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RESHAPING THE GROWING MIND: HOW DIGITAL TECHNOLOGY CHANGES THE WAYS CHILDREN LEARN LANGUAGE AND WHAT CAN WE DO?

Abstract: *Digital technologies are dominating our daily lives. From smartphones and tablets to applications and virtual or augmented reality, they provide useful solutions, for e.g., navigating in new environments, learning languages, or acquiring literacy skills, in addition to entertainment. While available technologies may extend our mental capacities, our brains also adapt to those technologies and acquire many of their features (Carr, 2008). Concerns have been raised about the consequences of this digital reality for processing information and acquiring knowledge (Wolf, 2018). Extensive exposure to digital technology may impact specifically strongly young children, due to increased sensitivity to external input and brain plasticity in the first years of life. This then offers the opportunity to harness new technologies for educational purposes and align them with evidence-based and age-appropriate educational goals.*

Keywords: *digital technology; child development; language acquisition*

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ФОРМИРАНЕ НА ДЕТСКОТО СЪЗНАНИЕ: КАК ДИГИТАЛНИТЕ ТЕХНОЛОГИИ ПРОМЕНЯТ НАЧИНИТЕ, ПО КОИТО ДЕЦАТА УСВОЯВАТ ЕЗИЦИ

Резюме: *Дигиталните технологии доминират нашето ежедневие. От смартфони и таблети до приложения и виртуална и разширена реалност, те ни предоставят практични решения, например навигиране в нова среда,*

изучаване на езици или усвояване на грамотност, а също и забавления. Наличните технологии наистина разширяват нашите умствени способности, но същевременно нашият ум се адаптира към тези технологии и усвоява много от техните особености. Вече съществува загриженост относно последствията от тази дигитална реалност за усвояването на информация и познания. Прекомерното излагане на дигитални технологии може особено силно да повлияе на малките деца поради повишената чувствителност към външно влияние и пластичността на мозъка в началното развитие. Това създава благоприятни предпоставки да се оползотворят нови технологии за образователни цели и да се съобразят с научно подкрепени и подходящи за възрастта цели.

Ключови думи: *дигитални технологии; детско развитие; усвояване на език*

1. Introduction

Despite the rapid change in children's ecology and the rapid advance of technology in everyday life, research on the impact of Digital Technologies (DTs) on children's communication and language development is still scarce and highly fragmented with no unitary approach across disciplines (Vulchanova et al., 2017). New technologies create environments that could alter how we process information, the degree to which we take risks, how we socialise and empathise with others and, even, how we view our own identity. Parents experience that toddlers can handle digital tools with a level of sophistication that they can only envy. We are immersed in a 'digital ecology' increasingly populated by devices that are both tools and interactive agents with a degree of autonomy which is increasing rapidly.

While AI-powered interactive digital platforms are being developed at a fast and unprecedented rate, and schools are spontaneously adopting digital solutions for the acquisition of academic skills, such as literacy, at present, there is no adequate research base documenting the effects of digital tools on language or other learning outcomes in young children. Neither are current software solutions based on developmental, educational or psycholinguistic principles (Hirsh-Pasek et al., 2015; Kolak et al., 2021). On the one hand, it can be expected that this digital ecology may provide new opportunities and ways of (1) enhancing existing learning environments and (2) devising technologies that can improve learning and adjust to the needs of a variety of groups, and in particular, vulnerable and at-risk groups. On the other hand, the new digital environment may hide undesirable consequences for early child development. "Social networking sites could worsen communication skills and reduce interpersonal empathy; obsessive gaming could lead to greater recklessness, a shorter attention span, and an increasingly aggressive disposition; heavy reliance on search engines and a preference for [Web] surfing rather than researching could result in agile mental processing at the expense of deep

knowledge and understanding" (Greenfield, 2014, p. 265). Newly published research suggests an adverse impact of screen time on children's cognitive development (Portugal et al., 2021; Madigan et al., 2020). There is also emerging evidence that English-speaking children's developmental speech patterns have changed in the past 15 years and that this might be attributed, in part, to the new digital ecology of language development (Holm et al., 2021). The challenge, then, is to develop a solid and independent multidisciplinary and longitudinal knowledge base to explain under which conditions harmful versus beneficial effects occur in the context of digital environments, so that effective social, educational, health and online safety policies, and practices can be developed.

A clear advantage is that the use of DT in education and language development, such as AI-powered language learning apps and robot tutors in educational settings, may offer innovative tools to exploit the power of digital interactive systems. Children can, for example, benefit from active learning and exploration by using tablets and augmented reality systems, and from the physical embodied interaction with robot tutors. At the same time, this DT approach requires a better understanding of how these embodied and interactive systems shape the language learning process, and how environmental education factors affect development and education in different socio-economic settings. Furthermore, little is known about the impact on social cognition and how our social brain responds to increasingly more physical agents, such as telepresence robots, where remote contacts get a physical co-presence, virtual reality, where interaction is perceived to be three-dimensional, and social robots, which autonomously engage in a social interaction with their user (Barassi, 2020). What avenues and choices are we then facing in harnessing the potential of DT, while at the same time mitigating possible negative consequences for developing minds? In what follows, we outline factors and scenarios which provide viable opportunities to exploit digital technologies in an optimal way.

2. Conceptual ground

Current embodiment theories of cognition and language propose that human cognition and language are grounded in experience, and that concepts and their linguistic labels are formed in rich interaction with the world (Barsalou, 2008). Word learning is a fundamental building block in language acquisition. In development, early acquired words are almost overwhelmingly concrete, and mostly nouns. Abstract words are documented only later, both in comprehension and production (Bergelson & Swingley, 2013). It has also been proposed that there might be different underlying mechanisms that

support the acquisition of these two categories. While, for concrete words, a direct association might be formed between the linguistic label (phonological segment) and perceptual properties of the referent, for abstract words, additional skills might be necessary, e.g., social skills, and in particular, the ability to read the intentions of the speaker, as such words are often used by caregivers in the absence of the referent (Carpenter, Nagell, Tomasello, Butterworth & Moore, 1998). An alternative account suggests that learning abstract words is data-driven and taps the statistical properties of the input to which the child is exposed. Against this backdrop, digital environments offer a number of opportunities to manipulate the context of introducing the novel label, and the possibility to interact with the representation of the object it refers to. Such opportunities offer a much richer context for learning the object label not only through active interaction, but by situating the learning experience, and thus enhancing stronger associations in long-term memory. This is aligned with current understanding of language learning, as well as processing, as situated in specific learning experiences, in addition to being embodied (Reggin et al., 2023).

2.1. Capitalising on the environment: robots

Developmental robotics strategically offers an innovative methodological approach to the modelling of language learning processes and the effect of environmental and embodiment interaction, by taking direct inspiration from developmental psychology theories and experiments (Cangelosi & Schlesinger 2018). For example, developmental robotics models, coupled with child psychology experiments, have shed light on the role of postural attention strategies in early word learning (Morse et al. 2015). It is thus likely that the motor strategies afforded by social robots in abstract word learning (e.g. pointing and finger counting gestures for the learning of numbers and quantifiers), can facilitate the acquisition of abstract vocabulary (Pecyna et al. 2020), in addition to object manipulation in the case of concrete nouns as object labels.

First language acquisition benefits from embodied social interaction with others, notably parents, siblings and peers. However, when learning a second language in formal educational settings, this interactive element is missing. This is often because of lack of resources, something which the introduction of interactive technologies can remedy. The sea change in this is that this new technology removes the 2-dimensional constraints of the digital screen. Instead, there is now an opportunity to offer a physical, embodied and situated interactive experience to second language learners, for example through the use of social robots (Belpaeme et al., 2018a). Such strategies

radically change the mode of delivery from class-based teaching to one-to-one tutoring between the learner and a robot (Belpaeme et al., 2018b).

Social robots have already shown great promise as a technology to support learning in the classroom or at home (Belpaeme et al. 2018b). Learners display more social behaviours that are beneficial for learning and demonstrate increased learning gains when interacting with physically embodied systems over virtual agents (van den Berghe et al., 2019). However, earlier work has shown that second language learning with robots, while promising, is also a particularly challenging domain. While children do learn from robots (Vogt et al. 2019), the full potential of robot tutoring has not yet been realised, either due to technical reasons or due to our, as yet limited, understanding of how the interaction with robots contributes to learning.

2.2. Capitalising on the environment: educational apps

Digital media, including apps, are increasingly used at homes and in early years settings. Thanks to their interactive design, apps can offer children a range of engaging activities and interactions, including promoting parent-child engagement via parent instructions onscreen. Furthermore, children's touchscreen apps have considerable educational potential for pre-school age children (Xie et al., 2018) and language development specifically, with children learning new vocabulary from apps (e.g., Arnold et al., 2021; Dore et al., 2019). Importantly, while children's educational digital media may have a positive impact on language development, non-educational digital media use appears to be negatively related to language development (Madigan et al., 2020). Given the amount of time children spend using digital media at home worldwide, harnessing this time to support children's language development would be invaluable (Konok et al., 2020; Ofcom, 2019; Rideout & Robb, 2020). A number of child groups can benefit from educational apps.

Children from low-income households and children from minority language homes (i.e. bilingual children with/without a heritage language) are at risk of starting school without adequate language skills, resulting in lower academic achievement compared to monolingual middle-class children (Hoff, 2013). Such children may also struggle with both oral language and reading comprehension at school (Melby-Lervåg & Lervåg, 2014). There are currently debates concerning the extent to which bilingual children with a background in a minority language (whether heritage language or not) are at a disadvantage in language acquisition. Success at acquiring structural language skills in both languages depends on a number of factors, such as e.g., amount of exposure, language dominance, family SES and language attitudes, cognitive skills underlying language acquisition (sometimes dubbed language

aptitude), variation in the language input (e.g., spoken by speakers of a wider age range, including peers, as well as dialectal variation), language status (Vulchanova et la., 2012; Paradis, 2023; Grose-Hodge, Dabrowska & Divjak, 2024). These factors lead to the commonly observed large individual variation in language ability in this population (van Osch et al., 2025). These findings from research suggest that providing opportunities for these numerous factors to interact optimally may be the path to follow. For instance, supporting bilingual children's skills in their home language can help them acquire the language of the host country more efficiently (Roberts, 2008), which is crucial for their future academic success. In this context, vocabulary learning apps may benefit specifically unprivileged children. Recently, Grøver et al., (2020) showed that after receiving a shared book reading intervention at home (in their home language) and at school, Norwegian pre-schoolers improved their vocabulary and grammar in their second language. However, currently we are still lacking studies reporting the effect of vocabulary apps on young bilingual children.

Educational apps, and augmented reality when integrated with mobile technology may be particularly beneficial for autistic children. Augmented Reality (AR) is currently becoming popular as an educational tool due to affording the possibility to superimpose additional information onto our view of the real world. There is also evidence that AR can promote attentional behaviour and improve social and communication skills in autistic children (El Shemy et al., 2024). However, little is known whether AR can also provide a useful environment for language learning. The autistic language profile is characterized by wide variation. While some children with autism may acquire adequate structural language skills (grammar and vocabulary), the majority of children with an autism diagnosis continue to struggle with core aspects of language, and about 30% of those children will remain minimally verbal (Pickles, Anderson & Lord, 2014; Schaeffer et al., 2023). In the domain of word learning many autistic children experience challenges, specifically related to the mapping of the auditory label to the referent out in the world (Vulchanova, Saldaña & Baggio, 2020). A number of accounts have been put forth to explain the mechanisms which conspire to produce this difficulty, among which, problems with categorization (Hartley & Allen, 2014), an advantage at acquiring the formal aspects of words (phonology) against a problem with semantics (Norbury, Griffiths & Nation, 2010), and problems with symbolic thinking (Vulchanova, Vulchanov & Allen, 2023).

Toddlers' early vocabularies in many languages are dominated by nouns as the labels of concrete everyday objects (Samuelson & Smith, 1999). Thus, it is crucial to identify potential problems autistic children may experience in mapping early words they hear onto the objects they name. In addition to the

tendency to learn such labels associatively rather than symbolically, there is emerging evidence that children with autism and children with language delay may not be relying on object shape as a cue in word learning (Tek et al., 2008). Problems with mentally rotating objects have also been identified (Larson, Bochynska & Vulchanova, 2024). This is where Augmented Reality comes into play. By allowing the child to actively interact with the represented object via a touch screen, including the possibility to manipulate it (e.g., via rotation) and explore it from different angles, the AR app affords multiple learning opportunities which are not usually available in real life learning situations. The positive effect of AR on word learning in minimally verbal children with autism has been demonstrated in a recent participatory design (El Shemy et al., 2024; under revision). Furthermore, a recent survey among parents and caregivers of children with neurodevelopmental communication disorders suggests that AR may be a useful and motivational tool, if it is affordable and implemented with training and technical support (Bryant et al. 2024).

3. Are children developmentally up to the task?

3.1. Touchscreens and cognitive skills

Given the increasing role of digital technology as a primary source of language input, understanding the complex processes involved in learning and acquisition within the digital landscape has become a priority. Touch-screens, in particular, involve simultaneous exposure to rich auditory and visual material, and require advanced auditory (speech perception), visual and haptic (fine motor) skills. The question then is to what extent very young children possess those skills and whether they can thus benefit and learn from exposure to touch-screen devices. There is ample evidence in research that the development of cognitive skills (e.g., phonological and working memory, the ability to see patterns in the environment (also dubbed fluid intelligence), visual perception skills) supports language development (Vulchanova et al., 2014; Vulchanova & Vulchanov, 2021). In this context, much research has been devoted to investigating the role of Statistical learning.

Statistical learning (SL) has been identified as a powerful implicit learning mechanism which operates in all modalities. It is usually defined as the ability to extract statistical regularities from the sensory input the child is exposed to (Saffran et al., 1996a; Saffran et al., 1996b; Romberg & Saffran, 2010). SL is particularly relevant from an embodied and situated perspective on language learning which places the focus on extracting patterns in the sensory information which provides the context and rich input for language acquisition (Reggin et al., 2023). Importantly, individual differences in the ability to extract statistical information may partly explain variability in

language development (Batterink & Paller, 2017; Abreu et al., 2023). Observed across different age groups (Saffran et al., 1996a; Raviv & Arnon, 2018), SL has been described as both a broad cognitive mechanism operating across sensory modalities and domains, as well as input- or modality-specific (Saffran & Kirkham, 2018). In a recent scoping review, we aimed to establish which modality is more tightly yoked with language skills (Abreu et al., 2023). The reviewed evidence suggests that the relevance of statistical learning skills for language development is dependent on sensory modality. The results provide preliminary support for the statistical learning account of language acquisition, mostly in the domain of lexical outcomes, indicating that typically developing infants and children with stronger auditory and audio-visual statistical learning skills perform better on lexical competence tasks. We further explored how auditory statistical learning develops with age in a cross-sectional design of Norwegian pre-schoolers (4-6 years old), which is an understudied age group in this respect. Preliminary results from a neural entrainment to structured sound stream demonstrate that auditory statistical learning is well developed at this age (Zantonello, Vulchanov & Vulchanova, 2024; Zantonello, Vulchanov, Sivridag & Vulchanova, in submission). The 4-6 year-old participants showed sensitivity to the statistical structure of the speech stream, exhibiting a mature-like entrainment pattern, with neural oscillations aligning preferentially to words over syllables when statistical regularities were present (underscoring results in Moreau et al., 2022 and Choi et al., 2020). This work provides novel insights into the neural underpinnings of implicit statistical learning in early childhood and its potential implications for language development, and suggests that rich exposure to auditory input, such as the one afforded by digital technology, can be successfully processed by pre-school children. However, a still open question is whether integrating information from auditory sources and rich visual input, as afforded by screens, is optimal for the purposes of language learning in this age group.

In other studies in a recently completed Marie Skłodowska-Curie Actions (MSCA) research network, we asked whether children and adults are sensitive to gaps in their knowledge, and whether they actively elicit information to resolve such knowledge gaps. In a word learning task, 5-year-olds, 6- to 9-year-olds and adults were asked to estimate their knowledge of newly learned word–object associations. The results showed that all age groups are sensitive to knowledge gaps, but only adults and older children actively work to reduce uncertainty and knowledge gaps, while younger do not (de Eccher et al., 2024). These results indicate that not all information available in digital media can be successfully exploited for learning, and that there may be meta-cognitive constraints on learning in younger users.

3.2 Touchscreens and social skills

Early language skills are shaped from the first months of life by dyadic social interactions of infants/toddlers and their caregivers. These dyadic exchanges provide crucial repeated, daily opportunities for acquiring new communicative skills and fine-tuning multiple aspects of behavioural control (attention shifting, movement, posture, acting on objects) that are necessary for the emergence of efficient speech comprehension and production. Over subsequent months, infants learn to take turns in a proto-dialogue, to produce meaningful speech sounds and words and to time their responses at appropriate moments in a conversation. Social communicative skills emerge at a remarkable rate, so that toddlers can manipulate objects, follow attention and actions of others, while simultaneously processing the incoming speech and speaking themselves.

Early communication and word learning during toddler-caregiver play requires the coordination not only of their looking, but also their actions on objects that are manipulated and labelled (Smith & Yu, 2012). Caregivers label objects predominantly when toddlers view and manipulate them (West & Iverson, 2017). Altogether, toddlers' language learning requires a delicate balance of attention-sharing on the parent and objects of play, speaking and processing incoming speech, all dynamically changing from moment to moment.

With increased access to digital technology, the physical nature of social interactions has never been more altered. The daily, repeated experience of structured social interactions with caregivers shapes multiple social and cognitive skills of infants and toddlers, including expressive language and attention control (e.g. Niedzwiecka et al., 2018). Through early social interactions young children learn how to coordinate their attention and actions on objects with that of another person. They also learn to speak and act within a turn-taking structure, which sets the foundation for conversational dialogue. Touchscreen devices and apps are increasingly used by parents in their play with children from 12 months of age (e.g. Cristia & Seidl, 2015), and their frequent use may adversely affect attention control (Portugal et al., 2021).

What happens when the toddlers' daily experience includes frequent interactions with mobile touchscreens? Touchscreens are increasingly woven into the structure of parent-child interactions – they are used to soothe, distract, facilitate feeding, as well as for sharing and learning in much the same way as baby books (Cristia & Seidl, 2015). They are likely to reshape basic attention skills. Thus, toddlers who are frequent users show faster orienting to external stimuli, but reduced endogenous attention (Portugal et al., 2021). While, notably, emerging evidence from surveys suggests that the most

common digital technology in households in European countries are smartphones and tablets (Aldemir et al., under review), currently, little is known about the long-term effects of touchscreen use on the dynamics of social interactions.

4. Closing remarks

Exploring the profound effects the ever-increasing exposure to digital technology may have for child development is a challenging task. It requires a concerted effort across disciplines ranging from developmental psychology, cognitive science, psycho-linguistics, developmental robotics to education studies and technology developers in computer science and the AI-domain. Digital technology has come to dominate every-day lives and a successful future strategy is to harness its advantages for the benefit of young learners, while at the same time safe-guarding their learning premises and rights as they navigate the digital social and information landscape (Diprossimo et al., 2024).

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