The Impact of digital Technology on Cognitive Processes and Learning Outcomes in early childhood: Evidence from Neuroscience

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Executive summary:

- Young children are exposed to a range of digital technologies more than ever before.
- Evidence on the impact of these technologies is mixed with some studies showing clear positive benefits on learning and brain functioning and others suggesting negatives impacts, especially on attention and obesity.
- Much depends on the type of technology, the content of that technology, and the context in which it is embedded.
- Guidance around educational technologies should focus on the quality of the learning experience and how to support learning through digital technologies, rather than the quantity of screen time.

Digital technologies include a wide range of devices that use binary code to communicate, display, generate, receive, send, share, store, or process information. Within current family homes, a multitude of digital technologies can be found, including TVs, cameras and recording devices, audio devices (e.g., microphones, earphones, blue tooth speakers etc.), any type of phone, computer devices (including PCs, laptops, touch screen tablets etc.), computer peripherals (i.e. scanners, printers, keyboard etc.), wearable devices (i.e., smart watches, smart glasses, VR sets, etc.), storage devices (i.e., hard disks, USB drives, etc), digital measurements (i.e. thermometers, digital scales, digital water meters, etc.), as well as robots and AI devices.

The variety of digital technologies children engage with has considerably broadened and children spend more time on digital technologies than ever (Keeley & Little, 2017), with pre-schoolers now using digital devices about 2 hours each day (Ofcom, 2019). A lot of this time is spent on touch screen tablets or watching TV (Ribner, et al., 2021). Over 94% of children own or have access to touchscreen tablet devices in the UK and USA, and children in low- and middle-income countries, such as South Africa, are more likely to have access to a tablet device, compared to a laptop or television (Marsh et al., 2020).

The increase in usage has drawn considerable focus on the implications of technology usage, especially its effects on young children's cognitive, socio-emotional, and physical development. On one hand the increased usage of digital technologies has been harnessed as a potential solution for the global learning crisis and offers a range of opportunities. For example, the internet allows knowledge to be accessed more easily. In addition, digital technologies offer opportunities for personalised learning that can reach disadvantaged and marginalised groups when it is "designed and implemented in an ethical, inclusive, and equitable manner" (Duraiappah et al., 2022, p.61). As a result, there has been an increase in the development and availability of educational apps that target young children. Digital technologies have also provided a lifeline for education as well as social relationships during the COVID pandemic. For example, video-chats have been shown to support intergenerational sensitivity and positive infant affect between infants and their grandparents during COVID-19

(Roche et al., 2022).

On the other hand, there have been public concerns about young children spending long times on digital technologies that have led to policymakers to provide guidelines that restrict access to screens and digital technologies for young children (World Health Organization, 2019). Issues related to the frequent use of digital technologies include concerns about the wellbeing of young children and children being exposed to inappropriate content, questions whether these technologies raise educational outcomes or replace opportunities for young children as well as questions about data privacy. Although some incorrect beliefs about educational technologies have been addressed in behavioural studies (Plowman & McPlacke, 2013), it is unclear whether digital technologies have any impact on cognitive processes or learning more broadly for very young children. As a result, this article focuses on the current state of evidence about the impact of digital technologies, especially touch screen tablets for young children (aged 0 to 5 years old).

The impact of digital technologies on cognitive development and learning

Motor skills are a fundamental prerequisite for learning and development. For example, fine-motor skills, such as pointing and finger grip, have been linked to language learning in infancy or writing abilities in older children. In contrast, gross motor skills such as crawling and walking have been argued to link to general wellbeing and educational outcomes, especially maths outcomes (Katagiri et al., 2021). Although a few studies have argued that early use of touch screen tablets can be linked to fine motor skills milestones such as pointing and swiping in infancy (Bedford et al., 2016), longitudinal studies have shown that there is a negative impact of excessive screen time on fine motor skills with children who have more screen time had less fine

motor skill development one year later (e.g. Martzog & Suggate, 2022). In addition, excessive use of digital technologies puts pre-schoolers twice as much at risk for obesity (Li et al., 2020).

Attention control and executive function abilities, such as switching and inhibition, are two domains of cognitive development that have been found to relate to a number of educational outcomes (Robson et al., 2020). There is a large body of research that has looked at the impact of television watching on children's cognitive abilities, and it has often been argued that watching TV can negatively impact children's attention abilities, whilst others have argued that playing video games can improve children's attention, their ability to switch, and improve multi-tasking. However, much of this research has focused on older adolescents (see Altarelli et al, 2020 for a discussion). A recent systematic review by Bustamante et al. (2023) examined the relationship between screen time in general and executive functioning abilities in children aged 0 to 6 years and found no positive or negative significant impact of screen time on executive functioning abilities in young children. Indeed, it seems that whether or not digital technologies impact on children's attention abilities depends on a number of contextual factors, including the content and type of the technology as well as the interests, motivation and self-control of the child (Lodge & Harrison, 2019).

Language and communication abilities play a pivotal role in the process of learning and acquiring knowledge across various domains. One of the main concerns about screen time in young children is that they would have fewer opportunities for social encounters and as a result, would have poorer language and communication abilities. Indeed, a recent systematic review has found that excessive passive screen time (such as watching TV) can negatively impact young children's vocabulary and comprehension abilities (Massaroni et al., 2023). Yet, the content of the activity matters, as previous studies have found that some programmes can improve language outcomes (e.g. Sesame street, Fisch et al., 1999), especially active educational apps that target vocabulary and language learning (Hirsh-Pasek et al., 2015).

When it comes to maths and reading, evidence from systematic reviews suggests that educational technology can provide meaningful learning opportunities that can support young children's basic maths and literacy skills (Griffith et al 2020; Kim et al., 2021; Outhwaite et al., 2022). However, it is important to consider the design of the educational technologies and apps. For example, children younger than 4 years may face barriers when accessing educational app software based on their language skills, particularly if the software is designed for independent use by the child (Outhwaite et al., 2020). Other studies have shown that designs features such as levelling and the type of feedback that children receive within the app matter (Outhwaite et al., 2022).

Although sleep is not a developmental outcome itself, sleep is a key mediator for learning. Not only does enough sleep allow for better alertness and attention during learning experiences, sleep also allows for better consolidation of newly learned knowledge (Newbury et al., 2021) and during sleep the brain also cleans itself from toxic waste (Hauglund et al., 2020). One clear negative finding that has not only been replicated for children as well as adults is that the blue light of screens, impacts the levels of melatonin in the brain and as a result affects sleep quality and delayed sleep onset (Cheung et al., 2017; Charter et al., 2016).

In sum, there is mixed evidence from behavioural studies on the impact of digital technologies for early childhood learning and cognitive development.

Quality over quantity

Seeing the plasticity of the brain and the fact that the human brain requires input from the environment to develop (Johnson & de Haan, 2011), it seems reasonable to expect that early digital experience (including the screen time and the digital use) would impact the functionality and structure of the brain. Functionality of the brain refers to the fact that over development the functionality of the neurons can change, whilst structural change includes changes to the networks and circuits of brain activation.

Although the research is in its infancy, a recent systematic review (Wu et al., 2023) identified 33 studies that examined children's digital use (ages 0–12) and its impact on brain development. Fifteen of the reviewed studies focused on the frontal lobe, especially the prefrontal cortex (PFC) which is the neural base of executive function. This review found that evidence for the impact on the functionality of the brain was mixed: whilst six studies reported positive effects on how the brain works (including more activation in the frontal lobe, middle temporal cortex, and superior temporal sulcus), 15 studies demonstrated negative ones, and two reported mixed results. Also, for the structural impact on the brains of young children there was mixed evidence: Two studies reported no impact, five demonstrated negative ones, and two reported mixed results. Importantly, no

studies reported any positive impact related to the structure of the brain.

There are various reasons that can explain the inconsistencies of the findings. First, the content and modality of technology (gaming, passive TV watching or active touch screen activities) varied considerable amongst the studies which could impact on the findings. In addition, the studies varied in terms of how and when impact was measured, with very few studies looking at long-term effects. As most studies looked at correlations rather than development over time or causation, it is unclear whether the null findings can be explained by lack of longitudinal studies. Finally, the age range of the children in the studies varied a lot and thus, it is difficult to draw any conclusions. Rather, it seems that whether or not positive or negative impacts on the functionality and structure of the brain can be found as a result of digital technologies depends on a number of factors, especially the quality of the input, and more research in this area is required.

Conclusion and implications

Early evidence suggests that young children's cognitive development and learning may be influenced by their digital experiences. However, the real impact of digital technologies on the development of the brain is not clear yet. There are only a few studies that have examined brain structure and function in relation to digital technologies and correlations are often small (and correlations do not provide evidence of causation). In addition, findings depend on the content and type of digital technology used (Lodge & Harrison, 2019). For example, apps that have levelling and give corrective feedback as well as motivational feedback provide greater learning effects in preschoolers than apps that do not include these features (Outhwaite et al., 2023). So, parents and educators should select the content that preschoolers are exposed to carefully and some researchers already provide evidence-based guidance (see Hirsh-Pasek et al., 2015; Kolak et al., 2020; Outhwaite et al., 2023). However, this guidance is piecemeal and difficult to find. Policy makers could help provide this support by enabling a hub where all information is consolidated.

In addition, the impact of digital technologies on learning and development is moderated by several factors, especially those related to parents. For example, maternal education and family income (Barragan-Jason & Hopfensitz, 2021) and the active involvement of parents (Anderson & Subrahmanyam, 2017). However, not all parents and teachers know how they can best support a child with the use of technology devices in education and learning (Chaudron et al., 2017). As such, policy advice could help address this gap by supporting guidance on how digital technology access in young children should be addressed by parents and educators to create the biggest benefits for learning with educational technologies. For example, by being involved when the child accesses the digital technologies caregivers and teachers can comment on the content or child's activities or provide additional feedback and explanation. In addition, the shared experience would also allow the child and caregiver/teacher to discuss the content even when no longer using the digital technology. This would therefore also require educators to be trained on how to use digital technologies with all students, including those with learning difficulties.

Finally, more research in this area is required, not only in terms of evaluating which digital technologies can create the greatest impact on children's learning and development, but the current evidence is often of low quality (Ophir et al., 2021) and interdisciplinary research is required. Resources and incentives to develop and assess digital interventions designed to enhance brain development in children will be critical.

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