent, often referring to well-known things, persons, or behaviours such as 'mama,' 'dada,' 'hi,' 'bye,' and 'ball.' They are typically simple, often comprising repeated syllables, and are associated with significant people or objects in the infant's life, but when they are exposed to language more frequently, their vocabulary grows, and they start to realise that words can be applied to a variety of contexts. However, research by Hoff and Naigles (2002) suggests that frequency is not enough; the quality and diversity of linguistic input significantly affect language development. Even with a limited vocabulary, infants can use gestures such as pointing and facial expressions to express their intentions.

At 15 to 18 months of age, they start to form short (two) word combinations, and spoken words begin to go beyond gestures, establishing a foundation for early grammatical development. They go through a period that is commonly known as the "vocabulary explosion" or "spurt"; during this time, they are able to learn new words each day (Bergelson & Swingley, 2012). However, it is important to notice that only around one-third of children experience this vocabulary explosion, whereas the rest have a growing, continuous vocabulary increase rather than an unexpected one (Ganger and

Brent, 2004). McMurray (2007) claimed that the vocabulary explosion is not a distinct phase of language development but rather a natural outcome of learning more words over time. However, as their vocabulary grows, kids start to learn the fundamentals of speech. It means by 24 months, they are not just engaging in simple interactions with carers but also participating in pretend play and talking about past events, indicating an early development of narrative abilities, even as they become aware of communication gaps and modify their voice or gestures to express themselves, and by the time they are 30 months old, they are taking longer turns in conversations, but most of their speech is still receptive rather than expressive at this time.

Following, individual differences in vocabulary growth are influenced by various factors, including language input, cognitive abilities, and social interaction. Infants are exposed to rich and dynamic linguistic environments. Rowe (2012) highlights that both the quantity and quality of child-directed speech are crucial; exposure to a diverse and sophisticated vocabulary, along with engaging conversations, significantly enhances early language learning. For instance, toddlers who participate in joint attention activities, such as pointing while naming objects, develop stronger word-learning skills, as these interactions help connect words to their referents (Tamis-LeMonda et al., 2001). These developmental milestones show how biological maturation and linguistic experience affect the process of early language acquisition by highlighting the interrelated processes of phonological growth, vocabulary growth, and conversational development. Therefore, the journey from vocalisations to babbling, from babbling to words, and from words to conversations is complicated and interactive; also, it is determined by cognitive, linguistic, and social factors. For example, while some infants have a vocabulary explosion, others develop it slowly, which shows the diversity of early language learning ways in these individual differences. Understanding provides important information about how infants progress from prelinguistic vocalisations to structured, meaningful speech. Furthermore, beyond these foundational stages, the path to fluent speech involves more than just biological maturation and linguistic exposure; the way infants interact with their environment, carer responsiveness, and cognitive processes supporting language learning all influence how effectively they progress beyond early vocalisations. Comprehending these influences clarifies why certain infants progress swiftly while others develop more gradually. The following

section will explore these key factors, shedding light on how early language experiences shape long-term communication skills.

1.3 The role of memory in language development

From birth, or possibly earlier, memory plays a crucial role in language acquisition and the learning process in general. It helps infants to recognise the speech patterns, interpret and store linguistic inputs, and gradually connect sounds with meanings, and these connections ultimately support the development of vocabularies and grammatical structures, which in turn enable infants to engage in more complex and meaningful communication over time.

Newborns use auditory memory from birth, and they can differentiate sound and segment words. This allows them to tell apart native and non-native phonemes. In early language acquisition, Kuhl (2010) highlights perceptual narrowing as one of the primary drivers. They can recognise phonetic contrasts from all languages, but as they grow, they become more specialised in processing their native phonemes while gradually losing sensitivity to non-native sounds. This change helped them process speech and set a foundation for their later linguistic growth. From the moment of birth, implicit memory in many ways effortlessly promotes learning through repetition. For example, Benavides-Varela et al. (2012) claimed that babies can, within a few minutes of being exposed to words, encode sounds and even store them in their memories. This indicates that the fundamental memory structures necessary for speech are functional at birth. Also, right frontal regions, which are normally linked to the retrieval of speech memory in adults, showed greater neural activity in response to familiar vowel sounds in newborns by using functional near-infrared spectroscopy (fNIRS). Also, the research achieved the noteworthy finding that infants retain vowels more effectively than consonants, which indicated that vowels are critical to early phonological memory.

As infants grow, short-term memory expands this capacity, helping them to store and manipulate the linguistic inputs. This ability is especially useful for recognising word patterns in fluent speech. By the age of six months, they have the ability to remember word sequences long enough to their speech segments, allowing them to break down continuous speech into meaningful chunks (Seehagen et al., 2015). Additionally, they

also begin to recognise common native language words and phrases, which are already confirmed by experimental investigations. At the age of eight months, infants have the ability to remember word sequences that can be used later for vocabulary development, even if they are given a slight delay (Rovee-Collier & Cuevas, 2009). By the age of six to twelve months, babies have linked objects to words, thus gradually increasing their semantic memory and vocabulary (Fenson et al., 1994). When children reach the age of two years, the active role of short-term memory develops further, especially when it comes to language. By this time frame, they have the ability to store and manipulate some of the linguistic inputs, which helps them to learn and retain new words.

Baddeley and Hitch's working memory model (1974) states that the phonological loop becomes increasingly crucial when an infant starts acquiring language because it allows an infant to retain speech sounds and practice them. The infant's central executive tendencies also tend to improve at this stage, which helps them focus their attention, word switching, and the gradual growth of new vocabulary. Meanwhile, long-term memory begins to form, enabling them to retain basic grammatical structures, phrases, and words over time. The gradual formation of these memory systems is, indeed, tied to the maturation of brain areas like the hippocampus and prefrontal cortex, which have significantly grown during this time and are important for language development (Gomez and Edgin, 2015).

When an infant is six months old, they begin to associate certain words with events in their surroundings with the help of episodic memory. They recall specific experiences, which is supported by the developing structures of the brain, such as the hippocampus (Bauer, 2015). For example, if a carer is feeding the infant, they constantly repeat the word 'bottle'; eventually, the infant starts to associate the word with the object. While these early connections support language learning, the ability to fully recall personal experiences continues to develop as brain structures like the hippocampus mature. As they grow older, they depend more on semantic memories, and the gradual development of the hippocampus helps with language acquisition. Unlike episodic memory, which recalls unique experiences, semantic memory holds broad knowledge and vocabulary meanings. Studies have shown that at the end of the first year of life, an infant starts to develop the ability to recognise words even if they are not in their immediate environment (Fenson et al., 1994).

Procedural memory, which develops after long-term memory, is another important system that operates unconsciously and allows infants to naturally learn language rules; they automatically learn verb conjugations and word order without being directly taught. As they are exposed to language on a daily basis, in one experiment, infants exposed to a fixed word order later demonstrated a preference for grammatically correct sequences, indicating that their brains had extracted and internalised syntactic rules through procedural memory (Marcus et al., 1999; Saffran et al., 2001). Also, results showed that the Serial Reaction Time (SRT) Task has proved that children with Specific Language Impairments (SLI) have difficulties in sequential patterning, supporting the idea that language difficulties may stem from impairments in unconscious learning mechanisms (Lum, Gelgic, & Conti-Ramsden, 2010). Language learning is both conscious and automatic, shaped by the interaction between explicit and implicit memory. While implicit memory, closely tied to procedural learning, supports fluency and natural speech, explicit memory, including episodic and semantic memory, is also crucial. With age, there is an increase in specialisation of the brain in infants; there is a greater dominance of the left hemisphere in the phonological and lexical aspects of the language, while the right hemisphere is still important for prosody and contextual information. The development of language is facilitated by the simultaneous action of all these distinct memory systems, as previously stated; semantic memory provides a store for words, procedural memory helps internalise grammatical structures, while episodic memory associates words with experiences. Along with this, sensory processing and short-term memory allow them to efficiently absorb speech by processing and recognising language inputs in the real world. Because of these systemic processes, infants are able to acquire sophisticated language abilities during the first few years of their lives.

1.4 Sleep in Memory and Language Development

Much more than just resting, sleep helps in the consolidation of memories and the acquisition of new languages by facilitating the processes of learning new words, grammar rules, and speech patterns. In early childhood, the process of memory consolidation during sleep helps infants retain words, sounds, and various other patterns to which they can relate this knowledge in new contexts (Gómez & Edgin, 2015). Evidence indicates that sleep promotes the generalisation of linguistic rules, enabling infants to extract patterns from speech. For example, infants that were 15 months of age and were exposed to a set of predictable word order rules were able to generalise the rules after having a nap, providing evidence that sleep plays a role in abstracting linguistic structures (Gómez et al., 2006). In the same way, Friedrich et al. (2017) found that infants aged 9 to 16 months that napped after the introduction of new word-object pairings were able to remember novel words and use them with entirely new objects. This demonstrates how sleep supports to strengthen brain plasticity at an early stage as well as language acquisition.

At the neural level, sleep actively integrates new linguistic input into long-term memory, when infants sleep, the hippocampus reactivates and processes recently learnt words, phonetic patterns, and grammatical structures and transfers those inputs to the cortex for long-term memory, and this process improves language processing while increasing recall and retention of language inputs, and it is also uniquely influenced by various stages of sleep. Non-rapid eye movement (NREM) sleep, which is characterised by slow-wave oscillations and sleep spindles, plays a key role in memory retention during infancy, even EEG studies highlight the importance of NREM sleep in early language acquisition by showing that it is linked to the retention of language inputs such as phonemes and vocabulary (Gómez & Edgin, 2015). Furthermore, Horváth and Plunkett

(2018) investigated the effects of naps on infants' cognitive development under five, demonstrating the importance of sleep in language and memory consolidation in children, and their findings indicated that naps improve neural activity related to language processing, lessen cognitive overloads, and help infants remember more words. In contrast, active sleep, which is also referred to as rapid eye movement (REM) sleep, is critically involved in the reinforcement of neural connections and the processing of daily experiences, which prevents the loss of language input acquired during waking hours and ensures its integration into long-term memory. The combined function of NREM and REM sleep emphasises their importance in supporting cognitive and linguistic development during early childhood. Spencer and Riggins (2022) suggest that as infants' memory networks mature, their sleep architecture evolves to facilitate more efficient memory storage between six months and three years of age. Also, they contend that nap transitions, such as switching from multiple naps during the day to a single nap, are driven by hippocampal development and help infants retain information for longer periods of time while lowering their need for frequent sleep intervals.

Sleep influences vocabulary and grammar acquisition, two crucial stages in language development, in addition to improving linguistic input. Infants strengthen associations between new words and familiar objects through repetition while awake and reprocessing during sleep (Otto, 2018). Research shows that infants who took a nap after being exposed to new words recalled those words better than children who stayed awake. Furthermore, children who follow a regular sleep schedule are more likely to learn new words and retain them better than children who don't; this highlights the significance of regular sleep schedules for language and cognitive development. Sleep also influences the process of social language learning, thereby enhancing language acquisition; they can remember better if nap after learn new words in an interactive social setting. 15-month-old babies who napped after being exposed to an artificial language in social settings demonstrated improved language rule retention and generalisation, according to a study by Gómez et al. (2006). This connection between memory, sleep, and social experience demonstrates the impact of environmental factors on the brain processes that it effect on language learning (Kuhl, 2010). However, the high screen exposure can impair sleep-related language development. McHarg et al. (2020) discovered that infants aged 4 months who were exposed to screen media underperformed in inhibition skills by 14 months, potentially delaying language

development; therefore, In early childhood, sleep deprivation correlates with delays in vocabulary acquisition and grammatical development, while healthy sleep practices have demonstrated improvements in language outcomes (Breslin et al., 2014; Williams & Horst, 2014).

In conclusion, it is readily apparent that sleep has a vital impact on how infants segment and process speech, they move from random vocalisations to meaningful words and phrases, and sleep helps them for that early developmental language because it supports speech segmentation, grammatical generalisation, memory retention, and social language acquisition, and the awareness of these effects clarifies how infants develop the cognitive and neural foundations required for fluent communication.

1.5 Individual Differences at a Neural Level in Language Development

Language development in infants is a fascinating interplay of biology, neural processes, and environmental influences that all work together to shape each child's distinct path. The foundation for this developmental journey is provided by the human vocal system, which begins with the first coos and babbles. It was noted by Locke (1983, 1992) that the earliest vocalisations of infants, such as simple vowels and consonants, originate from their natural motor ability and developmental milestones. These universal patterns demonstrate the biological predispositions shared by all infants, independent of their linguistic background, establishing a common foundation for phonological development. As newborns grow, their environment will start to support their natural skills; when they reach six months old, a phenomenon known as "babbling drift" occurs in which the sounds that babies make gradually mirror the phonological characteristics of their mother tongue. This change shows how biology and experience interact dynamically. Enriched environments enhance neural development, improving both cognitive and linguistic achievements (Taintor et al., 2023). While infants initially show a universal preference for vowel sounds common across languages, their daily exposure to a specific linguistic environment fine-tunes these preferences, gradually modifying their vocalisations to align with the phonological characteristics of their native language.

Because it involves both structural and functional adaptations in major brain regions, this process is closely related to neural plasticity.

At the neural level, language development is shaped by dynamic processes such as myelination, synaptic pruning, and cortical maturation, which significantly impact how quickly infants reach language and cognitive milestones. Structural MRI studies reveal that during the first two years of life, there is rapid myelination in the arcuate fasciculus, a crucial white matter tract connecting Broca's and Wernicke's areas, facilitating speech production and comprehension (Dubois et al., 2016). Additionally, the hippocampus and prefrontal cortex play a major role in executive functioning and memory retention, both of which are necessary for language acquisition (Stiles & Jernigan, 2010). Event-related potentials (ERPs) are used in electrophysiological research to show that infants begin to process native phonemes more effectively at six months of age while decreasing their sensitivity to non-native contrasts (Werker & Tees, 2002). This phenomenon, commonly known as "perceptual narrowing," shows how neural plasticity allows infants to specialise in processing sounds pertinent to their linguistic surroundings, and also, an interesting magnetoencephalography (MEG) study found that bilingual infants have improved neural flexibility and efficiency to manage multiple phonological systems, which shows that neural commitment to language processing begins in infancy (Kuhl et al., 2008).

The early lateralisation of language processing is a factor that contributes to this adaptability. At first, the right hemisphere is responsible for prosody and phonological recognition; however, the left hemisphere becomes increasingly specialised in these areas as the development process progresses (Gomez et al. 2014) and this is confirmed by functional near-infrared spectroscopy (fNIRS) studies that the right hemisphere processes sentential prosody most vigorously; as a result, prosodic cues are essential for early language acquisition (Homae et al., 2006). Sensorimotor integration is also important in speech perception, as evidenced by studies showing that auditory and motor regions are co-activated during speech processing in six-month-old infants, implying an early link between speech perception and production (Imada et al., 2006). The hypothesis that early speech perception is not passive but rather involves active neural engagement in preparation for vocal production and imitation is supported by this finding. In addition to these brain processes, the environment has a huge impact on language development. According to Grigg-Damberger (2016), infants who are

brought up in environments that are rich in language have stronger neural connectivity, which improves their cognitive and linguistic performance. Furthermore, studies show that variations in carer input influence neural development, with higher-quality linguistic exposure resulting in more efficient processing of syntactic and semantic structures (Rowe, 2012).

Individual differences in phonological memory, processing speed, and personality traits also contribute to language acquisition variability. Outgoing children tend to receive more verbal input from carers, accelerating their language development, whereas children with stronger phonological memory acquire vocabulary at a faster rate (Gathercole & Baddeley, 1990). Furthermore, sex-based differences in vocabulary development have been observed, with girls frequently developing larger vocabularies earlier than boys, possibly due to differences in processing speed and social interaction patterns (Bornstein, Hahn, & Haynes, 2004; Fenson et al., 1994).

The acquisition of grammar varies considerably among children and is affected by working memory capacity, parental input, and the structure of the native language (Van der Lely & Pinker, 2014; Kidd, Donnelly, & Christiansen, 2018). Children with better working memory demonstrate an earlier mastery of complex grammatical structures, according to neuroimaging studies, underscoring the importance of cognitive skills in syntactic development (Montgomery, Magimairaj, & Finney, 2010). In the early stages of language acquisition, some kids start stringing words together to form sentences as early as 18 months, while others might not start until they are about two years old. These differences extend to the ways that infants use to learn syntax; some concentrate on smaller linguistic units, such as syllables and phonemes, while others rely on larger speech patterns. A child might say, “I don’t want to go night-night” as two pre-memorised chunks. While this approach allows for longer utterances, it lacks the flexibility of sentences constructed by using true syntactic combinations.

Neural networks grow rapidly in early childhood, with gene expression and environmental factors influencing developmental outcomes. According to Stiles and Jernigan (2010), the dense synaptic networks that are present in the early postnatal brain are gradually refined through the process of pruning in order to maximise the efficiency of the neural system, and this process stresses the importance of a

stimulating and encouraging linguistic environment and is impacted by both responsive caregiving and genetic predispositions. In general, the interaction between genetic, neurophysiological, and environmental factors is the cause of individual differences in language development at a neural level, and the diverse trajectories in early development are due to the infant brain's remarkable plasticity, which adapts to linguistic input. By comprehending these brain mechanisms, scientists can learn more about the basic mechanisms underlying infant language acquisition.

Chapter 2: Factors Affecting Language, Memory, and Sleep Development

As pointed out in the first chapter, infants are born with incredible neural networks that facilitate early language acquisition, allowing them to process speech patterns (Kuhl, 2010), distinguish phonemes (Werker & Tees, 1984), and communicate verbally and nonverbally (Iverson & Goldin-Meadow, 2005). A complex interplay of biological development, cognitive abilities, and carer interactions is responsible for the development of infants' language, memory, and communication abilities, and the preservation of grammatical structures and lexical associations is dependent on memory's role to store and organise the linguistic inputs (Gerken, 1999). Since research shows that getting enough sleep improves language processing and memory retention, sleep is also essential for processing early experiences (Friedrich et al., 2017). Nonetheless, language and cognitive development are influenced by early experiences, neural differences, brain plasticity, cognitive ability, and similar developmental pathways (Benavides-Varela et al., 2012).

Keeping this background in mind, understanding contextual factors is critical for having a deep comprehension of how to develop language, memory, and sleep during infancy. The following chapter will shift its focus from the biological and cognitive processes that support language, memory, and sleep to the external influences that shape them. It will investigate how early development is influenced by variables such as socioeconomic status (SES), interaction patterns, carer responsiveness and communication, and modern challenges such as screen exposure. This will help us better understand how environments affect an infant's communication, learning, and development in the early stages of life.

2.1 Socio-Economic Status (SES)

The child's world begins with the mother's rhythmic voice, a gentle lilt of a lullaby, the parent-infant interaction, play, and eye contact; all these communications help infants develop, but not every child grows up in the same households. Therefore, socioeconomic status, which is defined as the economic and social position of a family in comparison to others and is based on a combination of characteristics such as income, education, and occupation, quietly affects the language, social interactions, and cognitive development of an infant (Hackman & Farah, 2009). Growing up with books, engaging conversations, and interactive play gives infants the chance to develop their cognitive networks and expand their vocabulary (Hart & Risley, 1995). On the other hand, low-income families usually do not have access to these resources, which limits those opportunities for their children to be offered a wide range of educational opportunities and language patterns (Weisleder & Fernald, 2013). Financial hardships also can affect the infant's cognitive development by forcing them into noisy, overcrowded homes where frequent interruptions affect deep, restorative sleep, making it harder for the brain to consolidate new words and information (Bernier et al., 2010).

Beyond the financial aspect, parental education is necessary in building a child's cognitive and linguistic environment. Weisleder and Fernald (2013) found that parents with high levels of education engage in more frequent and sophisticated verbal interactions with their children, participating in in-depth conversations and teaching new words through narrative and play, which helps boost language processing and working memory. According to Gago-Galvagno et al. (2023), children whose parents have lower educational backgrounds may experience a lack of cognitive stimulation and linguistic input, which can impact their language development. Hart and Risley (1995) conducted a study in which they observed 42 families from three different socioeconomic status groups: high-SES families (professional families), middle-SES families (working-class families), and low-SES families (welfare families), and they recorded and analysed all verbal interactions between parents and children for a period of one hour per month for

a period of two and a half years, with a particular emphasis on children aged seven months to three years. Their findings indicated that high-SES parents participated in more elaborate and intricate conversations, often employing open-ended questions and expansions that promoted verbal exploration. In contrast, low-income parents relied more on directive speech (e.g., "Stop that," "Do this"), which limited children's opportunities for language development. Furthermore, while low-SES children heard more directives and prohibitions, which further limited their linguistic interactions, high-SES children were exposed to more affirmations and encouraging language, which promoted confidence and conversational engagement.

Educated parents engage in conversations more responsively and take turns, while low-SES infants hear less complex phrase patterns and fewer conversational turns, according to research using the LENA (Language ENvironment Analysis) system (Piot, Havron, & Cristia, 2021; Perry et al., 2018). A meta-analysis covering 22 studies with 1,583 children found a small but significant correlation between higher SES and increased adult word counts in children's surroundings (Piot et al., 2021). Similarly, Perry et al. (2018) discovered that high-SES children had more conversational turns and greater vocabulary exposure. Fortunately, evidence indicates that language development is adaptable, and interventions can help to close this gap. The Providence Talks Project (York & Loeb, 2018) used the LENA system to help low-SES parents increase conversational turns, which resulted in significant vocabulary growth. While low-SES toddlers process language more slowly, engaged, responsive interactions accelerate their development (Fernald et al., 2013). The Reach Out and Read (ROR) initiative was analysed by Zuckerman and Khandekar (2010) in their programme which was designed to provide children between the ages of six months and five years with literacy advice and books during well-child appointments, and results to promote parent-child reading interactions and enhance vocabulary development and storytelling skills, particularly in low-income households.

An infant's ability to learn, communicate, and reason is based on both language and memory. Language provides structure to inputs, while memory facilitates the gradual acquisition and recall of new words. Since early linguistic deprivation and chronic stress have an impact on the neural networks that support memory consolidation and language acquisition, SES subsequently has a significant impact on both domains. In a crucial experiment, Fernald et al. (2013) demonstrated that infants from higher

socioeconomic status (SES) backgrounds recognised words and shifted their attention to the appropriate picture more rapidly than infants from lower SES backgrounds, highlighting that more rich linguistic environments enhance word recall and memory retrieval efficacy. According to Hackman and Farah (2009) and Brito and Noble (2014), low-income families frequently face housing instability, unsafe neighbourhoods, and financial stress, all of which contribute to chronic stress and elevated cortisol levels, which can negatively affect hippocampal function and memory storage. Moreover, based on the study of Brehmer et al. (2007), children from low-SES backgrounds did poorly on delayed recall tasks, which lends credence to the theory that long-term stress impairs memory consolidation and makes language retention more challenging. Similarly, Hackman and Farah (2009) found that low-SES children have lower medial temporal lobe activity, which affects word encoding, retrieval, and working memory. Sleep disruptions due to environmental stressors, irregular routines, and screen exposure affect memory, language, and emotional regulation in low-SES infants (Gómez & Edgin, 2015).

Breslin et al. (2014) and Touchette et al. (2007) emphasise the critical role of slow-wave sleep (SWS) and REM sleep in the formation of memory and language. In the evaluation of infant sleep regulation, Bernier et al. (2010) discovered that increased nighttime sleep duration was linked to better executive function, particularly impulse control. Furthermore, digital media use before bedtime is more common in low-income families, resulting in delayed sleep onset, shorter sleep duration, and lower sleep efficiency due to melatonin suppression (Brauchli et al., 2024; Hale et al., 2019).

2.2 Interaction Patterns

Early language and social development depend on communicative interactions, and an infant's communication skills are greatly influenced by the responsiveness of the carer—the carer's capacity to identify, decipher, and react appropriately to a child's signals, needs, and communication attempts in a timely and sensitive manner. Infants are treated as conversational partners from birth, despite their limited initial contributions of smiles, coos, and cries, and these early interactions help infants discover the potential of communication as carers build supportive interactions around the child's vocalisations and gestures. Bell and Ainsworth (1972), for example,

discovered that infants whose mothers were very receptive to their cries between the ages of 6 and 12 months cried less and showed better communication skills at 12 months, underscoring the link between early vocal development and carer' responsiveness. Bornstein and Tamis-LeMonda (1989) discovered that infants vocalise more frequently when their mothers respond actively to their vocalisations. Furthermore, Rheingold et al. (1959) discovered that infants' vocalisations were augmented when their mothers responded with smiles, touch, or speech, indicating that social interaction is a factor in the reinforcement of early communication. These studies underscored the significance of contingent mother responses in promoting the development of speech in newborns at a young age.

Language acquisition in infancy is deeply rooted in social interactions between carers and children, which provide essential linguistic input that shapes cognitive, lexical, and syntactic development. Infants do not passively absorb language; rather, they actively interact with their environments, using structured linguistic input, joint attention, and conversational dynamics to extract meaning from speech. Research emphasises that both the quantity and quality of language input play fundamental roles in determining language outcomes (Hoff & Naigles, 2002). Specifically, interaction patterns like child-directed speech (CDS), linguistic scaffolding, and conversational turn-taking function as essential mechanisms for children's language acquisition. In a social setting, infants learn language through reciprocal exchanges with carers. The structure and responsiveness of social interactions fundamentally influence the process of lexical acquisition, which is not solely a cognitive task, as indicated by Hoff and Naigles (2002). Infants acquire language through shared experiences, according to the social-pragmatic theory of language development, in which the adult follows the child's attentional focus and offers significant linguistic input (Tomasello & Todd, 1983), and through joint attention—where both the carer and the infant focus on the same object or action—they are able to associate better words with their referents, facilitating early vocabulary acquisition.

The way in which carers react to the vocalisations and actions of infants has a significant impact on language acquisition to a greater extent than simple word exposure. when they actively participate in turn-taking conversations with infants offer reinforcing feedback that enhances speech processing and promotes vocal experimentation (Tamis-LeMonda et al., 1996). Typically, infants who are raised in

environments where carers frequently elaborate, repeat, and expand on their utterances develop more sophisticated grammatical structures and a broader vocabulary (Hoff, 2006). Actively engaging infants in reciprocal dialogues promotes linguistic and cognitive growth, according to these findings.

As early research on language acquisition emphasised the sheer volume of words that an infant hears; however, more recent research has emphasised the significance of high-quality linguistic input in influencing development (Hoff & Naigles, 2002). The well-known Hart and Risley (1995) study found that children raised in linguistically enriched environments have larger vocabularies by the age of three and subsequent research, however, indicates that greater language proficiency is predicted by speech complexity, diversity, and responsiveness rather than merely word count (Rowe, 2012). Rich vocabulary, complex syntax, and interactive engagement are all characteristics of high-quality linguistic input. For instance, verbal mapping, which involves carers describing objects and actions in real-time (e.g., "Let us put on your shoes; this is the left shoe; now let us tie it up"), embeds new vocabulary into meaningful contexts, thereby improving comprehension. Linguistic scaffolding, in which carers elaborate on a child's speech, is also essential for improving grammatical development (Bruner, 1978). For example, if a child says, "Truck," a carer might build on this by responding, "Yes! That's a big red truck; it carries logs. Where do you think it's going?" These interactive strategies expose children to complex sentence structures while ensuring engagement, thus promoting vocabulary enhancement and syntactic development. Furthermore, the contingency of adult responses is equally important. Research has shown that when carers provide a response that is both immediate and contextually appropriate, infants demonstrate improved speech processing abilities and higher rates of language acquisition (Hoff, 2006). This responsiveness is especially evident in one-on-one interactions, where the adult adjusts their speech patterns to the child's developmental stage, progressively becoming more complex as the child's language skills advance.

In addition to language input, research increasingly highlights conversational turns—reciprocal exchanges between infants and caregivers—as a crucial factor in language acquisition, facilitating children's refinement of syntactic structures, development of phonological awareness, and active engagement in speech processing (Ferjan Ramírez et al., 2020). The frequency of conversational turns is one of the best indicators of future language proficiency, according to neuroscientific research, even the

neuroimaging studies show that infants exposed to a high number of conversational turns exhibit greater activation in Broca's area, a brain region associated with speech production. processing (Gilkerson et al., 2018). These findings indicate that turn-taking interactions not only improve linguistic proficiency but also facilitate the neural processes associated with speech and comprehension.

Furthermore, infants who participate in frequent turn-taking interactions show improved predictive processing abilities, which means they learn to anticipate responses and structure their own utterances accordingly. Longitudinal studies indicate a strong correlation between expressive vocabulary size at 24 and 36 months and the number of conversational turns experienced between 6 and 18 months (Ferjan Ramírez et al., 2020), highlighting that language development is fundamentally interactive, requiring active participation rather than passive exposure. Child-directed speech (CDS), also known as parentese, is a primary tool for facilitating conversational turn-taking. Characterised by exaggerated intonation, higher pitch, and slower tempo, parentese has been found to encourage infants to vocalise more and engage in sustained interactions with carers (Kuhl et al., 2020). In order to reinforce turn-taking dynamics, carers who use parentese inherently pause their speech to allow infants to respond, and this pattern of interaction helps infants develop their interaction and conversational skills, improve phoneme discrimination, and strengthen their ability to process syntactic structures. The acquisition of language is not solely dependent on the simple act of hearing words; it is also influenced by the responsiveness, interactive nature, and structure of linguistic input, and research strongly indicates that infants acquire knowledge most effectively when carers offer varied, stimulating, and enriching linguistic experiences.

While the quantity of input is important for vocabulary growth, the quality of input and active conversational exchanges shape linguistic and cognitive development. One of the most potent predictors of early language outcomes is the reciprocal nature of carer-child interactions, particularly conversational turn-taking. Through turn-taking conversation, infants enhance their phonological, lexical, and syntactic abilities, thereby strengthening the social and neural processes that facilitate language acquisition. In order to ensure that infants receive the interactive support required to develop strong language abilities, these findings highlight the significance of creating language-rich environments that

foster dynamic and meaningful communication and carers set the stage for lifelong communication and literacy development by encouraging early conversational skills.

2.3 Communicative Interactions

This section will focus on how interactive reciprocity and timing in conversations help infants with their language acquisition, which is not a process that occurs in a passive manner; rather, it is deeply rooted in the quality and quantity of communication and interaction. Conversational turns and conversational contingency are important communication strategies that influence language and cognitive development. The term "conversational turns" describes the back-and-forth interactions in which a child and a carer build on each other's statements. For instance, a mother might ask her young child, "What do you see outside?" "Bird!" is the child's response. The mother continues, "Yes! A little bird. What colour is it?" and the child replies, "Blue!". These interactions are essential for language development, as they introduce children to new vocabulary, sentence structures, and social communication skills. Conversative contingency is also very important, and it refers to the degree to which a carer's response to a child's utterance is directly relevant and meaningful to the child. Highly contingent responses, like expanding on what the child said or asking related questions, maintain engagement and learning. For example, if a child says, "Doggy run!" a highly contingent response would be, "Yes, the dog is running so fast! Where do you think he's going?" Instead of changing the subject, carers who keep the conversation flowing create an environment rich with language that helps with attention, social interaction skills, language acquisition, and cognitive and communicative development in the long run.

Conversational turns and contingent responses help language acquisition and stimulate social cognition and speech processing brain regions. Research conducted on event-related potentials (ERPs) demonstrates that infants exhibit improved auditory memory traces when they are exposed to consistent and contingent speech patterns.

This suggests that these interactions speed up the process of early word memory formation. Infants who engage in meaningful responsive dialogues with their carers develop stronger theory of mind skills, which aid them in comprehending the emotions and intentions of others. Conversative contingency also extends beyond language processing to influence social and emotional cognition. Sundqvist et al. (2022) found that preschoolers who were conversing with their carers about their thoughts, feelings, and opinions exhibited superior social cognition.

Since conversational interactions are crucial for cognitive and linguistic development, early intervention programmes teach carers how to increase the number and calibre of their conversational turns. Programmes like Providence Talks show that encouraging parents to have more structured and interactive conversations with their kids boosts vocabulary and comprehension. In a study conducted by Gilkerson et al. (2018), it was discovered that families who participated in the intervention increased their daily conversational turns by nearly 30%, resulting in measurable improvements in the language comprehension and vocabulary acquisition of infants. Furthermore, neuroscientific evidence indicates that these interventions result in measurable changes in brain structure and function. According to Romeo et al. (2017), children who had more conversational turns showed increased activation in the Broca's area, which is important for verbal fluency and language processing. Similar to what was demonstrated by Romeo et al. (2021), increased conversational turn-taking was found to correlate with cortical thickening in the left inferior frontal and supramarginal gyri, which are regions of the brain that are associated with language processing and executive function.

Language interventions improve neural plasticity in key brain regions and improve linguistic outcomes, supporting the importance of early carer-child interactions in shaping developmental trajectories. Conversational turns and contingency are important foundations in early language acquisition because they promote the development of predictive processing abilities, strengthen neural networks, and improve social communication skills. By responding and controlling interactions, parents help infants progress from simple vocalisations to complex speech in order to maximise long-term language development results.

2.4 Infant-Directed Speech (IDS)

Another crucial element of early contacts is child-directed speech (CDS), also known as "parentese," which is an essential element of early interactions. It is distinguished by a higher pitch, exaggerated intonation, slower tempo, and repetitive structures. CDS attracts infants' attention and simplifies linguistic input, which facilitates processing and learning. A carer might say, for instance, "Look at the puppy!" pointing to a dog and asking, "Do you see the doggy?" According to research, CDS plays an important role in phonological and lexical learning because it captures infants' attention, improves speech segmentation, and facilitates early word learning (Kempe, Ota, & Schaeffler, 2024), and the outcome of this way of speech not only helps infants distinguish phonological patterns but also introduces vocabulary and syntax in a developmentally appropriate way, laying the groundwork for comprehension and production.

Therefore, children's exposure to language is enhanced by a variety of interaction patterns in addition to CDS, verbal mapping, and linguistic scaffolding that affect infants language processing. Verbal mapping involves narrating actions or describing objects in detail to embed vocabulary in meaningful contexts. For example, a carer might say, "Let's put on your shoes; this is the left shoe, slip your foot in, now let's tie it up." This technique provides children with structured linguistic input while reinforcing vocabulary and syntax. Linguistic scaffolding builds on children's existing efforts. If a child says "Truck," the carer might respond, "Yes, that's a big red truck. It carries logs. Where do you think it's going?" This technique supports the child's speech while copying more advanced structures and encouraging language development. Carers encourage and enhance a child's communication efforts, allowing them to use more complex language (Bruner, 1978).

Parentese, also known as Infant-Directed Speech (IDS), is a distinct speech register used by carers to communicate with infants. It is distinguished by a higher pitch, exaggerated intonation, slower tempo, and clearer articulation, making it more appealing and accessible to infants (Fernald & Simon, 1984). This specialised speech

style not only captures the infant's attention, but it also highlights key phonological patterns that aid in word segmentation and early vocabulary development (MacWhinney, 2011). Additionally, the rhythmic and melodic features of IDS emphasise syntactic boundaries and word groupings, helping infants identify linguistic structures more readily (Kuhl, 2010). IDS bridges the gap for early language acquisition by emphasising phonemic distinctions, simplifying speech patterns, and creating emotionally supportive interactions. Ultimately, IDS facilitates the ability of infants to map words onto meanings by exaggerating prosodic cues, which helps them detect word boundaries within continuous speech. Infants are more likely to remember and reproduce words presented in IDS than adult-directed speech (Golinkoff et al., 2015), encouraging lexical acquisition.

Infants as young as 4 months prefer IDS, according to Fernald (1985). Infants consistently chose infant-directed speech (IDS) in experiments where they had the ability to control whether they heard adult-directed speech (ADS) or infant-directed speech (IDS) by turning their heads. This was accomplished regardless of the language that was being spoken. Enhanced phoneme discrimination and word segmentation are two of IDS's key benefits, and this preference arises from the acoustic properties of IDS, which include elevated pitch and melodic contours that babies find appealing. Furthermore, Kuhl et al. (2003) looked into the impact of IDS on phoneme learning and found that social interaction with IDS improves language acquisition more than ADS, their research engaged 9-month-old English-learning infants, who were exposed to Mandarin Chinese during 12 interactive sessions over the course of one month. The infants in the IDS group demonstrated a significantly higher level of discrimination of Mandarin phonetic contrasts than those in the ADS group, as determined by a head-turn preference procedure. Similarly, Liu et al. (2003) showed that IDS prolongs vowels and emphasises syllable boundaries, helping infants process speech. Along with its linguistic benefits, IDS is important for establishing emotional bonds and providing contextual cues. These traits also help infants form phonemic categories, which is an important stage in early language acquisition. Furthermore, the emotional tone of IDS fosters positive associations with language, thereby establishing a learning environment that is both engaging and secure. For example, a carer saying, "You're such a happy baby!" with a warm, exaggerated tone not only captures the infant's attention but also strengthens the emotional bond between carer and child, and this bond motivates

infants to participate in communicative interactions, further supporting their language development. In support, Ganek et al. (2018) examined cultural differences in parent-infant conversational turn-taking. By using the LENA system to track interactions, they found that the frequency of conversational turns varied across cultures, reflecting IDS use and engagement styles, but IDS still had a significant impact on language outcomes, demonstrating its universal importance in language acquisition.

Beyond capturing attention and enhancing speech processing, IDS also facilitates memory encoding for linguistic patterns. Martinez-Alvarez et al. (2022) indicated that infants exposed to IDS could more effectively recognise prosodic contours, as evidenced by increased activation in the right temporal lobe using near-infrared spectroscopy (NIRS); this ability to recall and retain prosodic patterns underscores IDS's role in building the neural foundation for language learning. Similarly, Benavides-Varela et al. (2011) found that newborns exposed to IDS retained familiar words for longer periods and exhibited significant brain activation when processing prosodic contours. These findings highlight how IDS not only supports immediate language learning but also contributes to the long-term consolidation of linguistic knowledge.

IDS-driven interactions also play a critical role in early conversational dynamics, which directly impact language development. Wang et al. (2020) conducted a meta-analysis to evaluate the predictive power of LENA's automated measures, including adult word count (AWC), child vocalisation count (CVC), and conversational turn count (CTC) for early language skills. Their analysis confirmed that higher IDS exposure, measured through these interaction-based metrics, serves as a strong predictor of language development, emphasising the importance of frequent, high-quality carer-infant exchanges. Similarly, Kuhl et al. (2003) found that live IDS interactions significantly enhanced infants' ability to distinguish Mandarin phonetic contrasts compared to audio or video recordings.

Although IDS is nearly universal, its use varies across cultures, revealing its adaptability and significance. In Western cultures, carers frequently use IDS to engage with infants, but in some communities, such as Samoan, Mayan, and Aboriginal Australian societies, carers may not prioritise directed speech toward prelinguistic infants. Despite this, infants in these cultures still acquire language, relying on alternative social and

environmental cues. This variability suggests that while IDS is not strictly necessary for language development, it provides significant advantages in facilitating faster and more efficient learning. Research by Grigg-Damberger (2016) and Galland et al. (2012) highlights that societies with enriched IDS practices tend to produce better linguistic outcomes, with infants displaying stronger phonological skills and advanced language development. This adaptability demonstrates IDS's role as a facilitative tool, complementing other forms of linguistic input.

Beyond its cognitive and linguistic benefits, IDS is also important for emotional and social development. IDS fosters the development of early communicative skills in infants by establishing a secure and emotionally engaging environment that encourages them to engage with their carers. Repeated phrases like "Wow, what a big ball!" with exaggerated intonation and warmth capture an infant's attention and reinforce positive language associations, and the development of these emotional connections helps to foster motivation and engagement, both of which are necessary for both sustained learning and language acquisition. It is the adaptability and responsiveness of IDS to the developmental stage of an infant that determines its effectiveness. Carers naturally adjust their speech patterns to match the child's linguistic development, providing incremental scaffolding to aid learning. Infants are guided from the process of perceiving sounds to the production of meaningful words through this personalised approach, which guarantees that they receive engaging and developmentally appropriate input.

2.5 Screen Exposure

In today's digital world, screen exposure has become an unavoidable part of daily life, as parents are increasingly engaged with digital media. Their usage patterns inevitably shape their children's exposure, influencing their daily routines and lifestyle. As a result, infants are frequently exposed to screens as part of their daily routine. By the time they are two years old, they spend an average of one to two hours a day viewing screens and are already familiar with electronic gadgets like tablets, TVs, and mobile phones (Brown et al., 2011). Early and frequent exposure raises concerns about its effects on

early development, particularly during infancy, when the brain develops rapidly and neuronal plasticity is highly active.

Children begin spending time in front of screens as early as infancy, and their exposure rapidly increases as they get older. According to a Brazilian population-based study (BMC Public Health, 2023), 41.7% of newborns under the age of 12 months spent more than one hour per day in front of screens. A Japanese cohort study (Takahashi et al., 2023) of 7,097 infants discovered that those who utilised screens for more than four hours per day had a significantly increased risk of communication impairments by the age of two. A Swiss study (Brauchli et al., 2024) indicated that toddlers aged 12 to 36 months often surpassed one to two hours of daily screen time, with numerous children engaging with screens for even longer durations. Nearly 40% of 18-month-olds in Australia used screens for more than two hours every day, and exposure rose as babies got older (Brauchli et al., 2024).

It is crucial to recognise that the timing of exposure is equally as important as the duration, as it can influence cognitive development, sleeping patterns, and emotional regulation. Due to its impact on sleep cycles and attention regulation, studies have indicated that using screens in the evening is particularly harmful (Brauchli et al., 2024). Exposure to screens at night disrupts sleep cycles, resulting in impaired memory consolidation and cognitive processing difficulties (Kerzel et al., 2021). Those toddlers who spent more time in the evening in front of screens had higher levels of negative affect and greater difficulty regulating their emotions, which made it more difficult for them to fall asleep, as stated by Brauchli et al. (2024). Similarly, a Japanese cohort study (Takahashi et al., 2023) discovered that infants who spent more than four hours per day on screens had a 4.78-fold higher risk of communication difficulties by age two. Consequently, every extra hour of screen time adversely affected toddlers' social competencies and problem-solving skills (BMC Public Health, 2023).

Beyond exposure duration and timing, infants' interactions with digital media have a significant impact on how they develop. Kuhl et al. (2003) demonstrated that infants are unable to acquire language from screens unless they are involved in real-time social interactions and this is attributable to the significance of social cues, including eye contact, joint attention, and responsive turn-taking, which are essential for learning and language acquisition. As a result, a more beneficial way of screen exposure is

co-viewing, in which carers and infants interact with content displayed on a screen together.

Beside the duration and timing, there are many different ways infants can be exposed to screens, and the type of exposure is a key factor in determining how an infant's cognitive, linguistic, memory, and sleep development will be shaped. One of the most common ways newborns interact with digital devices is through active screen exposure, where the child engages interactively with digital content by responding to stimuli, touching, swiping, or using educational apps designed to foster early learning. Compared to passive viewing, this type of exposure requires active engagement, which can encourage early digital literacy and problem-solving abilities. Bedford et al. (2016) conducted a study to investigate the correlation between toddlers' active touchscreen use and their fine motor skills. Their research looked into the effects of scrolling, object selection, and scrolling on touchscreen devices on the development of motor coordination and sensorimotor skills in infants ranging in age from 19 to 36 months. They discovered that toddlers who engaged in active touchscreen interaction demonstrated a higher level of fine motor proficiency than those who used screens infrequently or not at all, as determined by standardised motor skill assessments. Using interactive touchscreen apps, Russo-Johnson et al. (2017) tested infant word learning. Two groups of children (ages 18–30 months) were enrolled in the study: one was exposed to interactive touch-based learning activities, while the other was exposed to passive video content and their findings indicated that children in the interactive group exhibited enhanced word retention, contingent upon the involvement of carers in the learning process.

In contrast, passive screen exposure refers to non-interactive digital media consumption, such as watching TV shows or videos on a phone and this type of exposure does not require active cognitive effort or motor involvement, suggesting a deficiency in the interactive elements that are essential for the development of cognitive capabilities and fine motor skills. High levels of passive screen exposure, especially watching television, may impair an infant's executive function and problem-solving skills compared to active play or interactive digital activities, according to research by Supanitayanon et al. (2020) and Christakis et al. (2009). Bhutani et al. (2024) discovered that when carers actively discuss digital content with their children, they create opportunities for turn-taking, which can reduce the negative impacts of high

screen exposure on language development. This was found to be the case when the carers actively discuss digital content with their children. This suggests that co-viewing and responsive engagement can help reduce some of the negative effects of excessive screen time. Screen exposure is becoming more common in infancy; however, its impact on development is contingent upon the engagement of infants with digital content, as well as the duration and timing of exposure. Interactive and co-viewing experiences, which offer chances for social learning and language-rich interactions, are more advantageous than passive screen time, according to research. Intervention programmes should educate parents on the importance of meaningful interactions—whether in person or through guided screen experiences—for healthy cognitive, linguistic, and emotional development in early childhood.

It includes parents watching movies, playing apps, or engaging in digital activities with their newborns while explaining, encouraging communication, and reinforcing language learning. As a result, carers provide critical scaffolding to assist infants in processing and comprehending new words and concepts. Co-viewing screen content with carers was positively associated with early language development in 12-36-month-old toddlers, according to Gago-Galvagno et al. (2023). Research indicates that infants who participated in shared screen time with an adult exhibited improved language milestones, indicating that active parental involvement can improve learning by facilitating more meaningful and engaging digital interactions. According to Tsuji et al. (2021), toddlers learnt words more effectively through face-to-face interactions than through video chats, although the results were not entirely consistent. This emphasises the importance of social presence in the acquisition of language, underscoring the potential limitations of screen-based learning strategies. Co-viewing allows conversational turn-taking, contextual explanations, and linguistic pattern reinforcement, which can reduce screen exposure's negative effects and support early language acquisition, according to the study.

Aside from active, passive, and co-viewing exposure, another prevalent form of screen interaction in infancy is background exposure. This occurs when a television, tablet, or smartphone is playing in the background while an infant is engaged in other activities. Background media can influence cognitive and social engagement, even if the infant is not watching the screen. However, this type of exposure can result in a decrease in linguistic interaction between infants and their carers (Takahashi et al., 2023). Similarly,

Kerzel et al. (2021) found that screen exposure in the background disrupts infants' sleep patterns due to the drowsiness caused by constant digital noise and artificial light. interfere with their natural sleep cycles, which affects memory consolidation and cognitive development in general.

Other important factors that impact the outcomes of screen exposure include self-directed (infants freely access screen content) or parent-guided screen use. Self-directed activity, which is not monitored or controlled by a carer, has been linked to an increased risk of overstimulation and less verbal interaction (Slobodin et al. 2023). Parent-guided exposure is a systematic digital engagement wherein parents oversee content selection, establish time constraints, and promote interactive learning. Infants who use screens under their parents' supervision exhibit better linguistic abilities and cognitive development than those who use screens on their own (Cao & Li, 2023).

Furthermore, research indicates that educational content, including interactive, developmentally suitable, and deliberately paced programming, facilitates language development and early cognitive skills, particularly when carers enhance learning through dialogue (Gago-Galvagno et al., 2023). Non-educational and fast-paced content, such as rapid scene changes in animated entertainment, has been linked to shorter attention spans and difficulty processing information (Eirich et al., 2022). A longitudinal study by Slobodin et al. (2023) found that infants exposed to large amounts of non-educational screen content by age 3 had delayed expressive vocabulary and poor sentence-producing skills, so content selection is crucial. In summary, the developmental impact of screen exposure in infancy is influenced by the type of exposure, level of parental participation, content quality, and environmental factors. Passive and background exposure may diminish carer involvement and disrupt natural learning processes, whereas active engagement and co-viewing typically yield superior cognitive and linguistic advantages. Screen time, whether used as a distraction or an educational tool, has a significant impact on early development outcomes.

In the upcoming chapter, I will perform a systematic review to investigate how screen time affects infants' language development, memory, and sleep. This section will review existing empirical studies to assess the extent to which digital engagement affects early cognitive and linguistic development, building on the groundwork established in the preceding chapters. The chapter will commence with an introduction that delineates the

significance of this subject in contemporary research. Subsequently, a comprehensive methodology will be provided, which will outline the criteria for selecting the studies that will be included in the review. The findings regarding the effects of screen exposure on language learning, memory formation, sleep regulation, and caregiver-infant interaction will be presented in a systematic manner in the results section. Ultimately, the discourse will integrate these findings, contrasting various viewpoints and emphasising potential ramifications for early childhood development and policy suggestions. This chapter aims to provide a comprehensive understanding of how early digital engagement can shape an infant's developmental trajectory by critically evaluating the existing literature.

Chapter 3: A Systematic Review on the Role of Screen Exposure on Language Development, memory and sleep

3.1 Introduction

The digital world is expanding at an unpredictable and rapid pace, with infants increasingly becoming one of its target audiences, both actively and passively; 68–90% of children under two are exposed to screens, averaging 58 minutes to 2 hours per day depending on the geographical region, where they live and SES (Zimmerman et al., 2007; Ramírez et al., 2021). Moreover, the average daily screen exposure increased from 1.23 hours at age 1 to 1.69 hours by age 2; for instance, children under the age of two in the United States spend an average of 2.62 hours per day watching television and 0.37 hours per day using smartphones (Chen & Adler, 2019). Also, parents are dependent on technology, and digital media and screens have become a part of their everyday life. This can have a significant effect on the infant's early development in the critical period of their life, characterised by rapid brain development, which affects cognitive growth, sleep regulation, memory development, and language acquisition. However, scientists strongly advise against or restricting infants' use of screens. The World Health Organisation (WHO, 2019) advises that children under one year of age should not engage with screens at all. Similarly, the American Academy of Paediatrics (Council on Communications and Media, 2016) recommends that infants aged 18 to 24 months do not use any digital media other than video chat. Despite the clarity of these standards, there is a great deal of variation in the recommendations and media-related practices.

By considering that screen exposure is an unavoidable component of parents and infants' lives. This systematic review is inspired by several research gaps that serve to emphasise the necessity of gaining a more in-depth understanding of the impacts that screen exposure has on infants who are less than two years old. Studies that are now

available frequently fail to consider infancy, this particular age group, instead concentrating on children older than 3 years, so as a result, important concerns about this foundational developmental period remain incompletely resolved. Furthermore, there is a lack of research that evaluates the quality of screen use, particularly active exposure, which includes engagement and interaction, not passive exposure, which includes background media noise. In addition, the current review has a tendency to place more emphasis on the qualitative distinctions in how screens are utilised instead of the amount of time spent in front of screens. In addition, the influence of screen exposure on developmental areas, such as sleep regulation, language acquisition, and memory formation, has not been properly investigated. These domains are inextricably linked, as sleep is critical in consolidating memory and supporting cognitive functions required for language acquisition (see Chapter 1). Similarly, early language acquisition depends on memory functions to store and process linguistic input, while sleep quality can affect both memory retention and language-learning capabilities; thus, it is essential to address these gaps to understand how screen exposure impacts three crucial developmental domains in infancy: sleep, language development, and memory formation.

Applying this comprehension of the intricate relationship between cognitive development and brain activity necessitates interdisciplinary methodologies that incorporate advancements in neuroscience and linguistics. Collectively, these domains offer a thorough framework for examining the impact of biological and environmental factors on essential developmental milestones, especially in early childhood. This facilitates researchers in formulating evidence-based recommendations to enhance parental practices, shape early education policies, and inform therapeutic interventions by evaluating the consequences of screen exposure. To address the developmental ramifications during infancy, insights from diverse disciplines are imperative. This review, which synthesises previous research, will provide a thorough understanding of how screen exposure affects these critical developmental processes.

Research Questions:

1. What insights have been made by the empirical evidence about the impacts of screen exposure on developmental trajectories such as language acquisition, memory formation, and sleep regulation in infancy?
2. What does the literature indicate about how parents and carers can reduce the potential negative outcome of screen exposure while maximising its effective use in supporting healthy cognitive and emotional development during infancy?

3.2 Method

3.2.1 Literature Search Strategy

The impacts of screen exposure on infants' development were investigated through an in-depth review of the literature, with an emphasis on memory formation, language acquisition, and sleep regulation. Only English-language, open-access research from the fields of psychology, medicine, and neuroscience that was published between 2000 and 2025 was taken into consideration for the review. Scopus and ScienceDirect, two of the major scientific databases, were searched for the content of the aimed topic. Furthermore, highly relevant studies were selectively searched on various platforms, including PubMed, to uncover and include noteworthy findings from these sources. Also, the search keywords were derived from studies and literature reviews on the subject and then refined systematically. The keywords chosen addressed important aspects of infant cognitive development, such as "infant development," "early development," "brain plasticity," "cognitive development," "attention," and "memory formation." Screen exposure-related terms, including "passive screen exposure," "digital media use," "electronic media," and "screen time," were incorporated to guarantee a comprehensive approach. To ensure coverage of the three critical areas of cognitive development in infancy, developmental domains focused on specific terms such as "language acquisition," "language delays," "vocabulary development," "sleep," and "sleep disruption." (Table 3).

3.2.2 Inclusion and Exclusion Criteria

A strict set of inclusion and exclusion criteria was used, according to the Population, Exposure, Outcome, and Study Design (PEOS) framework, to make sure the selection of relevant and high-quality research. Typically developing infants under the age of two years were the focus of the population criteria, and studies involving older children were not included unless they provided data that was relevant to this age group. Exposure is defined broadly to include both active and passive exposure to electronic devices, which can be direct interaction with screens such as video chat, social media, the internet, mobile phones, televisions, and video games, as well as passive exposure, where screens were present in the environment without the infant actively engaging. Contextual factors associated with regular screen use within familial settings were also taken into account, and for the purpose of evaluating the results of development, the review exclusively looked at studies that investigated cognitive development by focusing on language acquisition, sleep regulation, and memory formation. Table 2 provides a detailed classification of the outcome measures, also peer-reviewed and reviewed. Papers were only taken into consideration for inclusion if they included experimental and quantitative data along with statistical analysis of the findings. In addition, investigations had to be published in English and made accessible through open-access journals in order for transparency and the possibility of replicating the findings.

However, excluded studies included non-human subjects and did not focus on infants younger than two years or did not investigate at least one of the intended developmental areas. Books, meta-analyses, reviews, and theoretical studies that did not contain empirical data were also not included, and also, in order to keep consistency in the interpretation of the data, studies that were not written in English were excluded; moreover, atypical populations, such as children with developmental disabilities or medical issues, were typically not included in research. In addition, a systematic screening approach was used to evaluate the research's relevance once they had been extracted from different databases. First, eligibility was assessed by looking at abstracts and titles. At this point, studies that were not relevant to the research focus were removed. In order to verify their eligibility for inclusion, the remaining papers were subjected to a full-text review in order to minimise bias and enhance dependability. The validity and reliability of the review were enhanced by the use of this systematic

approach, which ensured that only the studies that were the most relevant were taken over to the final analysis.

3.2.3 Article Screening and Selection Process

The study selection process started with an in-depth search and identified a total of 356 records from Scopus and 156 records from Science Direct, resulting in 512 studies. Following the removal of duplicates, 103 articles from ScienceDirect and 168 articles from Scopus were left for screening. From the beginning, the titles and abstracts of these papers were carefully screened in order to find out whether or not they were relevant to the research subject. 77 papers from Scopus and 35 from ScienceDirect were chosen for full-text evaluation at this point, while the remaining studies were excluded based on the specified inclusion and exclusion criteria. After a comprehensive full-text assessment, 29 studies from ScienceDirect and 28 studies from Scopus met the eligibility requirements and were added to the final review. Moreover, after screening the reference lists of the selected papers, relevant studies were identified that might significantly improve the review's comprehensiveness; therefore, another 103 related studies were found through references and other data sources such as PubMed, Research Gate, and other relevant databases. After applying the same inclusion criteria, 16 studies were added to the final review.

The 39 studies in all were chosen for this systematic review. These studies were divided into four major research areas: cognitive development (11 studies), language development (10 studies), sleep (6 studies), verbal interaction (4 studies), and memory formation (8). Because of this careful selection process, only papers that were highly relevant and had a direct link to the study issue were finally included. Additionally, 68 studies were used to support the background and discussion in the other two chapters, providing a broader theoretical and empirical foundation for understanding infant memory, language acquisition, and sleep development. This review summarises the

available evidence on the effects of screen exposure on early infant memory, linguistics, and sleep-related development by including articles from various sources and strictly enhancing the dataset (figure 1).

3.3 Results

3.3.1 Description of the studies

After carefully reviewing the 39 included studies, it is clear that the research on infant screen exposure is complex. Various studies examine a range of developmental outcomes, employing distinct methodologies to evaluate the impact of screen time on early growth and learning. Although all studies focus on children under the age of two, some include data on older toddlers if it is relevant to questions about infant development. From the 39 research articles, 11 studies concentrate on cognitive milestones and early attention abilities, as well as more general cognitive development. 10 studies are solely concerned with language development, including vocabulary expansion and screen-time interactions between parents and children. 6 studies investigate sleep outcomes, studying the relationship between screen usage, bedtime behaviours, and overall sleep quality. 4 studies focus on vocal communication, specifically parent-infant communication and how technology can help or hinder it. Lastly, 8 studies explore memory formation, investigating how early recall or recognition of inputs by infants may be affected by different kinds of screen media and the duration of exposure

The studies that are part of this review differ in terms of their methodological approach and subject focus. Longitudinal studies provide insight into the long-term effects, particularly in areas such as socioemotional skills, language acquisition, and cognitive development, whereas cross-sectional studies assess the direct correlations between screen exposure and developmental outcomes. Meta-analyses and systematic reviews aggregate multiple studies, highlighting methodological deficiencies, trends, and research voids. Sample sizes are diverse, ranging from small experimental studies with as few as 16 participants to large-scale surveys involving over 7,000 mother-child pairs and the smaller, controlled studies offer in-depth analyses of particular mechanisms, while larger studies offer broader population insights. This variation impacts the

generalisability of findings. Although research is distributed across many different regions, the majority of studies come from East Asia, Europe, and the United States. A considerable proportion, however, originates from middle-income nations such as the Philippines, Thailand, and Brazil, providing insights into the socioeconomic and cultural impacts of screen exposure on infant development.

Furthermore, distinct research utilises distinct types of screen exposure. Some researchers examine overall screen exposure (television, tablets, digital devices), while others focus on specific formats such as interactive applications, video conferencing, social media, and infant DVDs. Researchers have demonstrated that passive screen exposure is frequently linked to cognitive deficits, language delays, and socioemotional issues. Conversely, interactive screen use and co-viewing with carers may mitigate adverse effects and, in certain instances, enhance learning outcomes. Significant gaps remain in spite of these discoveries since there are currently few longitudinal studies, it is challenging to establish a causal link between early screen exposure and subsequent developmental consequences. Although studies have identified risks, there is still a lack of understanding regarding the significance of protective factors such as material quality, parental mediation, and individual differences to gain a better understanding of the effects of digital media on early infant development, future research should focus on long-term studies and intervention strategies.

3.3.2 Screen exposure and language development

Infants' language acquisition is through live interactions and directly engaging carer's interactions. Studies suggest that face-to-face interactions activate key brain regions more than screen exposure, which emphasises the importance of direct social engagement in early development (Hutton et al., 2024). For instance, Roseberry et al. (2014) found that infants aged 12–30 months were able to learn new words through socially interactive video content, but not from passive television exposure. Similarly, Lauricella et al. (2011) reported that when infants engaged in interactive video chats with carers, their word retention was comparable to that of face-to-face interactions. Also, Bhutani et al. (2024) found that when carers actively discussed digital content with

children, they provided opportunities for conversational turn-taking, reducing the negative impacts of screen exposure on language development and Linebarger & Walker (2005) discovered that curriculum-based educational television programs increased expressive language results, but only when combined with active parental involvement.

Exposure to a screen does not provide the necessary interactive feedback to support these actions, which may cause a delay in the transition from non-verbal to verbal communication. Huber et al. (2018) examined different screen exposure types and found that passive exposure (such as background TV or non-interactive digital content) was linked to delayed expressive vocabulary, whereas structured educational touchscreen experiences showed fewer negative consequences. In a large-scale Brazilian study (Rocha et al., 2021) assessing 3,155 children aged 0–60 months, they found 41.7% of infants (0–12 months) who were regularly exposed to screens had lower communication scores, and an increase in their screen exposure correlated with a notable decrease in their language outcomes, they indicated a dose-dependent relationship between screen exposure and delayed language development. Similarly, longitudinal studies conducted in the United States and the United Kingdom by Ribner & McHarg, (2021) followed 303 families from 4 to 24 months. They discovered that higher screen exposure resulted in slower vocabulary growth and also verbal working memory. They used latent growth mixture modelling to analyse different screen exposure trajectories and discovered a statistically significant negative correlation between early media use and later language skills, which can interfere with linguistic cognitive development over time at a neurobiological level. On a neurobiological level, screen exposure has been linked to structural changes in brain areas responsible for language processing. Using magnetic resonance imaging (MRI), Hutton et al. (2020) established a correlation between decreased white matter integrity in regions of the brain associated with language processing and increased screen use between 9 and 24 months. For example, the superior temporal gyrus, which is an essential region for the processing of phonological information, has less cortical grey matter as a result of regular exposure to digital media, which can result in language difficulties that extend over time.

Besides the screen exposure effect, whether passively or actively, early language acquisition heavily depends on verbal interactions, turn-taking, and parental responsiveness. Infants raised in digitally distracted environments may experience

delays in their linguistic development, particularly evident in toddlers exposed to YouTube and online videos (Azevedo et al., 2022; Elias & Sulkin, 2017). Radesky et al. (2014) introduced the idea of "technoference," which refers to parental distractions produced by digital devices that reduce linguistic responsiveness and result in fewer conversational exchanges with children. However, as studies showed, not all digital exposure is harmful. Co-viewing digital media with infants, compared to passively exposing them to screens, has been shown to more effectively foster conversational contingency (Karani et al., 2022). Roseberry et al. (2014) discovered that children between the ages of 12 and 30 months were able to acquire new vocabulary through the watching of socially engaged video content rather than passive exposure to TVs. Similar to this, Bhutani et al. (2024) discovered that when parents are engaged with their kids during digital media, they give them the chance for turn-taking, which may reduce the negative impact of screens on language development. Also, Linebarger and Walker (2005) discovered that curriculum-based educational television programs increase expressive language results, only when combined with active parental contact. Similar to the findings of Bhutani et al. (2024), who conducted a scoping review of 16 studies and found that while five studies determined a significant correlation between high screen time and language delays, two studies suggested that co-viewing high-quality educational content could have a neutral or even positive impact on language development

Despite many studies linking screen exposure to delayed language development, the role of socioeconomic status (SES) is still complicated. It was found by Slobodin et al. (2023) that increased screen use at 6 and 12 months predicted higher risks of language and communication delays at 36 months, although this was only in moderate to high-SES families. Low-SES families, on the other hand, did not show the same correlation, which could be caused by differences in parental mediation, availability of a language-rich environment, or self-report accuracy. High-SES parents may be more aware of suggested screen-time guidelines and underreport their child's exposure, but low-SES families may not see screen time as a developmental concern, reducing the accuracy of findings across SES categories, and minimising the screen-related language delays requires parental mediation.

However, studies on screen exposure and language outcomes use parental reports and standardised assessments like the MacArthur Communicative Development Inventory

(MCDI), Peabody Picture Vocabulary Test (PPVT), and Clinical Linguistic Auditory Milestone Scale (CLAMS) using predictive models to control for factors such as socioeconomic status, parental involvement, and playtime. However, screen exposure itself is often assessed through parent-reported surveys (e.g., ScreenQ), time-use diaries, observational studies, wearable actigraphy, and device-tracking software, providing insights into screen duration, content type, and contextual factors like co-viewing and parental mediation. The researchers eventually came to a finding that just parental mediation does not completely remove the negative effects of early screen exposure, which takes us to the point that limiting screen exposure is still the best way to enhance early language acquisition (Bhutani et al., 2024). All of the results point to the negative effects of early and high screen exposure on language development, including reduced verbal working memory, delayed expressive vocabulary, and decreased language production, and the effects are most prominent in passive screen exposure without adult engagement, which lacks vital social learning processes including shared attention and turn-taking. Interactive video and educational media co-viewed with carers may help, but direct interactions are the best for infant language acquisition. These findings highlight the critical need for screen limitations and a greater focus on real-world social interactions to foster early language development.

3.3.3 Screen exposure and memory development

Hutton et al. (2024) show that passive videos reduce the DMN (default-mode network) activity, which supports episodic memory for the theory of mind and scene formations and can cause a weaker memory and reduce the ability to recall, and this is because of the disruptions from the actual interaction and engagement. This effect is most evident in infants under 24 months, who demonstrate greater memory recall for events that take place in the actual world, and this early passive exposure might interfere with the neural mechanism, which is essential for encoding and retrieval. Another study by Hutton et al. (2020) focuses on the types of media exposure, which indicates that preschool-aged children who watched fast-paced animated content had a significantly poorer recall of story details than those who heard the same story on audio or read it in the book, and this is because animated media's rapid shifts in scene overstimulate the visual-perceptual network and reduce connectivity in memory-related brain areas, which

can affect long-term memory. Adams et al. (2023) underscore that passive screen exposure is more consistently associated with memory delays in infancy, despite the fact that some interactive digital tools may facilitate cognitive development. Their findings underscore the importance of studying the context and quality of screen use rather than only its duration.

Moreover, the research conducted by Lytle et al. (2018) illustrates that toddlers who were exposed to touchscreen devices before the age of 18 months showed weaker working memory skills compared to those who had no or minimal screen exposure. A potential cause is that frequent app switching and fragmented digital experiences come across as overload attention, which reduces memory consolidation ability. Swider-Cios et al. (2023) believe that screen media might replace real-world experiences that are necessary for memory development, such as social interactions, exploratory play, and social contact. through the study, which indicates infants under the age of 24 months who were frequently exposed to background television had lower levels of focus and poorer memory recall. In addition, a study by Nyberg et al. (2020) found that 12-month-old infants who engaged in joint attention and social interaction during learning activities showed greater memory recall at 24 months, while those heavily exposed to screen-based media demonstrated poorer memory retention, which all emphasises the fact that infants learn better through interpersonal exchanges than through isolated digital content; therefore, carers have a crucial role to foster this early cognitive development.

All those findings were also confirmed by one large-scale research study that was done by the German KUNO kids' study; it reported that 10% of 12-month-old infants who are regularly exposed to digital media will later have weak performance for memory-related tasks (Durham et al., 2021). Similarly, Ribner & McHarg (2021) found lower memory recall when they were exposed to passive screen exposure like TV background distraction and attention disruption to have direct social interaction and environmental learning. and following, Rocha et al. (2021) found that this type of exposure in infants aged 0–23 months has poorer development outcomes; they had lower scores in memory tasks based on problem-solving, and Elias & Sulkin (2017) found the same impaired working memory result, but based on the content that infants are exposed to, toddlers aged 18–36 months, when they watch fast-paced YouTube content, have difficulty recalling the contextual details. This implies that cognitive engagement and

memory development may be impeded by auto-play digital media, as the frequent rapid transitions between scenes prevent the deep encoding of information.

However, not all screen exposure negatively affects memory development. Huber et al. (2018) found that the type of screen use has a significant impact on memory formation, with passive screen exposure demonstrating negative associations and interactive media engagement demonstrating cognitive benefits. According to the findings of their research, infants between the ages of 24 and 36 months who engaged in interactive tasks with touchscreens had a higher capacity for recall than those who only looked at passive content. Lauricella et al. (2011) also found that interactive video chats and instructional apps had fewer negative effects on memory development than passive television viewing. These findings imply that active engagement, contingent interaction, and structured educational content may improve memory recall.

Additionally, McHarg et al. (2020) assessed that infants who were exposed to screen-based media at the age of 4 months demonstrated weaker motor skills, but they did not show significant deficits in working memory or cognitive flexibility, so the study showed that screen exposure may selectively impair attention-related cognitive functions rather than broad memory abilities. Other longitudinal studies, such as the ones conducted by Huber et al. (2018), confirmed the same result that passive screen exposure between the ages of 6 and 12 months was associated with poorer delayed recall at 24 months, while the usage of interactive media (such as learning through touchscreens) was associated with better memory outcomes. Even they discovered that children (aged 24-36 months) who engaged in touchscreen-based interactive tasks had greater recall capacity than those who watched passive content. Another finding done by Lauricella et al. (2011) indicated that interactive video chats and educational apps had a less negative effect on the development of memory compared to passive exposure to television. Importantly, Ribner & McHarg (2021) also highlighted that children who engaged in interactive, high-quality digital content designed to promote cognitive engagement did not experience the same memory deficits as those who were passively exposed to screen media. Their findings suggest that digital interaction, particularly when paired with carer involvement, may enhance learning and memory recall rather than impair it. Similarly, Roseberry et al. (2014) found that contingent

interactions via video chat improved infants' word retention, a critical component of memory consolidation; therefore, findings reinforce the idea that the quality of screen exposure matters more than the quantity, with interactive, educational, and carer-supported digital experiences showing fewer negative consequences on cognitive and memory development.

This is supported by Clemente-Suárez et al. (2024), who discovered that low-SES families rely on passive screen exposure as their primary source of engagement, replacing rich verbal and social interactions that are essential for memory development. Similarly, Gago-Galvagno et al. (2023) found that low-SES toddlers aged 12–36 months exposed to background TV for an average of two hours daily had lower levels of parent-child interaction, which directly impacted early vocabulary acquisition and memory retention. This suggests that both the duration and type of screen exposure play a crucial role in memory development, particularly in disadvantaged households.

However, research on screen exposure and memory development in infants under two years employs parental surveys, observational studies, and age-appropriate cognitive assessments. Common methods include Visual Paired Comparison (VPC) tasks for recognition memory (Burbacher & Grant, 2012), deferred imitation tasks for memory retention (Roseberry et al., 2014), and delayed response tasks for early working memory development (Huber et al., 2018).

These studies collectively demonstrate consistent patterns of memory damage that are linked to screen exposure; the results point to the fact that infants whose parents expose them to screens in the early years of their lives experience poorer executive functions, lower attention spans, and weaker memory retention as they grow into toddlerhood. Passive digital media exposure, background television, and animated content with rapid scene transitions all result in poorer memory retention and recall; nonetheless, controlled touchscreen interactions, video chat with carers, and interactive digital tools could minimise some of these effects.

3.3.4 Screen Exposure and Sleep Disruptions

Sleep plays a crucial role in memory consolidation; disruptions caused by screen exposure not only affect rest but also affect cognitive processes, which can be vital during early learning acquisition and development (Hutton et al., 2024; Nagata et al., 2021; Zhu et al., 2020; Staples et al., 2021). Infants aged 6–24 months who were exposed to screens before bedtime slept about 40 minutes less every night than infants with limitation or no screen time, and one of the main causes is that exposure to blue light suppresses melatonin production, which leads to delays in sleep onset and reduces sleep duration (Hutton et al. 2024). Nagata et al. (2021) achieved a similar result: toddlers aged 12–24 months who watched screens an hour before bedtime required 15 minutes longer to fall asleep. Furthermore, by using actigraphy, parental reports, and house observations. Zhu et al. (2020) and Staples et al. (2021) confirmed the earlier findings, the study found that children 30 months old used screens within an hour of bedtime, while parents reported screen use as part of their sleep routine. Actigraphs were also worn by children in order to monitor their sleeping patterns and the data obtained revealed that there was a correlation between more screen time before bedtime and a greater number of sleep pattern changes, shorter sleep, increased nighttime awakenings, and a later sleep onset. Even infants as young as six to eighteen months old who participated in the study conducted by Zhao et al. in 2023 showed a higher number of nighttime awakenings and a lower sleep efficiency.

In addition, the German KUNO Kids' Study showed that 20% of 12-month-old infants spent at least 30 minutes per day in front of a screen; therefore, that exposure and its increase are associated with poorer sleep outcomes in infants and toddlers aged 6 to 36 months, which reduced total sleep time and increased night awakenings (Diler & Başkale, 2022). Moreover, other studies show the same negative effect, McArthur et al. (2021) conducted a longitudinal study of infants who averaged 60 minutes of daily TV/DVD viewing and slept 24 minutes less at night. In a meta-analysis, Carter et al. (2016) revealed that high screen exposure, especially before bedtime, reduced sleep duration, nighttime awakenings, and sleep delay, which have also been confirmed by the study by Elias & Sulkin (2017) and Chindamo et al. (2019), who found that toddlers aged 18–36 months frequently exposed to YouTube content or other screen activities before bedtime had irregular sleep patterns. Also, they indicated that even mobile screens may have a more significant influence than television viewing.

Chonchaiya et al. (2017) investigated the differences in sleep disruptions based on the type of screen content and found that fast-paced, rapidly changing animations had a stronger impact on sleep disturbances than slower, structured educational content. This suggests that not only does screen exposure matter, but also the type of content children are exposed to before sleep. Besides the negative effects that have been approved through the studies above that are associated with sleep regulation by screen media exposure, some studies emphasise the role of carers and parents as crucial in their early life period, as Sundqvist et al. (2022) indicate that infants exposed to less than 30 minutes of screen time daily had significantly higher sleep efficiency than those exceeding two hours. The US and UK longitudinal study by Ribner & McHarg (2021) supports this finding, demonstrating that children aged 4–24 months with strict parental screen-time limits experienced fewer sleep disturbances compared to those with unrestricted access. Furthermore, a study by Hale & Guan (2015) found that children with parents who implemented consistent "screen limitation" before bedtime exhibited better sleep quality, reduced night wakings, and earlier sleep onset. These findings align with Tandon et al. (2021), who reported that parental involvement in setting screen limits is one of the most effective interventions to mitigate sleep disruptions caused by digital media exposure. So this screen parental restriction could depend on socioeconomic factors. Durham et al. (2021) reported that lower-income families and households had greater digital media exposure daily, which led to more sleep disruptions. Additionally, Paruthi et al. (2022) found that in low-SES families, mobile device use before bedtime was often linked to later sleep onset and lower total sleep duration, as screens were used for entertainment or calming purposes rather than structured educational activities. This further supports the argument that the type and timing of screen exposure play a critical role in sleep regulation

However, parental reports, sleep diaries, and questionnaires were used in the majority of studies evaluating infants' sleep patterns; these methods may be biased in reporting (Guerrero et al., 2019). However, studies using actigraphy-based monitoring, which objectively assesses sleep patterns by using movement tracking, found significant reductions in overall sleep duration linked with screen use (Zhu et al., 2020). It was also discovered by actigraphy that using a screen for more than sixty minutes before going to bed led to noticeable delays in the onset of sleep and higher overnight arousals. These findings were in agreement with the accounts that were provided by the parents.

Biologically, the blue light that is released from digital screens suppresses melatonin, which is responsible for the regulation of sleep (Wood et al. 2013).

The findings provide comprehensive evidence for the negative effects of media exposure, which cause shorter sleep duration, frequent awakenings during the night, delayed sleep onset, and generally changed sleep patterns and quality, even when they are exposed to the screens before their bedtime and the effects become more pronounced as screen time increases or even the rapid scene content. In order to encourage healthy sleep patterns in newborns, parents should mediate their children's screen time and establish regular bedtime routines. However, there is a need for additional studies to investigate the long-term developmental effects of persistent sleep disturbances caused by exposure to screens.

3.3.5 Interaction during screen exposure

Since we mentioned the studies and research that addressed the three cognitive components of language, memory, and sleep, as well as the role of parents in minimising both the negative and beneficial consequences, the parent-child interaction would be a topic because it has a huge influence on cognitive development, which is affected by media screen exposure (Mermelshtine, 2017). To prove this, Anderson and Pempek (2005) explain how active parental involvement reduces the "video deficit" effect, in which young children about 1 to 3 years struggle to learn from screens without direct social interaction. Parents can help infants in bridging the gap between screen-based learning and real-world comprehension by engaging in conversation about the content, asking questions, and guiding attention. The study showed all would help infants to improve their language processing, memory retention, and cognitive engagement.

Therefore, passive exposure affects social engagement, which has been confirmed by the study of Radesky et al. (2015) that infants who passively watched television from 9 to 24 months of age spent less time engaging with others, which resulted in lower social engagement scores at 24 months, so this disruption also affects turn-taking abilities and joint attention, two fundamental elements of early communication development. Additionally, Ribner & McHarg (2021) found that infants frequently exposed to background television had less social engagement; even passive media exposure can disrupt attentional development and carer-infant bonding. Also, Azevedo et al. (2022) conducted a study of 435 mothers with infants aged 0–36 months and found that many used smartphones and tablets to entertain their children while doing household tasks, reducing verbal and physical engagement; they miss out on valuable conversational experiences that shape their development. Even Radesky et al. (2014) introduced the term "technoference" to describe how carers frequently interrupt face-to-face interactions to check their phones, which can lead to infant frustration, social withdrawal, and less language input, which highlights how parental screen distractions impact early childhood social and emotional development. Similarly, Ribner & McHarg (2021) found that background media when screens are on but not actively watched reduces caregiver responsiveness and affects infants' attention regulation. Even when the screens aren't the main focus, their presence can still disrupt parent-child interactions and learning environments.

However, interactive screen exposure has a significant impact on infant cognitive and language development. Kirkorian et al. (2016) discovered that structured, educational touchscreen apps assist toddlers in retaining information and engaging more effectively than passive TV viewing. The content, which includes real-time feedback, active participation, and problem-solving, enhances cognitive flexibility and learning. The way screen-based content is designed affects how well children learn and stay engaged. Roseberry et al. (2014) discovered that live video interactions enhanced joint attention and language acquisition, whereas passive video viewing had minimal to no impact. Instant feedback and social cues that aided language development were offered by interactive media, such as video chats with attentive carers. However, these advantages are dependent on carer participation because infants still require supervision when applying digital learning to real-world scenarios. Taylor et al. (2024) conducted a systematic review and discovered that children who viewed media with an adult

co-viewer experienced greater vocabulary gains. According to Gago-Galvagno et al. (2023), toddlers aged 12–36 months who co-viewed versus solitary screen exposure improved their language acquisition when their parents discussed media content. Furthermore, learning outcomes are improved by digital content that promotes contingent interactions. Research indicates that the most effective screen-based learning environments are characterised by verbal scaffolding, gestural reinforcement, and attentional direction, particularly when adult engagement is present (Kirkorian et al., 2016; Roseberry et al., 2014). Lauricella et al. (2011) established that toddlers utilising interactive educational applications, especially with carer assistance, displayed enhanced recall and problem-solving skills relative to those exposed to passive digital media. They found that structured digital engagement, especially with parental explanations, improves attention regulation and executive function. This is also consistent with the findings of Toub et al. (2023), who discovered that young children aged 24-36 learnt significantly more words from interactive educational media than from passive television exposure, especially when carers reinforced the content through discussion and repetition.

Children under two years of age are especially susceptible to the adverse effects of passive media, which have been linked to reduced social interaction, constrained language development, and diminished attentional regulation (Ribner & McHarg, 2021; Azevedo et al., 2022). Elias and Sulkin (2017) discovered that toddlers aged 18-36 months who watched YouTube frequently had fewer turn-taking conversations with their parents, indicating that unsupervised screen time reduced opportunities for interactive learning. But structured digital engagement, interactive dialogues, and co-viewing greatly improve language learning and memory (Gago-Galvagno et al., 2023; Taylor et al., 2024). The findings of this study highlight the fact that not all exposure to screens is equally harmful. Interactive educational content that is well-designed and is accompanied by parental guidance has the potential to provide cognitive benefits while simultaneously minimising the negative effects of passive media consumption.

Nevertheless, additional research is required to ascertain the most effective engagement strategies that will optimise the advantages of digital learning while minimising potential developmental risks. Given the growing impact of digital exposure in infancy, future research should focus on understanding how parental mediation and structured interactive screen use can improve early learning outcomes.

4. Discussion

This review looked at the impact of early screen exposure on infant language development, memory formation, and sleep regulation. The results illustrate the substantial impact of screen exposure on these three fundamental cognitive domains and a notably clear association between early learning and neurodevelopment and high screen exposure, which surely leads to developmental delays. All of the studies agree on one thing: exposing infants to screens has many effects on their language acquisition, memory formation, and sleep patterns. One consistent finding is that passive, unstructured screen time frequently replaces high-quality social interactions, such as child-directed speech and shared play, which are both essential for early linguistic and cognitive development (Zimmerman et al., 2007; Elias & Sulkin, 2017). As a result, it is crucial to consider how often and what kinds of screens they use. Multiple longitudinal and cross-sectional studies indicate that early and high exposure to television, digital applications, or YouTube content correlates with delayed emotional and communicative milestones, reduced vocabulary acquisition and development, and diminished parent-infant interactions (Azevedo et al., 2022; Ribner & McHarg, 2021; Rocha et al., 2021). Myers and Arterberry (2022) state that digital media exposure in children under three years old can have varying effects depending on the type and context of use, and while co-viewing and parent-guided screen time may reduce some of the negative effects, passive screen exposure often limits opportunities for real-world interactions that are crucial for early learning. This highlights the fact that the quality of screen exposure, as opposed to the duration of screen exposure, plays a crucial role in shaping early linguistic development (Gago-Galvagno et al., 2023; Sundqvist et al., 2022; Bhutani et al., 2024).

Not only does early media exposure influence language development, but it also influences the formation of memories. Exposure to screen content that is cognitively demanding or poorly designed can result in cognitive overload (Clemente-Suárez et al., 2024), disrupt joint attention, and affect working memory by reducing opportunities for exploratory play and face-to-face interactions, which are crucial for memory consolidation (Swider-Cios et al., 2023). Although a few studies have suggested that there may be some advantages to using high-quality, interactive digital tools, particularly those that encourage infant participation and parental mediation (Hutton et al., 2024; Miller et al., 2017), actual use of such optimised media is still limited. Studies have

associated passive screen exposure, including background television and mobile applications, with heightened externalising behaviours, diminished attentional control, and impaired memory retention by preschool age (Mallawaarachchi et al., 2025; Supanitayanon et al., 2020). Passive screen exposure is more common than active screen exposure, and there is a need and necessity of distinguishing between "passive" or "overstimulating" digital formats and "engaging" ones, emphasising the intricate relationship between media exposure and cognitive development.

Multiple studies have shown that infants who are exposed to screens before bedtime had shorter nighttime rest, later sleep onset, and more frequent awakenings. This is another finding that has been observed repeatedly (Staples et al. 2021 and Pickard et al. 2024). While parents frequently use screens as a "pacifier," especially in high-stress situations (Brauchli et al., 2024), this strategy appears to be detrimental, increasing fragmented sleep and negatively impacting subsequent language processing and memory (Morawska et al., 2023). Additionally, the extent of household variables, socioeconomic status (SES), that influence the timing and manner of infants' exposure to screens is substantial (Paulus et al., 2024; Monteiro et al., 2022), including , education level and the attitudes of the parents, their income. Lower-SES households may rely more heavily on digital media for childcare, increasing the possibility of communication deficits and cognitive delays (Slobodin et al., 2024; Takahashi et al., 2023). However, screen exposure is almost common in many modern families and this body of evidence shows high screen exposure significantly affects cognitive development, leading to delays in language acquisition, memory, and sleep regulation. Studies confirm that passive screen exposure reduces parent-child interactions and weakens phonological processing, delaying language milestones (Gago-Galvagno et al., 2023). In addition to causing cognitive overload, high screen exposure also affects memory retention and attention (Clemente-Suárez et al., 2024). Additionally, screen use before bedtime disrupts sleep cycles, reducing slow-wave sleep (SWS), which is essential for cognitive flexibility and memory consolidation (Brauchli et al., 2024).

Consequently, passive, high-exposure, or unstructured use may disrupt the developmental trajectories of infants, which encompass critical milestones in language, memory, and sleep and Interactive and parent-mediated strategies for conversation, labelling, and turn-taking can minimise these adverse effects and potentially enhance cognitive function. Educational apps, live video calls, and background TV should all be

investigated longitudinally to see how they affect family routines, carer stress, and sociocultural contexts. By comprehending these consequences, it is feasible to establish policies that safeguard early development while acknowledging that, when employed prudently and in moderation, digital devices are not necessarily detrimental to infants.

5. Conclusion

This review highlights the intricate and varied impacts of screen exposure on language acquisition, memory formation, and sleep regulation—three essential domains of infant cognitive development. The results demonstrate that developmental delays, including delayed vocabulary acquisition, impaired memory, and disrupted sleeping patterns, are consistently linked to high screen exposure, particularly passive and unstructured use, and the studies support the World Health Organisation (2019) and the American Academy of Paediatrics (2016) guidelines for limiting screen time for infants, particularly those under two. The review highlights the significant role that social interaction and the mediation of carers play in significantly reducing the adverse effects of screen exposure and passive screen exposure is unable to fully replicate the real-world interaction, joint attention, and conversational turn-taking that infants learn best through (Kuhl, 2010). However, recent research suggests that interactive and developmentally appropriate screen content, when combined with active carer engagement, may improve cognition. According to research, contingent digital interactions, structured engagement, and co-viewing can help with language acquisition and memory retention; however, these benefits are heavily dependent on parental mediation and content quality (Roseberry et al., 2014; Hirsh-Pasek et al., 2015).

These findings influence policy, practice, and research. Parents and carers should prioritise interactive social experiences, such as reading, play-based learning, and direct conversations, over passive media exposure from a practical standpoint, also is crucial to limit screen time before bed in order to prevent sleep disturbances, which can harm memory and cognitive development. Based on new neuroscientific and developmental research findings, public health organisations should revise their legislative recommendations for screen exposure. A further point to consider is that there is a growing demand for rules in the media that encourage the production of content that is of a high quality, interactive, and suitable for the development of infants, and by

considering that, digital exposure would be in line with the better practices for the early development of cognitive abilities. In low-SES communities, where screen usage is typically elevated due to environmental limitations, policymakers should implement educational programmes to enhance parental awareness of the potential risks and benefits associated with screen exposure. Future research should focus on determining how different types of screen interactions, passive, interactive, educational, and contingent, shape infant development over time. Longitudinal research is necessary to determine the long-term effects of early screen exposure on executive function, memory networks, and language outcomes and to investigate the fundamental brain mechanisms of screen-related cognitive alterations, neuroimaging techniques such as EEG, fMRI, and fNIRS should be employed. To conclude, this review underscores the importance of promoting real-world interactions in infancy and restricting passive screen exposure, despite the fact that digital media is an inevitability of contemporary life and as it advances, it is a necessity that policymakers, medical professionals, and carers collaborate to establish evidence-based screen time regulations that support the development of cognitive and language skills, and optimising early development is possible by ensuring screen-based experiences complement social interactions.

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Figure 1. PRISMA 2020 flow diagram for new systematic reviews

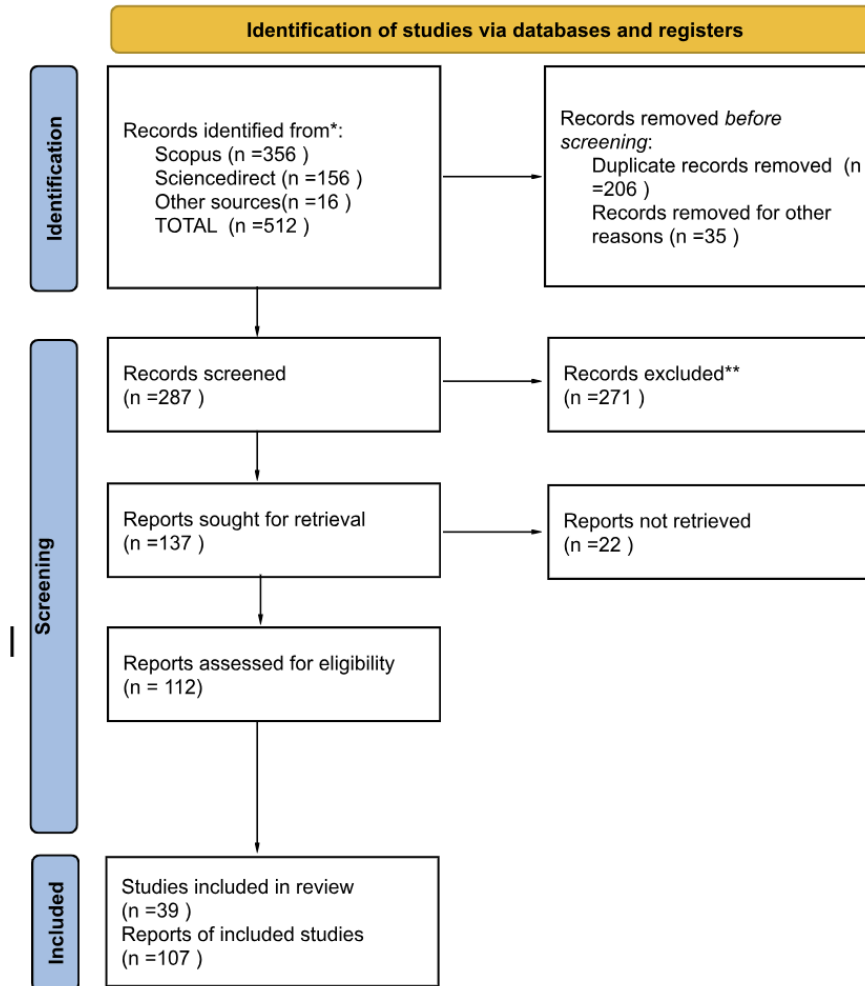


Table 1: Categories of Screen Exposure and Contextual Factors

Exposure Type	Description	Devices Involved	Interaction Level	Contextual Factors
Active Exposure	Direct interaction with screen content through touch, swiping, or responding to stimuli.	Tablets, smartphones, interactive apps, video chat.	High— requires cognitive and motor engagement.	Can involve educational apps or parent-guided activities.
Passive Exposure	Watching screens without interaction (e.g., TV shows, videos, social media content).	Television, tablets, mobile phones.	Low—no direct engagement.	Often occurs when carers use screens nearby.
Background Exposure	Screens are playing in the environment while the infant is engaged in other activities.	Television, smartphones, tablets.	None—indirect exposure.	May disrupt interactions, attention, and sleep cycles.
Co-Viewing	Parent and child watching/interacting with screen content together.	Television, tablets, educational apps.	Moderate—parent scaffolds learning.	Supports language development through shared attention and discussion.
Self-Directed Use	Infant freely accesses and interacts with digital content without supervision.	Smartphones, tablets.	High—unstructured engagement.	May lead to overstimulation and reduced parental interaction.
Parent-Guided Use	Screen use is monitored, content is selected by carers, and interaction is encouraged.	Any digital device.	High—structured and intentional use.	Associated with better cognitive and linguistic development.

Table 2: Classification of Outcome Measures in the Reviewed

Developmental Domain	Outcome Measure	Assessment Tools/Methods	Key Indicators Evaluated
Language Development	Vocabulary acquisition	MacArthur-Bates CDI, Peabody Picture Vocabulary Test (PPVT), LENA system, parent-reported measures.	Expressive and receptive vocabulary, phonological processing, word recognition, speech production.
	Communication skills	Communication and Symbolic Behavior Scales (CSBS), caregiver reports, conversational turn count (CTC) analysis.	Gesture use, joint attention, verbal interactions, conversational turns.
	Phonological processing	EEG, fNIRS, high-amplitude sucking paradigm (HAS).	Neural activation in language-related regions, phonemic discrimination, auditory memory traces.
Memory Formation	Recognition memory	Visual paired comparison task (VPC), deferred imitation tasks, eye-tracking studies.	Looking time differences, novelty preference, recall accuracy, word retention.
	Working memory	Delayed response tasks, object permanence tests, verbal recall tasks.	Retention duration, error rate, problem-solving abilities, semantic and episodic memory performance.
	Neural correlates of memory	EEG, fNIRS, fMRI, MEG.	Hippocampal activity, activation in memory-related brain areas, neural plasticity indicators.
Sleep Regulation	Sleep duration & quality	Actigraphy, polysomnography (PSG), parent-reported sleep diaries.	Total sleep time, sleep latency, night awakenings, sleep efficiency.
	Circadian rhythm	Melatonin secretion analysis, sleep-wake patterns from actigraphy.	Sleep phase shifts, disruptions in sleep cycles, bedtime screen exposure impact.
	Sleep-dependent learning	NREM & REM sleep monitoring via EEG, behavioral memory retention tests.	Memory consolidation, retention of newly learned words and linguistic structures.

Table 3.: full search strategy

Database	Cognitive Domain	Search Strings
Scopus	General Infant Development	("infant development" OR "early development" OR "cognitive development" OR "brain plasticity") AND ("passive screen exposure" OR "digital media use") AND (infant OR neonate" OR "infancy" OR "under 2 years OR "24 months old")
	Sleep	("passive screen exposure" OR "digital media use") AND ("sleep" OR "sleep disruption") AND ("infant" OR "under 2 years" OR "infancy")
	Language Acquisition	("passive screen exposure" OR "digital media use") AND ("language acquisition" OR "language delays") AND ("infant" OR "under 2 years")
	Memory and Cognitive Development	("passive screen exposure" OR "digital media use") AND ("memory formation" OR "cognitive development" OR "attention") AND ("infant" OR "neonate" OR "under 2 years")
	Comprehensive	("infant development" OR "early development" OR "brain plasticity") AND ("passive screen exposure" OR "digital media use") AND ("sleep" OR "sleep disruption") AND ("language acquisition" OR "language delays" OR "vocabulary development") AND ("memory formation" OR "cognitive development" OR "attention") AND ("infant" OR "neonate" OR "infancy" OR "24 months old")
ScienceDirect	cognitive Development	("infant development" OR "early development") AND ("passive screen exposure" OR "digital media use") AND (infant OR "under 2 years")
	Sleep	("passive screen exposure" OR "digital media use") AND ("sleep" OR "sleep disruption") AND ("infant" OR "under 2 years" OR "infancy")
	Language Acquisition	("passive screen exposure" OR "digital media use") AND ("language acquisition" OR "language delays") AND ("infant" OR "under 2 years")
	Memory and Cognitive Development	("passive screen exposure" OR "digital media use") AND ("memory formation" OR "cognitive development" OR "attention") AND ("infant" OR "neonate" OR "under 2 years")

Table 4: Summary of all included studies in the review

Author	Title	Year	focus	Study Type	Sample Size	Age Covered	Type of Screen Exposure	Passive or Active	Outcome	Key Findings	Gaps
Eirich et al.	Association of Screen Time with Internalizing and Externalizing Behavior Problems	2022	screen time duration and behavioral problems (general cognitive)	Systematic Review and Meta-analyses	159,425 participants (87 studies)	0-12 years	General screen time	Passive	significant correlation with problems.less	Screen time linked to externalizing and internalizing issues	Need to clarify causal relationships and long-term impacts
Gago-Galvagno et al.	Contributions of Screen Use on Early Language and Development Milestones	2023	Language	Observational	114	12-36 months	TV, Tablets, PCs, Background TV		effects on language development	Positive impact when shared with adults; negative for background TV	Further studies needed on contextual factors
Clemente-Suárez et al.	Digital Device Usage and Childhood Cognitive Development	2024	Memory	Narrative Review	157 studies reviewed	Childhood (0-12 years)	Digital devices		Impacts on attention, memory, and executive functions	Balanced usage enhances cognitive skills; excessive use risks cognitive overload	Limited understanding of long-term impacts and individual differences
Hutton et al.	Digital Media and Developing Brains: Concerns and Opportunities	2024	screen exposure: language development, parent-child interaction, and memory formation, but not sleep outcomes	Narrative Review	Focused on developmental stages	Infancy to adolescence	Screen media activity		Differential effects on brain structure and behaviour	Early exposure linked to language delays; benefits depend on content and context	Mechanisms of impact on neurodevelopment need further study
Azevedo et al.	Digital Media Use on Interactions Between Mother and Child	2022	Verbal Interaction	Survey	435	0-36 months	Digital media		Increased media use correlated with reduced	Frequent use linked to delays in emotional and	Impact of parental mediation strategies underexplored

									parent-child interactions	language development	
Sundqvist et al.	Child-Directed Parental Talk and Developing Vocabulary in 2-Year-Olds	2022	Language	Methods	87	2 years	Video content		Negative correlation between video watching and vocabulary	Parental engagement mediates media effects on language development	Lack of longitudinal insights and effects of specific media types
Slobodin et al.	Infant Screen Media and Child Development: A Prospective Community Study	2024	screen exposure	Longitudinal	179	6-36 months	Screen media		Early exposure linked to communication deficits at 36 months	SES moderates developmental risks of screen exposure	Limited evidence on protective factors for high-risk families
Miller et al.	Looking Beyond Swiping and Tapping: Digital Technology Use in Early Childhood	2017	screen exposure: early cognitive engagement with digital tool	Systematic Review	60 studies reviewed	0-5 years	Digital devices		Research methodology review for digital technology studies	Highlights gaps in longitudinal and sociocultural context studies	Calls for improved research designs focusing on developmental interplay
Morawska et al	Managing Screen Use in the Under-Fives: Recommendations for Parenting Intervention Development	2023	Sleep	Review	Varied studies included	0-5 years	General screen use		Framework for parenting and intervention models	Recommendations emphasize parental role and co-viewing benefits	Need for practical interventions in diverse sociocultural settings
Dy et al.	Measuring Effects of Screen Time on the Development of Children in the Philippines	2023	screen exposure: language development	Cross-sectional	419	24-36 months	General screen time	Passive	Screen time beyond 2 hours associated with lower language scores	Co-viewing mitigates some negative effects; excessive parental screen time increases child exposure	Longitudinal studies needed for causal inference

Brauchli et al.	Screen Time vs. Scream Time: Interrelations Between Screen Time, Negative Affect, and Effortful Control	2024	screen exposure;cognitive and socio-emotional development	Longitudinal	462	12-36 months	Digital media		Screen time linked to increased negative affect but not reduced effortful control	Evidence for independent effects of screen time on affect	Contextual and content-related factors underexplored
Ribner & McHarg	Screens Across the Pond: Longitudinal Screen Time Research in the US and UK	2021	screen exposure:language development and cognitive executive functions	Latent Growth Curve Analysis	303	4-24 months	Digital media		High media use associated with delayed language and executive functions	Cultural differences in parental guidelines impact usage	Interaction between cultural norms and screen effects
Rocha et al.	Screen Time and Early Childhood Development in Ceará, Brazil	2021	screen exposure:Language Development:	Population-based cross-sectional	3155	0-60 months	General screen time		Excess screen time associated with lower scores in communication and motor skills	Prevalence of excessive screen time rises with age	Focus on causal relationships and interventions required
Mallawaarachchi et al.	Types and Contexts of Child Mobile Screen Use and Associations with Early Childhood Behavior	2025	screen exposure:General Cognitive Development	Longitudinal	536	1-6 years	Mobile devices		Interactive app use linked to externalizing behaviors in toddlers	Stable screen use habits form early; need to focus on social context	Limited data on specific app content and child behavior outcomes
Swider-Cios et al.	Young Children and Screen-Based Media: The Impact on Cognitive and Socioemotional	2023	screen exposure:General Cognitive Development	Review	Various studies reviewed	0-5 years	Screen-based media		Parental mediation reduces negative	Interactivity improves learning outcomes; passive exposure risks delays	Need for targeted studies on interactive content and neuroplasticity

	Development and the Importance of Parental Mediation								effects of screen media		
Elias & Sulkin	YouTube Viewers in Diapers: Factors Associated with Amount of Toddlers' Online Viewing	2017	Verbal Interaction	Cross-sectional	289	18-36 months	Online platforms, YouTube	Passive	YouTube use integrated into daily routines	Parental decisions shape toddler viewing; concerns over unregulated content	Impact of specific content types on toddler behavior requires study
Marianne Thode Krogh et al.	A Longitudinal Examination of Daily Amounts of Screen Time and Technoference in Infants Aged 2–11 Months	2021	Sleep	Longitudinal Study	2015	2–11 months	Television, Smartphones, Tablets	Passive	Daily screen time increases with age; technoference negatively impacts interactions.	Technoference disrupts verbal and non-verbal interactions, highlighting the importance of minimal screen time.	Need for objective measures beyond parental reports; broader population samples.
Frederick J. Zimmerman et al.	Associations Between Media Viewing and Language Development in Children Under Age 2 Years	2007	Language	Cross-sectional Survey	1008	8-24 months	Baby DVDs/Videos, Educational and Non-educational TV	Passive	Negative association between baby DVDs/videos and language scores.	Baby videos negatively impact language development in infants but not toddlers.	Mechanisms of negative impacts on language need further exploration.
L.J. Myers and M.E. Arterberry	Digital Media and Children Under 3 Years of Age	2022	screen exposure: language development and general cognitive aspects	Review and Observational Methods	Varied across 25 papers	<3 years	High-quality children's programming	Passive and Some Active	outcomes; some learning with scaffolding but also socio-emotional problems.	Parent scaffolding critical for meaningful screen use; otherwise, poor developmental outcomes observed.	Lack of longitudinal studies linking screen use with long-term outcomes.
Naja Ferjan Ramirez et al.	Exposure to Electronic Media Between 6 and 24	2021	screen exposure: verbal interactions.	Longitudinal Study	24	6-24 months	TV, Computers, DVDs, Video Games	Passive	Negative association with SES and vocal activity;	High SES families reduced screen use with age; electronic media	Further research on long-term impacts of reduced vocal

	Months of Age: An Exploratory Study								screen time reduces parent-child interactions.	exposure decreases verbal interactions.	interactions due to screen exposure.
Carin Adams et al.	Screen Technology Exposure and Infant Cognitive Development: A Scoping Review	2023	Memory	Scoping Review	10	0-24 months	Various Screen Technologies	Passive and Interactive	Correlations between screen exposure and cognitive delay; some positive outcomes reported.	More robust methodologies needed; context of screen use is critical.	Few studies focus on interactive screen use; causal links unclear.
Canadian Paediatric Society	Screen Time and Young Children: Promoting Health and Development in a Digital World	2017	screen exposure: general cognitive development	Position Statement	Not specified	<5 years	Digital Media, TV, Tablets	Passive and Interactive	High screen use linked to delayed language and cognitive skills; live interactions superior.	Early overexposure increases developmental risks; screen interactions should be minimized.	Need for longitudinal evidence and differentiation between screen types.
Angela D. Staples et al.	Screen Use Before Bedtime: Consequences for Nighttime Sleep in Young Children	2021	Sleep	Observational Study	474	30 months	Television, Tablets	Passive	Screen use before bedtime linked to shorter, less consistent sleep patterns.	Bedtime screen use impacts sleep duration and consistency, requiring moderated routines.	Limited studies linking screen use timing with physiological sleep markers.
Nichara Ruangdaraganon et al.	Television Viewing in Thai Infants and Toddlers: Impacts to Language Development and Parental Perceptions	2009	Language	Cohort Study	260	6 months-2 years	Television	Passive	No link between >2 hours TV viewing and delayed language development.	Parental perception generally positive; males more likely to experience delayed language.	Research needed on program content's role in mediating language outcomes.

E.-Y. Lee et al.	Television Viewing, Reading, Physical Activity, and Brain Development Among Young South Korean Children	2017	screen exposure:cognitive development	Cross-sectional Study	1870	0-5 years	Television, Reading, Physical Activity	Both Passive and Interactive	Reading and physical activity correlate positively with cognitive and linguistic development.	Frequent interactive behaviors with caregivers enhance cognitive outcomes.	Stronger causal evidence required for physical activity's role alongside screen use.
Chao Li et al.	The Relationships Between Screen Use and Health Indicators Among Infants, Toddlers, and Preschoolers	2020	Sleep	Meta-Analyses and Systematic Review	80 studies (23 in meta-analysis)	0-7 years	Social Media, TV, Computers, Tablets	Passive	Excessive screen time associated with delayed language, sleep problems, and attention issues.	Screen time increases risk for cognitive, , and psychosocial delays.	Meta-analysis highlights heterogeneity; improved methodology needed for newer devices.
Hannah Pickard et al.	Toddler Screen Use Before Bed and Its Effect on Sleep and Attention	2024	Sleep	Randomized Clinical Trial	105	16-30 months	TV, Tablets, Smartphones	Passive	Screen time removal before bed improves sleep; no significant effect on attention.	Removing screen time before bed leads to better sleep quality; further study on attention effects needed.	Further exploration of screen content's role in sleep and cognitive impacts.
Katie Y.K. Lui et al.	Associations Between Touchscreen Exposure and Inhibitory Control in 10-Month-Old Infants	2021	screen exposure:General Cognitive Development	Cross-sectional	128	10 months	Touchscreen	Passive	Associations with inhibitory control	No association with inhibitory control but some positive links with executive functions.	Lack of longitudinal data to confirm causality.
Gemma Taylor et al.	Does Adult-Child Co-Use During Digital Media Use Improve Children's Learning Aged 0–6 Years?	2024	Verbal Interaction	Systematic Review and Meta-analyses	1288	0-6 years	Digital media	Active	Effect of co-use on learning outcomes	Small positive association of co-use with learning.	Mechanisms of co-use effect need exploration.

Carol Shieh et al.	Engagement Design in Studies on Pregnancy and Infant Health Using Social Media	2020	Memory	Systematic Review	30	Pregnancy and Infancy	Social Media	Passive	Engagement designs in health studies	Passive designs dominate, with limited use of interactive designs.	Limited focus on independent engagement designs.
Priyank Bhutani et al.	Is the Screen Time Duration Affecting Children's Language Development? A Scoping Review	2024	Language	Scoping Review	16 studies	0-12 years	Various digital devices	Passive	Impact of screen time duration on language development	Increased screen time negatively impacts language development; moderated by content and co-viewing.	Lack of diverse settings and comprehensive age-specific data.
Philipp Martzog & Sebastian Suggate	Screen Media Are Associated with Fine Motor Skill Development in Preschool Children	2022	screen exposure:general Cognitive Development	Longitudinal	141	Preschool children	Digital media	Passive and Active	Impact of screen use on fine motor skills	Negative association between media use and fine motor skills.	Need for diverse sample sizes and contexts.
Edyta Swider-Cios et al.	Young Children and Screen-Based Media: The Impact on Cognitive and Socioemotional Development and the Importance of Parental Mediation	2023	general Cognitive Development	Literature Review	Multiple studies reviewed	0-5 years	Screen-based media	Passive and Active	Cognitive and socioemotional development influenced by screen use	Both positive and negative impacts depend on content and parental mediation.	Stronger methodologies to isolate influences are required.
Ippei Takahashi et al.	Screen Time at Age 1 Year and Communication and Problem-Solving Developmental	2023	screens: cognitive developmental delay	Cohort Study	7097 mother-child pairs	1-4 years	TV, DVDs, video games, mobile devices	Passive	Increased screen time linked to developmental delays	More screen time at 1 year associated with delays in communication and	Does not examine potential mitigating factors like parental interaction

	Delay at 2 and 4 Years									problem-solving at 2 and 4 years	
Melania Paoletti et al.	Maternal Media Use and Infant Media Exposure are Associated with Developmental Outcomes at 4 and 8 Months	2025	Media exposure and developmental outcomes	Longitudinal Study	187 infants	4-8 months	TV, mobile devices, digital books	Both	Media exposure linked to socioemotional and communicative development	Positive parental media strategies can enhance development, excessive exposure can hinder it	Does not explore longer-term developmental impacts
Lauricella et al.	Toddlers' Learning From Socially Meaningful Video Characters	2011	Social learning and cognitive processing	Experimental study	-	Toddlers (exact range not specified)	Video characters	Active	Improved learning from interactive video characters	Toddlers learn better from socially engaging video characters	Focus on interaction rather than general screen effects
McHarg et al.	Infant screen exposure links to toddlers' inhibition, but not other EF constructs	2020	Executive function (inhibition)general cognitive	Propensity score matching study	416	4-14 months	General screen exposure	Passive	Negative effect on inhibition but no impact on working memory	Early screen exposure negatively linked to inhibition skills	Did not examine long-term effects on EF
Liu	The Impact of Screen Time on Working Memory Function of Children and Adolescents	2023	Working memory	Systematic review	-	3-5 years (some data included younger age groups)	TV, Tablets, Smartphones	Both	Both positive (interactive apps) and negative (overuse) effects	Prolonged screen use impairs working memory but interactive tools can enhance it	More distinction between screen types needed
Tsuji et al.	Toddler word learning from contingent screens with and without human presence	2021	Word learning and interactivity	Experimental study	16	16 months	Interactive screens, video chat	Active	Learning advantage in-person, lower via screen	Toddlers learned best in-person; video chat had mixed results	Further research needed on virtual vs. in-person learning

