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# Impacts of technology use on children: Exploring literature on the brain, cognition and well-being

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# IMPACTS OF TECHNOLOGY USE ON CHILDREN: EXPLORING LITERATURE ON THE BRAIN, COGNITION AND WELL-BEING

## OECD Education Working Paper No. 195

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*This working paper has been authorised by Andreas Schleicher, Director of the Directorate for Education and Skills, OECD.*

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## *Abstract*

Children in the 21st century are avid users of technology - more so than generations past. This rise in use has led to much attention on the consequences of technology use, and how this impacts children's brains and their socio-emotional, cognitive and physical development. Much of the research in these fields, especially brain-based research, is in its infancy. Furthermore, it often shows very small correlations between technology use and child outcomes; whether technology causes these outcomes is unclear, and small effect sizes bring questions about real-life implications for children. Despite these issues, policy-makers in various countries have set guidelines for technology use in children, which are often restriction-focused. This paper explores some of the literature on the effects of technology use on children in terms of their brain, cognitive, socio-emotional and physical development, and summarises what is clearly demonstrated in the literature. It also highlights where more quality research is needed to better understand the impact of technology on children, and support the development of effective, evidence-based guidelines.



## *Résumé*

Les enfants du 21ème siècle sont des utilisateurs avides de la technologie - plus que les générations passées. Cette augmentation de l'utilisation a suscité beaucoup d'attention sur les conséquences de l'utilisation de la technologie et sur son incidence sur le cerveau des enfants et sur leur développement socio-affectif, cognitif et physique. Une grande partie de la recherche dans ces domaines, en particulier la recherche sur le cerveau, en est à ses débuts. De plus, elle montre souvent de très faibles corrélations entre l'utilisation de la technologie et les résultats pour les enfants; il est difficile de savoir si la technologie est à l'origine de ces résultats, et le faible impact des effets soulève des questions sur les implications réelles pour les enfants. En dépit de ces problèmes, les décideurs de divers pays ont défini des directives pour l'utilisation des technologies par les enfants, qui sont souvent axées sur les restrictions. Cet article explore une partie de la littérature sur les effets de l'utilisation de la technologie sur les enfants en termes de développement cérébral, cognitif, socio-émotionnel et physique, et résume ce qui est clairement démontré dans la littérature. Il souligne également les domaines dans lesquels une recherche qualitative est nécessaire afin de mieux comprendre l'impact de la technologie sur les enfants et soutenir l'élaboration de lignes directrices efficaces et factuelles.

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# *Technology use and children*

In recent years, technology use has been on the rise worldwide. According to the Programme for International Student Assessment (PISA) 2015 results, 95% of 15-year old students on average across OECD countries had Internet access at home (OECD, 2017[1]). Furthermore, on a typical weekday students spent more than two hours online after school; this is an increase of 40 minutes since 2012 (OECD, 2017[1]). Children are "connected" in different contexts, not just the home environment. PISA 2012 data reported that across OECD countries 72% of students reported using computer technologies (desktops, laptops or tablet computers) at school versus 93% at home (OECD, 2015[2]).

Technology use is on the rise in other age groups as well, not just adolescents. Research suggests that preschoolers become familiar with digital devices before they are exposed to books (Brody, 2015[3]; Hopkins, Brookes and Green, 2013[4]). International trends are pointing to increases in use and younger ages of first access (Hooft Graafland, 2018[5]). In response to this increase, over recent years there has been a proliferation of research exploring potential linkages between emotional well-being/mental health outcomes and technology use in children, although the knowledge base specifically regarding how children under the age of 8 use technology is relatively sparse. In any case, most of the available research is correlational, shows small effect sizes, and the underlying mechanisms of these outcomes are unclear.

Despite these limitations, research of this nature is often cited or used as a guiding force in swaying public opinion and policy regarding issues around children and technology. Given the ubiquity of technology in today's society and the importance of this issue for policy and practice, it is essential to understand the impacts of technology use on the developing brains and bodies of children in the 21st century in order to guide policy delineating safe and effective use. Parents and guardians should be discerning when it comes to guidelines and research, while governments and groups with policy influence should be cautious of prescribing policy without exploring the evidence base in a holistic and thorough nature. This paper serves to explore the current research base, examining the potential impact this could have on future guidelines and national policy implementation.

## From research to recommendations on screen time for children

In recent years, research has focused more on psychological aspects of technology use, with less known about physiological outcomes (Afifi et al., 2018[6]). It is a newer phenomenon that there has been more emphasis on brain and body-based implications of technology use in children and adults. In order to understand more holistically the implications of screen time on children, it is essential to explore the available research in order to uncover trends, gaps and future directions for this work to take.

Parents and guardians, as well as education and child health professionals, may be uncertain as to how to structure children's screen time and how this should factor into their daily lives, as well as how to interpret the latest literature on these topics. There is thus a need for coherent guidelines on the matter. In order to make effective and evidence-based guidelines, the most recent and rigorous social science research should be complemented with evidence from the biological sciences as well to get a more holistic picture.

It is important to note, as scholars have done in recent years [i.e. (Bavelier, Green and Dye, 2010[7])] that effects of technology may depend on factors such as the type of technology being used and its purpose. Children might use computers during class time, cell phones to keep in contact with friends, a tablet to do school work in the evening and then will watch an hour television with their families to unwind. This can account to many hours over the course of the day. Therefore it is important to understand how and why children use technology and with which tools, when evaluating these guidelines and to determine whether limits are useful and how these should be set.

## Current screen time recommendations for children

Many groups concerned with children's health, including governments and medical societies, advocate for partially or fully limiting screen time for children and adolescents. For example, The American Association of Pediatrics (AAP), a prominent international voice in child health, publishes guidelines for screen time in children, the most recent of which were made available in 2016. These guidelines include a number of provisions such as avoidance of screens for children under 18 months (except for video-chatting), and limits of 1 hour per day of high quality programming for children up to the age of 5 (see Table 1.1).

Across many countries, similar guidelines suggesting limits on screen time and "best practices" for parents and guardians exist. Often, these are included as components of guidelines regarding physical activity and sedentary behaviours for children, and therefore take more of a physical health perspective than an emotional well-being or brain based rationale. Table 1.1 outlines a small sample of screen-use guidelines released in different OECD countries, from government or research institutes.

**Table 1.1. Screen time recommendations in different countries**

| Country/institution | Infants/toddlers | Early childhood | School-age - adolescence | Other recommendations |
|---|---|---|---|---|
| AAP (United States) (AAP, 2016[8]) | None, except video chatting (under 18 months); Only high quality programming (18-24 months) | 1 hour of high quality programming, co-view | Consistent limits on time and type | Turn off screens when not in use; ensure screen time doesn't displace other behaviours essential for health |
| Canada<br>Canadian Society for Exercise Physiology (CSEP, 2017[9])<br>Canadian Paediatric Society (Canadian Paediatric Society, 2017[10]) | None | <1 hour | <2 hours (CSEP only) | Limited sitting for extended periods (CSEP); Adults model healthy screen use (CPS) |
| Australian Government Department of Health (Australian Government Department of Health, 2017[11]) | None (under 12 months); <1 hour (12-24 months) | <1 hour | <2 hours (entertainment) | |
| New Zealand Ministry of Health (Ministry of Health, 2017[12]) | None | <1 hour | <2 hours (recreational) | Adapted from CSEP guidelines |
| German Federal Ministry of Health (Rütten and Pfeifer, 2016[13]) | None | 30 minutes | 1 hour (primary school) – 2 hours (adolescents) | Avoid as much as possible; avoid screen time completely for children under 2 including background television |

*Source*: Compiled by author

Some recommendations, such as those from the French Academy of Sciences, are more nuanced, avoiding quantitative guidelines in terms of number of hours of screen time, and focus more on qualitative elements. For example, between the ages of 2 and 12 "passive and prolonged exposure of children to television without an interactive and instructive human presence is not advisable", and the potential benefits of toddlers using touch screens and educational benefits for children are explored (Bach et al., 2013[14]).

Other general recommendations that tend to be echoed across countries and institutions include turning off devices when not in use, switching off screens an hour before bed, and designing times (i.e. while having dinner or driving) and locations (i.e. the bedroom) that are designated media-free.

The current guidelines from the AAP have been updated from previous ones that recommended no screen time for children under the age of 2 (American Academy of Pediatrics, 2001[15]), and were criticised by many researchers due to lack of empirical support for this zero-tolerance approach (Courage and Howe, 2010[16]). However, this guideline persists in many contexts, with some more restrictive guidelines suggesting no screen time for children until the age of 3 [e.g. the *carnet de santé* released by the French Ministry of Health and Solidarity suggests not even placing a child before the age of 3 in the same room where a television is on (Ministère des Solidarités et de la Santé, 2018[17])].

One of the motivations for this zero-tolerance approach, as put forth by the AAP for example, was that screen time was taking time away from participation in other less sedentary or more productive activities (Foster and Watkins, 2010[18]). This "limitation-focused" approach was questioned by researchers in developmental and clinical fields (Linebarger and Vaala, 2010[19]; Ferguson and Donnellan, 2014[20]), and there is some

criticism that the newer guidelines might be based on evidence that is from outdated patterns of use and devices (Straker et al., 2017[21]). Furthermore, these guidelines seem to overlook the convergence between online and offline play and social spaces that children and adolescents are establishing in the 21st century (Marsh, 2014[22]). Sweeping bans or limits on screen time or technology use may not adequately take into account the nuances regarding how children and adolescents engage with devices.

The updated AAP guidelines, and many of the above-mentioned national guidelines, claim to be supported by literature exploring different health and developmental concerns in childhood and adolescence. Some claims, linking posture or body weight outcomes to screen time, draw from quite a robust evidence base. However these guidelines sometimes cite contested findings from the cognitive science literature, and tend to not cite brain function and development as part of the rationale. This is due in part to a lack of empirical results in terms of technology and the brain (Bavelier, Green and Dye, 2010[7]), as well as the difficulty in linking structural and physiological findings to observable behavioural or cognitive outcome measures. Nevertheless, this is an important field to explore, especially as children's brains are more malleable than those of adults in response to experience (Hensch, 2004[23]). Pulling evidence from these domains may help in developing more holistic guidelines and help avoid being terrified by shock headlines telling us that technology is "rewiring children's brains". Parents and guardians can be uncertain regarding the impact of technology use on the development of children (Radesky et al., 2016[24]), thus having access to up to date and evidence-based guidelines is critically important.

The Royal College of Paediatrics and Child Health (RCPCH) published a guide in 2019 for clinicians and parents to help manage children's screen time, which is the first of its kind in the United Kingdom. The RCPCH reached similar conclusions as will be outlined subsequently in this paper, namely that there is not enough evidence confirming that screen time in and of itself is harmful to child health at any age. Therefore, the guidelines avoid recommending age-based limits for screen use, and focus on aspects of child well-being such as online safety (i.e. from bullying, exploitation, etc.) and access to inappropriate content. It is recommended that families negotiate screen time with children, based on the needs of the child as well as which screens are in use and how they may or may not displace other health-related behaviours or social activities. The guide finishes with a set of recommendations regarding how families can reduce screen time, if they feel the need to do so. This includes protecting sleep displacement via screen use, prioritising face-to-face interaction and being cognisant of parental media use, as children tend to learn by example (RCPCH, 2019[25]).

## Exploring the literature

This paper will explore some of the pressing issues regarding children's use of technology. For example, do outcomes depend on the quality of media consumed, or is all media created equal? Is technology in and of itself the culprit, or is there a difference in outcomes based on why the technology is being used? There are the age-old adages suggesting that watching too much TV can rot your brain, or turn children's eyes square. How much validity is there in these old wives tales, and how are biological outcomes impacted by the types, amount and reasons technology is being used?

Some research cites a potential "Goldilocks effect" in terms of technology use. This suggests moderate engagement in online and digital activities might actually be beneficial in terms of subjective mental well-being and adolescent connectedness, whereas too much

or too little might prove detrimental (Przybylski and Weinstein, 2017[26]). In this sense, the tendency to publish models of restriction might miss some of the nuances in the emerging literature base. "Problematic" or "excessive" use of technology may be dictated by whether the use interferes with normal daily functions and is difficult to control, rather than based on the absolute quantity of exposure (Howard-Jones, 2011[27]). Placing limits on sedentary screen time seems reasonable; however arbitrary limits on overall screen time might not take into account the nuances in terms of use of screens in childhood and adolescence. Furthermore, the research base in terms of well-being and biological outcomes is quite speculative and exploratory for the most part. Development in these fields is needed and will be aided by an increase in longitudinal research, randomised controlled trials and reproducible findings in large samples.

This paper consists of two parts. The first explores the literature concerning technology and neural, cognitive and behavioural outcomes. The second part will explore more wide-reaching health consequences of technology such as, for example, the implications for sleep and musculoskeletal concerns. Policy-makers should explore the highest quality biological and psychological research available to gain a better understanding of how media and technology impacts developing brains and bodies. This is important in order to ascertain whether children in the 21st century will grow up with mushy brains and square eyes, or is there more to the story?

# 1. Technology, the brain, cognition and well-being

## 1.1. Technology use in young people: what does the research say?

Young people today are more "connected" than ever. In counties with high rates of connectivity, young people aged 15-24 generally outnumber others in terms of overall online population (International Telecommunication Union, 2016[28]). Young people have shown preferences for using the internet for gaming, chatting and social networking purposes (Durkee et al., 2012[29]). The Pew Research Center published that 92% of teens surveyed in the United States report going online daily, with 24% saying they go online "almost constantly" (Lenhart, 2015[30]). It's a similar story in European countries, where data suggests children are going online using multiple devices (Mascheroni and Cuman, 2014[31]). Statistics from the United States suggest that youth between the ages of 8 and 18 spend on average seven and a half hours per day engaging with media content (Rideout et al., 2010[32]).

This could be particularly important due to the susceptibility of developing brains for "plasticity", or experience-dependent change. Our brains essentially change in response to our experiences, with childhood characterised as a time of high plasticity. Use of technology has been associated in the literature with changes that are both transient, i.e. changes in mood or arousal, as well as longer term effects in the brain or behaviour (Bavelier, Green and Dye, 2010[7]).

There is an emerging body of work linking certain elements of ill-being to technology use. Furthermore, overuse of technology more generally might be linked to poorer outcomes in adolescents including physical, behavioural, attentional and psychological issues (Rosen et al., 2014[33]). However, there are concerns regarding the quality of these studies, and the negative focus of much of the literature. Therefore, results must be interpreted with caution and the possibilities for positive outcomes associated with technology use taken into consideration. At this moment, the research base exploring the impact of technology on the developing brains of children and adolescents is even more limited. This section of the paper will explore some of this literature, highlighting some of the associated functional and emotional well-being related outcomes.

## 1.2. A quick note on brain plasticity

*"Neurons that fire together, wire together" – Donald Hebb, 1949*

As mentioned above, the brain is plastic, which suggests that it changes based on our experiences. This is especially prominent in the earlier years, and research suggests rapid development and considerable plasticity in the brains of newborns through the first few years of life (Barkovich et al., 1988[34]). Certain regions of the brain are more plastic than others, such as the hippocampus for example, which is implicated in learning and memory (Bliss and Schoepfer, 2004[35]; Pastalkova et al., 2006[36]).

Childhood and adolescence are periods of rapid development and maturation. During the first three years of life, a child's brain may create over 1 million new connections per

second[1], which is essential for development of various functions such as hearing, language and cognition (Center on the Developing Child, 2009[37]). These create the foundation for higher order functions, especially those formed in adolescence, as many neural networks underlying things such as decision making mature during this time.

Structural and functional magnetic resonance imaging (fMRI)[2] studies have shown extensive structural changes in the adolescent brain accompany these changes in function (Crone and Konijn, 2018[38]). Improvement of functions such as attention and cognitive flexibility in adolescence for example is likely a result of myelination and pruning in the frontal and parietal lobes (Luciana, 2013[39]; Paus, 2005[40]). Pruning refers to the selective elimination of synapses, which are initially overabundant in young brains. This process largely occurs throughout puberty and adolescence; children tend to exhibit higher density of dendritic spines than adults, with a subsequent decrease during puberty (Petanjek et al., 2011[41]). Sensitive periods in early childhood and adolescence when critical brain development and reorganisation occurs can be strongly influenced by experiences and environmental factors that can impact future functioning (Irwin, Siddiqi and Hertzman, 2007[42]; Petanjek et al., 2011[41]).

Sensitive periods used to be referred to as "critical periods", as it was believed that this was a window of opportunity in brain development that, if missed, would lead to the loss or underdevelopment of critical developmental abilities. However, the adoption of the term "sensitive periods" in favour of "critical periods" has become widespread, as research has demonstrated that development of language and visual processes, for example, once thought to occur only in "critical periods" of early childhood, can occur outside of this window (Fuhrmann, Knoll and Blakemore, 2015[43]). Deprivation does take a toll on brain and cognitive functions, however when previously deprived children are taken out of a deprived context some developmental processes can be recovered (Fuhrmann, Knoll and Blakemore, 2015[43]).

It is important to keep in mind that neuroplasticity is an underlying function of learning, although it is not an inherently good or bad thing. Depending on the magnitude and location of changes taking place, outcomes can be different. Furthermore, it is pertinent to note that "major brain changes, akin to what is suggested by the phrase 'rewiring the brain' are unlikely" (Mills, 2014[44]). Genetic factors also play a large role in changing of brain structures during childhood and adolescence (van Soelen et al., 2012[45]).

Measuring these changes and activation patterns can be difficult. For example, fMRI allows for detection of brain activity as shown through changes in local cerebral blood flow and from changes in oxygenation concentration (Glover, 2011[46]). fMRI is a non-invasive way of examining the central nervous system, and can provide researchers and clinicians with high resolution scans and demonstrate networks of engaged brain regions when specific tasks are performed (Glover, 2011[46]; Logothetis, 2008[47]). However, it does not clarify the neural mechanisms underlying certain functions (i.e. cognitive or behavioural functions) (Logothetis, 2008[47]). Additionally, when studying certain regions of the brain such as the temporal or prefrontal cortex regions for example, due to difference in magnetic

[1] This was previously thought to be 700-1000, and was updated by the Center on the Developing Child at Harvard University in 2017.

[2] Magnetic resonance imaging refers to producing structural images of organs, such as the brain/central nervous system; functional magnetic resonance imaging detects changes in blood flow following enhanced neural activity from task-induced cognitive changes or as a result of "unregulated processes in the resting brain" (Logothetis, 2008[47]) (Glover, 2011[46]).

susceptibility it can distort results [i.e. an "erroneous lack" of BOLD (blood oxygen level dependent) signal] (Glover, 2011[46]). Brain imaging can give some insight into brain structure and activation patterns, however functional relevance is difficult to infer, and this type of research is still in a rather exploratory phase.

Both nature and nurture play a role in the development of children and adolescents' brains and cognitive skills. Furthermore, measuring these changes in cognitive skills or brain "reorganisation" is not always clear cut, and does not produce definitive results. Consequently, shock headlines touting total restructuring of children's mind as a result of technology use are not based on empirical evidence and are inaccurate.

## 1.3. Impacts of television on children: cognition and well-being

There is a relatively large body of literature exploring television and children; in part this is because television has been around for a long time. Researchers have explored the implications on verbal abilities, as well as cognitive, physical and emotional development. However, the quantity of research in this field outpaces the quality; many studies report very small effect sizes, are correlational in nature (thereby unable to show causation), and there is much contradicting "evidence" presented even when analysing the same datasets. Thus, results in this domain must be interpreted with caution. This section serves to provide an overview of some of the literature regarding television viewing and child outcomes, and some of its limitations.

Some research has linked viewing television for longer periods of time during childhood with attention problems in adolescence (Landhuis et al., 2007[48]), and has suggested there may be modest adverse effects of watching television before the age of 3 on cognitive outcomes later in childhood (Zimmerman and Christakis, 2005[49]). One contested study suggested that one extra hour of television at age 1 was associated with a 28% increase in the probability of having attentional issues at age 7, with similar effect sizes for the amount of television watched at age 3 on inattention later in childhood (Christakis et al., 2004[50]). Subsequent reanalysis of the same dataset suggested that the risk of attention problems was significant only for the 10% of the children in the survey who watched 7 or more hours of television per day. One conclusion of this reanalysis was that modest levels of television viewing, even for younger children, may not be detrimental (Foster and Watkins, 2010[18]). Furthermore, retesting the hypothesis (that television is linked to later attentional/behavioural problems) in a Danish sample (the initial study was done in the United States) found no significant association between hours of television watching in early childhood and behavioural problems later on (Obel et al., 2004[51]). The authors do note that Danish children in the sample tended to watch less television than their American counterparts (only 6% watched over 2 hours of television at 3 years old vs. 50% in the American sample), which does not rule out potential threshold effects that this study was unable to determine.

Other longitudinal research has suggested watching over three hours of television daily might be associated with a small increase (0.13 points) in conduct problems at age 7 compared to children who watched for under one hour. However, there was no association found with outcomes such as attentional problems/hyperactivity as well as emotional symptoms, relationship problems and prosocial behaviour, nor with these outcomes and playing electronic games (Parkes et al., 2013[52]). Results implicating television watching in socio-emotional development of infants have also been inconsistent [in (Haughton, Aiken and Cheevers, 2015[53])]. However, on a more promising note, some literature points to more positive associations with television watching (in this case educational

programming) and children, suggesting it may promote literacy, mathematics, problem solving and science skills, as well as prosocial behaviour in preschool-aged children [for review see (Evans Schmidt and Anderson, 2009[54])].

Some scholars cite an opportunity cost associated with time spent watching television rather than engaging in more "educational" activities. For example, time spent playing attention training games versus watching popular children's videos may contribute to improvements in executive attention and intelligence (Rueda et al., 2005[55]).

### *1.3.1. This ~~is~~ might be your child's brain on TV*

Analyses of how children's brains react to television use are scarcer than those concerning cognitive or behavioural outcomes, and causality remains difficult to ascertain. Despite these limitations, some results indicate that television viewing is correlated with differences in volume in different regions of the brain. For example, Takeuchi and colleagues found positive correlations between viewing television and volumetric properties in regions such as the medial prefrontal cortex and frontopolar area, which was negatively correlated with verbal IQ and was predictive of a decrease in verbal IQ over time (Takeuchi et al., 2015[56]). Sensorimotor regions may also be affected by television viewing, which is theorised to be because children who view TV more frequently are likely to engage in less physical activity which may have an impact on the volumetric properties in these brain regions (Takeuchi et al., 2015[56]). Limitations of this research include use of small samples and lack of intervention; therefore it is not clear whether TV viewing directly causes the outcomes measured, and whether the results are generalisable. Furthermore, functional relevance of volumetric changes in different brain regions is not always clear.

As referenced in the previous section, time spent watching television may have an opportunity cost in terms of children engaging in other activities. For example, attention training in young children (ages 4-6) may be implicated in provoking adult-like brain response patterns (Rueda et al., 2005[55]), and can raise questions as to whether these kinds of activities are more beneficial in preparing children for early childhood education than watching popular, age-appropriate programming. It is important to note that attention training programmes delivered to children (especially in research settings) may also be screen-based, including elements such as stimulus discrimination and matching activities (Rueda et al., 2005[55]). In this sense, children are still engaging with screens and tallying up "screen time", although outcomes might be different regarding active versus passive engagement, and type of screen use and activity.

In sum, the effects of television viewing on children are not clear. If time spent watching television is time away from other activities, such as health-promoting behaviours, perhaps this could be a cause for concern. However, the evidence is conflicting, and there is no clear proof that moderate television watching displaces other behaviours essential for well-being or development. Moreover, if television watching does impact outcomes such as attention or volumetric differences in brain regions, there is a need for research on the mechanisms leading to these outcomes, as this is a current weakness in the literature.

### *1.3.2. In support of co-viewing?*

The AAP recommends that parents/guardians engage in "co-viewing" (i.e. when parents watch video material with infants). This is supported by a number of studies. While co-viewing, infants may pay more attention and potentially increase their ability to learn from video content (Barr et al., 2008[57]). This can be referred to as "scaffolding" and suggests parents pose questions, and give descriptions and labels during viewing (Barr

et al., 2008[57]). While co-viewing may increase infant attention on the content, it is unclear the extent of the cognitive outcomes associated with this practice. It is therefore important to supplement this research with experimental results in order to ascertain potential effects and magnitude of cognitive benefits, if there are any.

Other cross-sectional research suggests that daily television watching, reading and physical activity when done with a caregiver is associated with higher linguistic and/or cognitive development than in children who engage in these activities only once or twice per week (Lee, Spence and Carson, 2017[58]). One conclusion here might be that independent of the content of the activity, simply engaging in behaviours with a caregiver may be beneficial for child development (Lee, Spence and Carson, 2017[58]).

Another note about co-viewing, and parental mediation of screen content more generally, is that there is a deepening divide between high and low socio-economic status (SES) families. Children whose parents are able to spend time both curating and mentoring their experiences with screen time may reap more benefits than those in families with fewer financial resources and with parents who are less able to be involved in daily activities (Canadian Paediatric Society, 2017[10]). This equity dimension of television viewing is important to consider, especially if there is a relationship between cognitive outcomes and time spent watching television, as children from low SES backgrounds, or with low educated mothers tend to watch more television than children from higher SES backgrounds (Certain and Kahn, 2002[59]; Rideout and Hamel, 2006[60]).

### *1.3.3. "High Quality" programming: the quality vs. quantity debate*

Not all television is created equal. While there is much content with little purpose beyond entertainment, educational programming does exist and is referred to as "high quality programming" by the AAP. For example, this can include content offered by Sesame Workshop and Public Broadcasting Service (PBS). There is not much research exploring brain-based outcomes of educational television, however there has been some work done exploring different elements of cognition and there is a relatively large body of research supporting the positive effects of educational programming on cognitive development in preschool aged children (Anderson and Subrahmanyam, 2017[61]).

Some research suggests greater levels of school readiness in preschoolers who watched Sesame Street on a regular basis (Anderson, 1998[62]; Anderson et al., 2001[63]; Schmidt and Anderson, 2007[64]), as well as superior language development (Linebarger and Vaala, 2010[19]; Linebarger and Walker, 2005[65]; Linebarger and Piotrowski, 2009[66]). Other "educational" shows such as Dora the Explorer, Blue's Clues, Arthur, Clifford or Dragon Tales have also been linked to increases in language use and vocabulary development (Linebarger and Walker, 2005[65]). Moreover, neural responses in a region of the brain associated with mathematics abilities have been recorded as higher in numerical versus non-numerical segments of Sesame Street. The more closely children's brain activation in this region mirrored activation patterns seen in adults, termed "neural maturity", was predictive of formal mathematics abilities in a small sample of children (n=27) (Cantlon and Li, 2013[67]).

Furthermore, engaging with educational content may be especially beneficial for children from low-to-moderate income families, not only in terms of vocabulary, but also higher performance on reading and mathematics tests as well as overall school readiness (Wright et al., 2001[68]). Benefits of engaging with this type of content might also persist past early childhood. For example, some research has noted a positive relationship between viewing educational-informative television programmes during preschool years and high-school

achievement and time spent reading books for leisure (Anderson et al., 2001[63]). Furthermore, total time spent watching television, educational or not, has been found in some research not to be predictive of high-school performance (Anderson et al., 2001[63]) and there are implications for increasing linguistic development (Lee, Spence and Carson, 2017[58]). A systematic review of the literature exploring the association between television viewing and outcomes such as academic performance, language and play further highlights the complex relationship between television and children's development, highlighting the potential importance of individual characteristics, including social context and family factors. The authors suggest that watching high quality content is associated with academic skills and predictive of future academic performance, whereas watching television during infancy may be detrimental to play and language development (Kostyrka-Allchorne, Cooper and Simpson, 2017[69]). It is important to note that it is unclear whether some of these interactions are long-lasting, and generally the nature of this type of research does not allow for causation inferences.

Despite these results from educational or high quality programming, it is important to keep in mind the notion of the "video deficit" which posits that infants and toddlers do not learn as well from materials presented via video than they do from live sources (Anderson and Pempek, 2005[70]). There is not much support for toddler and infant learning from video sources beyond their exact reproduction of basic tasks (Anderson and Pempek, 2005[70]). Infants may show higher activation in sensorimotor regions of the brain when actions are witnessed live, versus when they are televised, which may further support the notion of the deficit hypothesis (Shimada and Hiraki, 2006[71]). However, some of the video deficit effects can be partially mitigated when simple actions are repeated (Barr et al., 2007[72]) or when the onscreen character is socially meaningful to the watcher (e.g. the child's mother) (Krcmar, 2010[73]). This video deficit may also affect language learning in infants during their first year of life, as viewing television before the age of two has some negative associations with language development and executive functions (Anderson and Subrahmanyam, 2017[61]). Live exposure, versus audio or video exposure, to foreign languages seems to have a larger impact on capacity to discern differences in phonetic units in languages (Kuhl, Tsao and Liu, 2003[74]).

In sum, there may be some benefits associated with engaging with child-tailored, educational content in terms of improved verbal abilities, cognitive development and neural maturity in children. However, the research also points to children learning better from live sources than from videos, despite the potential mitigation of this deficit by using socially meaningful or familiar onscreen characters. This could also have implications for children coming from low SES households or with working parents who have less time to spend together. Television watching perhaps can be incorporated into a schedule filled with other health and development-promoting habits, even for infants and young children. Limiting television viewing in children who do not exhibit problematic tendencies perhaps is unnecessary. Again, the literature in this domain can be contradictory and it is difficult to distinguish clear associations between these cognitive outcomes based on screen time habits.

## 1.4. Effects of video games on the brain and executive functions

Children playing video games has evoked concern in many different spheres; policy-makers, parents and the media are pretty consistently touting worry about children interacting with games, and their "addictive" propensity. "Internet Gaming Disorder" (IGD) was recently included in the Appendix of the Diagnostic and Statistical Manual of

Mental Disorders-V (DSM-V) and as "Gaming disorder" in the draft of the 11th revision of the World Health Organization's International Classification of Diseases (ICD-11). However, these additions are controversial and under debate in different research circles [i.e. (Starcevic, 2017[75]; Aarseth et al., 2017[76]; Király and Demetrovics, 2017[77]; van Rooij et al., 2018[78]; Rumpf et al., 2018[79])]. While the formal classification as a "disorder" is contentious in the scientific community (Turel et al., 2014[80]), some researchers prefer to use terms such as 'excessive internet use' to avoid using medical classification or terminology (Smahel et al., 2012[81]).

Gaming has been implicated in affecting brain regions such as those responsible for reward, impulse control and sensorimotor co-ordination (Weinstein and Lejoyeux, 2015[82]), and there are links in the literature to dopaminergic or reward pathways (generally associated with substance addiction) being implicated in gaming (Kuss and Griffiths, 2012[83]). However the research in this domain is not robust enough to liken "internet addiction" or "gaming addiction" to substance addictions (Weinstein and Lejoyeux, 2015[82]). It is important also to note that the vast majority of literature on gaming focuses on negative rather than positive outcomes (Granic, Lobel and Engels, 2013[84]), thereby providing a somewhat skewed view on the potential impact of video games on children.

While much of the research in this area focuses on adults, there has been some study of children. For example, one study noted small but significant differences in a region of the brain that was associated with decision making. Frequent gamers exhibited higher grey matter volume in this region, which was associated with lower deliberation time in comparison to infrequent gamers (Kühn et al., 2011[85]). Another study implicated increased connectivity in regions implicated in processes such as procedural learning based on acquiring new skills via practice (Pujol et al., 2016[86]). There is also evidence suggesting that playing active video games, at least in adult populations, may enhance aspects of attention such as attention to objects and selective attention over space/time and abilities to learn new tasks (Green and Bavelier, 2012[87]). Gaming is also linked to better working memory, as well as better spatial skills (Uttal et al., 2013[88]). Playing active video games may enhance spatial skills, which are malleable and related to performance in science, technology, engineering and mathematics (STEM) performance (Uttal et al., 2013[88]).

Playing Tetris (a visual-spatial problem-solving computer game), has been implicated in changes in cortical thickness in two regions in the brains of adolescent girls, one of which is implicated in integrating visual, tactile, auditory and internal physiological information (Haier et al., 2009[89]). Gaming can also implicated in maturation of the visual word form area of the brain, which is involved in mediating literacy. For example, playing "educational" games including activities such as mathematics and grapheme-to-phoneme correspondence, may impact maturation of the visual word form area (Brem et al., 2010[90]). Action video games in particular (i.e. distinguished from non-action video games for characteristics such as speed, unpredictable stimuli and high sensory-motor load) have been linked to enhanced reading outcomes in dyslexic children as well (Franceschini et al., 2017[91]). Furthermore, even modest amounts of gaming has been associated with faster motor response times (Pujol et al., 2016[86]). In a review by Tran and Subrahmanyam (Tran and Subrahmanyam, 2013[92]), informal computer use, and in particular games, were associated with many of the cognitive effects mentioned here such as visual-spatial skills, attention and processing speed.

Parents and educators often worry about the impacts of gaming on educational attainment, however as with "educational television", "educational gaming" might have positive

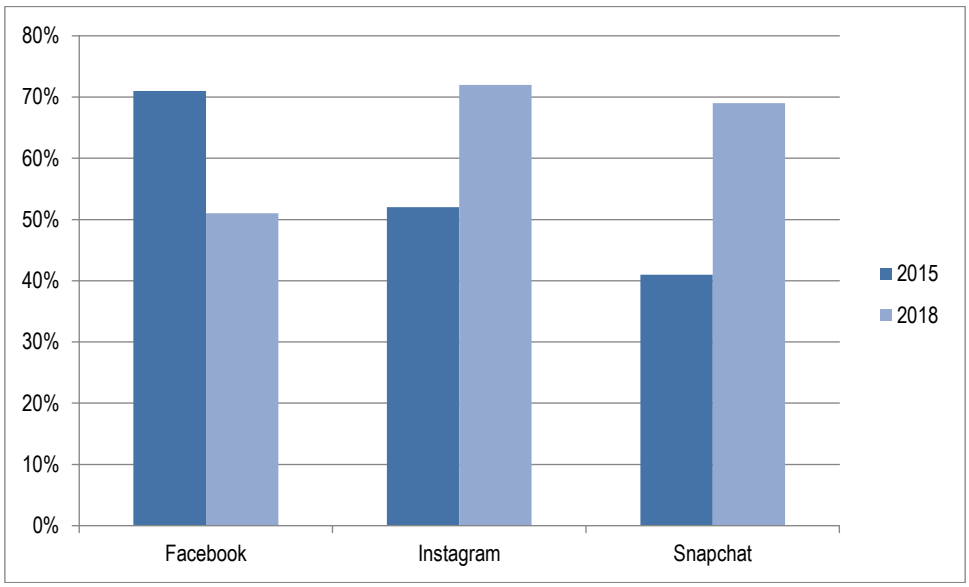
impacts on children. In one small experiment looking at 4-year-old children from low-income families, playing age-appropriate, educational games on a touch-screen surface showed higher gains in literacy and mathematics skills than the control group that only had access to age-appropriate entertainment software (Griffith et al., 2017[93]). In general, there is a lack of strong evidence supporting the notion that video game playing impacts educational outcomes. Impacts on performance, as indicated using PISA 2009 results, may be "too small to be considered problematic" (Drummond and Sauer, 2014[94]). There was little cross-country variation in this analysis. The literature in this domain points to a number of potential implications of video game use in children and adolescents. It is important to note that findings in studies such as those cited above can be quite inconsistent. Factors such as cross-sectional design, reliance on self-report (or parental-report) to determine time spent gaming, small sample sizes and research design provide major limitations in this field, which would benefit from more randomised-controlled trials, larger sample sizes, and more consistently reproducible findings. Furthermore, publication bias skews overall findings in this field. Generally speaking, it seems that playing video games may have both positive and negative impacts on children, in part due to moderate versus more extreme use.

## 1.5. 21st century children and social media

Adolescents (and children to a lesser extent) in the 21st century use technology to interact with their peers. Research on social media has been published at a rapid rate with the expansion of networking sites. Since 1997, over 10 000 published journal articles have used the term "social media", with experts in fields such as psychology, economics and sociology incorporating this into their research agendas (Meshi, Tamir and Heekeren, 2015[95]). This is for good reason, as recent estimates suggest over 90% of young people are using social media both day and night (Duggan and Smith, 2014[96]). Texting is a dominant form of daily communication in adolescence, as are mediums such as instant messaging, social media platforms and video chatting (Lenhart et al., 2015[97]). There is evidence to suggest that social relationships of children can be stimulated by digital technology and that online communication has a positive relationship between friendship quality and social capital in studies spanning samples of children, adolescents as well as young adults [for review see (Kardefelt-Winther, 2017[98])]. On the other hand, using a computer to study or for recreation time has been negatively associated with time with friends (Lee, 2009[99]).

There are differences in how young people use social media versus their older counterparts, with a shift in recent years regarding the most popular online platforms used by teens, as displayed in Figure 1.1. As of 2018, 35% of teens surveyed by the Pew Research Center in the United States stated they used Snapchat most often, which bucks the trend of heavier Facebook use in older populations (Pew Research Center, 2018[100]).

**Figure 1.1. Change in popular social media platform use in US teens from 2015-2018**




*Source*: Adapted from (Lenhart, 2015[30]; Pew Research Center, 2018[100]).

Despite the proliferation in research exploring social media use and the huge proportions of children subscribing to these platforms, empirical research is scare. In 2015, only seven published articles explored neurosciences and social media (Meshi, Tamir and Heekeren, 2015[95]). Furthermore, many studies focus on Facebook use, and the literature exploring other pervasive forms of social media used by 21st century children such as Snapchat and Instagram is sparser.

Some research has explored the size of social networks and brain structure in adults. For example, in adults social network size (including but not limited to the number of Facebook friends) has been correlated with an increase in grey matter in part of the amygdala implicated in emotional learning and memory, as well as fear conditioning (Balleine and Killcross, 2006[101]; Von Der Heide, Vyas and Olson, 2014[102]). This is consistent with other research on network size (Bickart et al., 2011[103]), suggesting the functional relevance of this increase in grey matter may be in supporting and maintaining social networks (Von Der Heide, Vyas and Olson, 2014[102]). Other brain regions have been correlated with real-world and online social network size. For example, a region implicated in associative memory has been correlated with online network size, as have regions implicated in social perception (Kanai et al., 2012[104]). It is important to note that it is not entirely clear the functional relevance of these various regions, or how morphological differences impact different processes.

Unfortunately, the research on children and adolescents in this domain is scarcer than that on adults. There is some research to suggest that social media use, especially at night, might be linked to outcomes such as poor sleep quality, with very small relationships between levels of anxiety and depression (in this particular reference, associations were higher between poor sleep quality and anxiety/depression, than between media use and anxiety/depression) (Woods and Scott, 2016[105]). Some of these outcomes are more widely substantiated by the literature than others. Despite this limited literature base, a number of neural pathways in adolescents have been implicated through research to be associated with

behaviours important in the use of social media such as social reward processing and emotion-based processing (Crone and Konijn, 2018[38]).

Youth today tend to maintain social media portfolios, consisting of accounts on different platforms to share photos, updates and connect with peers. Adolescents in particular tend to be attuned to the opinions of their peers, and the simple act of peers "liking" a recently published photo within the social media portfolio can act as a "quantifiable social endorsement" (Sherman et al., 2016[106]). Using fMRI data and a platform resembling Instagram, Sherman and colleagues found that how teens perceive photos is significantly affected by the popularity of the photo, in this case quantified by how many likes it had already received (Sherman et al., 2016[106]). For example, photos showing risky behaviours such as smoking marijuana or drinking were more likely to be "liked" by participants if the photo had been liked substantially by their peers. In terms of brain activity, more popular photos elicited a greater response. Regions of the brain that are associated with social memories and cognition, as well as imitation showed higher levels of activation (Sherman et al., 2016[106]). Furthermore, the authors noted greater activation of the visual cortex when participants viewed photos with many likes versus those with few likes. It was suggested that this might be because participants took greater care when looking at more popular versus less popular photos (Sherman et al., 2016[106]).

Research of this nature shows transient changes as a result of technology use/exposure. It would therefore be pertinent to supplement this with longitudinal work showing potential morphological impacts over time, as well as reproduce these trials in larger and more diverse samples. It is also important to yet again indicate that the functional relevance of certain regions or activation patterns is hypothesised.

### *1.5.1. "Facebook addiction", excessive social media use and risky behaviours*

As with the hype around video games, there has been much interest around the concept of "Facebook addiction" and phenomena such as "excessive" or "extreme" internet/social media use in children. For example, PISA defines "extreme internet users" as those who spend more than 6 hours per day online. Across OECD countries, an average of 26% of students fall into this category, and it tends to be associated with lower levels of self-reported well-being (OECD, 2017[107]). There is some research that suggests associations with brain regions implicated in impulsive outcomes and inhibitory processes and "Facebook addiction"/"internet addiction" (Turel et al., 2014[80]; Li et al., 2014[108]). However, as with "gaming addiction" and IGD, these classifications remain contentious.

The nucleus accumbens is part of the mesolimbic dopamine system, and is involved in the experience of pleasure and reward (Berridge and Kringelbach, 2013[109]), and in the motivation of goal oriented behaviour (Ikemoto and Panksepp, 1999[110]). It has also been implicated in behaviours related to the use of social media like sharing information (Tamir and Mitchell, 2012[111]) and receiving positive feedback (Sherman et al., 2016[106]; Davey et al., 2010[112]). Sherman and colleagues found this region exhibiting a robust response when participants received positive feedback on their own posts (i.e. when they viewed their own photos that had accumulated many likes), and also when viewing popular posts from peers (Sherman et al., 2016[106]). These preliminary results can begin to shed insight into why individuals devote so much time to maintaining social media portfolios, as these platforms provide a constant arena for self-disclosure to wide audiences.

Using photo sharing sites may also induce differences in activation of cognitive control regions when viewing images showing "risky behaviours". For example, in comparison to an older cohort, high school students showed lower activation than their university-aged

counterparts, which could imply differences in maturation of the frontal cortex in these age groups (Sherman et al., 2017[113]). This is consistent with the notion that frontal regions in adolescence are insufficiently capable of inhibiting responses to stimuli which can be affective, and often risky (Sherman et al., 2017[113]). University students might report taking more risks than high school students, which suggests that results of behavioural or neuroimaging studies need to be contextualised in terms of the environment and prevailing culture (Sherman et al., 2017[113]).

As children are engaging with social media more and more, these findings concerning social network size, "likes" and brain implications are interesting, yet the research is still in its infancy. Social media has been connected to facial recognition and memory, which could prove beneficial in establishing and maintaining strong social networks both on and offline in adolescence and later in life. However, these results are still quite exploratory; directional causality is not inferred and often the functional relevance of certain brain phenomena is unclear. More research is needed to explore these processes specifically in samples of children and teenagers in order to understand the cause and effect of online social networks and brain function especially at younger and younger ages. This could be achieved through longitudinal work that explores changes in the brain over time, as a function of social media use and network size (although these factors cannot be isolated in laboratory conditions, and are subject to self-report biases). More work exploring the direct effects of social media on brain functionality in experimental studies will also help further research in the field.

The research on the effects of social media on children is not conclusive. Furthermore, the literature base on "Facebook addiction" is quite extensive, although caution should be taken when classifying behaviours as addictive or having addictive qualities. Pathologising children's behaviour by labelling high use of social media or gaming as addictive can have negative impacts on children, and can overstate risks of harm (UNICEF, 2017[114]). Parents and educators should take notice of children "excessively" engaging with social media to the point that it interferes with daily activities, family time or schoolwork. It is important to note that this paper does not explore content, contact or conduct risks associated with social media/internet use that might have implications for well-being, such as cyberbullying for example which affects many children around the world (Hooft Graafland, 2018[5]).

## 1.6. Summing up

Despite the proliferation of research on child outcomes resulting from technology use, policy-makers need more in order to make clear and effective guidelines for technology use in children. Some of the main challenges in the available research, as outlined in the above sections, include:

- Lack of quality research and coherence across research – reanalysis of the same datasets has produced very different results, or results are contested.
- Reliability of brain science for understanding behavioural issues – challenges in identifying functional relevance of morphological differences/activation patterns; limitations in imaging such as fMRI.
- Study design issues – reliance on self-report data, small sample sizes and results infer correlation not causation.
- Chicken and egg dilemma – e.g. do behavioural tendencies/problems predict more screen time, or does screen time predict behavioural tendencies/problems?

- Need for patient-based research – much research is done on healthy populations; studying mental illness requires clinical populations.
- Large focus on negative effects of technology – unbalanced with potential positive outcomes.

These issues suggest a need for more high quality research that can elicit reproducible findings on a larger scale. Further to this, as it is often impractical for policy-makers to revert to primary studies, synthesising information through meta-analyses and systematic reviews is an important process in engaging in evidence-based decision making (Bello et al., 2015[115]) (see Annex A for an overview of reviews and meta-analyses included in this paper).

When formulating guidelines, there are some insights from quality research that can be taken into account. For example, it has been suggested that moderate use of screens, even in excess of many national recommendations or those of the AAP, is not associated with problematic outcomes such as delinquency, risky behaviours, reduced grades or mental health problems (Ferguson, 2017[116]). Moderate use might even be advantageous for students, the so-called "Goldilocks Effect"[3], posing no real risk to mental well-being of adolescents, although this can depend on factors such as type of media used and when it is used (i.e. during the week or weekend) (Przybylski and Weinstein, 2017[26]). Negative outcomes have been associated with media consumption in excess of 6 hours per day (Ferguson, 2017[116]), however the association with mental well-being is small (Przybylski and Weinstein, 2017[26]).

On the other hand, there are some new challenges faced by researchers and policy-makers as technology evolves and children's habits change. For example, the notion of "screen-stacking" or media multitasking (i.e. using more than one technological device at the same time) is a relatively new and understudied phenomenon that may have implications for children's cognition, behaviour, neural structure and academic outcomes (Uncapher et al., 2017[117]). With more time and research, this could have further implications for guideline development. Some of these factors, including research quality and potential benefits of technology, are not necessarily accounted for in restriction-based guidelines.

[3] This suggests moderate engagement in online and digital activities might actually be beneficial in terms of subjective mental well-being and adolescent connectedness, whereas too much or too little might prove detrimental (Przybylski and Weinstein, 2017[26])

# 2. Implications for health-behaviours and outcomes of screen time in children

There are a number of implications for different health-related outcomes and behaviours including sleep patterns, posture and sedentary behaviours. This second part of the paper assesses some of the potential risks and benefits of technology use on developing bodies.

## 2.1. Sleep

Have you ever wondered why your alarm clock has red numbers instead of blue, green or purple? This isn't something that manufacturers happened upon by chance, but is rather based on research regarding human's body clocks, also known as the circadian rhythm, and how different coloured light impacts this circadian clock network of the brain. The circadian rhythm is dependent on an internal clock located in part of the anterior hypothalamus called the suprachiasmatic nucleus (SCN), which plays a role in synchronising clocks in other regions of the body such as the heart and liver, and also directly manages circadian functions (Richards and Gumz, 2012[118]).

The SCN develops early in the gestational process, and circadian rhythms can be observed in newborns (Kennaway, Stamp and Goble, 1992[119]). It connects to the retina, part of the eye that is sensitive to light, and to the pineal gland, which secretes what is often referred to as the "sleep hormone", melatonin, which starts rising about 2 hours before a natural bedtime and signals sleep to the body (Figueiro and Overington, 2016[120]). While not the only modulating factor of the circadian rhythm, light plays a major role in adjusting and synchronising the body's clock (Touitou, Touitou and Reinberg, 2016[121]). Light that emits short wavelengths, such as blue and blue-green light, versus longer wavelengths of orange or red light, asserts more of an effect on the circadian photoreceptor (Brainard et al., 2001[122]; Thapan, Arendt and Skene, 2001[123]). Exposure to light, especially short wavelength light, counteracts the machinery in the pineal gland responsible for producing melatonin, and this suppression of melatonin has been correlated with both the irradiance and duration of exposure to light (Zeitzer et al., 2000[124]). Furthermore, melatonin production might be more sensitive to light in children than in adults, and even in pre- versus post-pubertal children and adolescents (Higuchi et al., 2014[125]; Crowley et al., 2015[126]).

While the link to alarm clocks in this sense is clear, what is the link between children and adolescents' sleeping behaviours and technology more generally? Many devices today emit short wavelength or blue light. This includes computers, cell phones and tablets, which over time have evolved to have larger and brighter screens. Using one of these self-luminous devices in the evening has been associated with reduced melatonin concentrations.

Dosage (i.e. time spent engaging with devices) and age might impact melatonin production. As mentioned above adolescents might be more sensitive to light than adults, and more time using a device has been associated with a larger reduction in the melatonin response (Figueiro and Overington, 2016[120]). A systematic review of the literature uncovered 67 studies from 1999 to 2014 exploring sleep among school-aged children and adolescents, in which 90% of the studies found adverse associations between screen time and sleep outcomes such as delayed timing and shortened duration (Hale and Guan, 2015[127]). It is

important to note again here that association, or correlation, does not infer causation. Furthermore, there tend to be issues with measurement error regarding screen time exposure and sleep times (Hale and Guan, 2015[127]). For example, teens are likely to over-report sleep time, and there is little research to validate assessments of youth engagement in screen time using self-report and parent-reported measures (Hale and Guan, 2015[128]). Using validated assessment and objective measures that go beyond self-report tools can help mitigate some of this error.

It is important to note also that different types of media use at bedtime might have different implications for sleep. For example, in a cross-sectional study of 11-13 year olds in the United Kingdom, difficulty falling asleep was associated with social networking, frequent mobile phone use and video gaming, with those who listened to music showing the greatest effect (Arora et al., 2014[129]). The largest reduction in weekday sleep duration in terms of the bedtime use of technologies was observed in those who frequently used social media sites. This was related to a reported almost hour less of sleep (Arora et al., 2014[129]). Furthermore, computer use for studying was negatively associated with weekday sleep duration as well, and children who frequently watched television at bedtime were more likely to report symptoms associated with insomnia (i.e. early awakening episodes) (Arora et al., 2014[129]). This was hypothesised to potentially be result from a combination of delayed melatonin release due to exposure to light emission, as well as mental excitation (Arora et al., 2014[129]). The findings specifically concerning computer use for studying and the impact on sleep are important to highlight as over 50% of adolescents across OECD countries reported browsing the internet for schoolwork outside of school at least once per week, according to PISA 2012 data (OECD, 2015[2]).

In addition to the impact of light, there is emerging evidence suggesting that exposure to radiofrequency electromagnetic fields from mobile phones may impact sleep architecture. In a double-blind study in a small sample adults (n=48) that subjected one group to 3 hours of exposure before bedtime (in comparison to a sham group that did not receive the radiofrequency exposure), time engaged in slow-wave sleep was slightly diminished and latency to slow-wave sleep was prolonged (Lowden et al., 2011[130]). The health effects of these patterns are not entirely clear, however reduced slow-wave sleep has been associated with outcomes such as insomnia and burnout [in (Lowden et al., 2011[130])]. While the reduction in slow-wave sleep in this particular study was low, effects could be cumulative. This needs to be replicated in larger samples, including with children, in order to state whether this is a definitive risk or not.

Therefore, implementing limits on when children and adolescents use technology (i.e. not in the hours immediately preceding bedtime), or providing children with protective equipment such as blue light-blocking glasses may help prevent sleep disruptions. Evidence suggests that these glasses are effective in mitigating melatonin suppression in teenagers (van der Lely et al., 2015[131]); therefore their use for late-night studying or scrolling through social media feeds before bed might be warranted. Research might be warranted in identifying whether activating features on mobile devices such “Night Shift” or “night mode” are effective in avoiding disruption in melatonin production. These steps could be incorporated into good sleep hygiene practices, which include behaviours such as avoiding excess (or any) caffeine, engaging in regular exercise, maintaining a regular sleep schedule and eliminating noise from the sleeping environment (Stepanski and Wyatt, 2003[132]).

## 2.2. Stress

When faced with a stressor, threat or a challenge, the human body responds through a series of events resulting in secretion of glucocorticoids such as cortisol which plays a role in preparing the body to react to a stressor (i.e. activating the "fight or flight" response) (Juster, McEwen and Lupien, 2010[133]; Afifi et al., 2018[6]). In healthy individuals, levels of cortisol follow a cyclic pattern and generally peak after waking followed by a pattern of steep drops at various stages in the day, with the lowest point before bedtime (Afifi et al., 2018[6]). Changes in this pattern or chronically high or low levels of cortisol can have negative effects on human physiology and psychological outcomes. It is important to note that subjective stress levels do not necessarily mirror physiological stress levels (Davidson and Irwin, 1999[134]; Damasio, 2000[135]).

Long periods of ICT use (i.e. three hours or more per day) and type of media used might impact the cortisol response in children (Wallenius et al., 2010[136]). In one study looking at Facebook use in teens aged 12-17 (n=88), cortisol profiles were associated with Facebook network size and Facebook peer interactions. In this study, there was a negative correlation between Facebook peer-interaction levels and cortisol, and higher levels of cortisol were associated with network size which was contrary to the hypothesis that network size would be inversely correlated with cortisol levels (Morin-Major et al., 2016[137]). Further research suggests that that adolescents who engage more with general media, use their phones more and have larger network sizes on Facebook may experience higher rises in cortisol after waking up (associated with poor mental and physical health problems) and rates of interleukin-6 (an inflammatory marker; its overproduction is associated with poor health) (Afifi et al., 2018[6]). Experimental and/or longitudinal work in this field is important to determine whether media use causes this biological response, or whether the response precedes media use.

Stress can be measured through biological markers, such as cortisol, and also through subjective measures such as perceived stress of respondents. In response to stressful events, children may consume media to manage stress or mood, through seeking entertainment for example. Some studies show that playing games for example can help transiently decrease physical stress, and improve one's mood after playing (Russoniello, O'Brien and Parks, 2009[138]). Further, social support in online and offline forums can help buffer how upset children feel during stressful life events (Leung, 2007[139]).

## 2.3. Overeating, sedentary and overweight…

Over recent decades, extended screen time, such as television watching and using the computer, has been linked with obesity in children (Subrahmanyam et al., 2000[140]). One way in which this might happen is through eating while watching television, which has been associated with an increase in energy intake (i.e. more calories or food eaten) through two different processes. The first is that this can delay normal mealtime satiation (i.e. the feeling of fullness), and the second by reducing signals of satiety from foods that had been previously consumed (i.e. children do not stop eating, even though they are already full) (Bellissimo et al., 2007[141]). Watching television could serve as a distraction from satiety signals and draws attention away from typical control over food intake (Bellissimo et al., 2007[141]). This does not into account the potential impacts of targeted advertising and marketing of high energy, low nutrient foods to children via technology.

Further links with obesity and screen time tend to be less linear. For example, some literature points to the notion of a "displacement effect", whereby time spent using

technology causes harm proportional to exposure and detracts from other potentially more "valuable" activities (Neuman, 1988[142]). However, a recent review of the literature suggests that reducing screen time may not motivate adolescents and children to engage more in physical activity (Kardefelt-Winther, 2017[98]), and other research has shown that screen-based sedentary behaviour and leisure-time physical activity are independent of one another (Gebremariam et al., 2013[143]). Television watching may displace other activities such as reading, however overall evidence for the negative impact of displacement is relatively weak (Evans Schmidt and Anderson, 2009[54]).

In any case, displacement effects can differ based on amount of use and activities being displaced: for example, heavy internet use may interfere with participation in clubs and sports whereas moderate use has shown to be supportive of participation (Romer, Bagdasarov and More, 2013[144]). This is a relatively consistent finding across the research; moderate internet use, and shared media experiences, allow young people to build rapport with their peers (Romer, Bagdasarov and More, 2013[144]; Romer, Jamieson and Pasek, 2009[145]; Pasek et al., 2006[146]).

## 2.4. …or active, energetic and co-ordinated?

With developments in technology, there has been a shift in video games from being sedentary, controller-based games to encompassing a range of games including active video games, which require players to engage in physical movements in order to interact with the screen-based game and can elicit light, or even moderate activity in children [in (Norris, Hamer and Stamatakis, 2016[147])]. Augmented reality games, or those that involve geo-tracking (or in the case of Pokémon GO a game that uses both) are also becoming increasingly popular and are argued to promote movement.

However, the evidence is mixed. A systematic review of the literature on active video games as efficacious health interventions within schools found that the research was not of a high enough quality, and recommended that randomised controlled trials with larger sample sizes were necessary in order for these to be used as health interventions (Norris, Hamer and Stamatakis, 2016[147]). In contrast, a meta-analysis including 35 articles on active video games concluded that these games can be a good alternative to sedentary behaviour, although they are not replacements for more traditional sports and physical activity in children and adolescents. Studies in this meta-analysis however ranged in null to moderate effect sizes (Gao et al., 2015[148]).

Technology might also be used for development of physical skills. For example, using applications that require motor skills on an iPad has been associated with improvements in motor co-ordination (Axford, Joosten and Harris, 2018[149]). These examples show the potential benefits associated with screen time. With the emergence of skill training applications and active video games such as Wii Sports, Dance Dance Revolution or augmented reality such as Pokémon GO, the ways in which the use of screens is recommended for children and adolescents may need to be re-evaluated. However, simply providing children with access to active video games is unlikely to provoke spontaneous engagement in more activity and may not provide a public health benefit (Baranowski et al., 2012[150]). More research in this field can bolster how active video games can be used to enhance activity levels and fitness in children, thereby serving as a public health tool rather than a hindrance.

## 2.5. Musculoskeletal discomfort and posture

There are other physiological implications associated with the proliferation of technology use by children at school and in home environments. Computer use in school and at home may be related to musculoskeletal soreness (Harris et al., 2015[151]). In a survey of Australian children published in 2000, 60% of respondents reported discomfort associated with laptop use, and 61% reported the same when carrying their laptop (Harris and Straker, 2000[152]).

This musculoskeletal discomfort associated with children's computer use has been noted in a number of studies (Jacobs and Baker, 2002[153]; Woo, White and Lai, 2016[154]), as have the postural risks associated with use of devices like computers and tablets. Certain conditions, including asymmetrical sustained posture of the lower extremities and holding a posture for more than one minute, might be higher contributing factors to postural risks, as well as using a tablet versus a laptop which might result in more sustained neck flexion (Ciccarelli et al., 2015[155]). More recent evidence also suggests increase in neck symptoms being related to television, phone and tablet use, and visual symptoms related to increased use of phones and tablets in particular (Straker et al., 2017[21]).

Furthermore, more generally in terms of mobile device use, parents, educators and young people should be aware of how to identify postural risks (Ciccarelli et al., 2015[155]). Identifying which postures pose risks – such as extreme head or neck flexion, asymmetrical postures or lying in a prone position, propped up on forearms – is important, as is establishing a suitable environment in which children can effectively and safely engage with ICT (Ciccarelli et al., 2015[155]).

In this sense, parents and educators should modify home and classroom environments, accounting for physical risk factors, and health practitioners share a responsibility in assisting education and prevention (Harris et al., 2015[151]). Physically changing where in the home or school environment children use devices can help vary which postures are used, and adults should help children understand that changes in posture and taking active breaks to include stretching and movement can be beneficial (Harris et al., 2015[151]). Safe adoption of computers into the curriculum can also be considered in teacher training programmes for pre- and in-service teachers. It is also important to note that many of these mentioned risks are not exclusive to using technological devices and can be applicable to sustained/static postures in classrooms (Murphy, Buckle and Stubbs, 2004[156])

## 2.6. Health risks of mobile phones

In recent years, the proliferation of mobile phone use and mobile phone networks has raised a number of concerns as their use is linked to risks such as radiofrequency damage, musculoskeletal problems, eyestrain and sleep disturbance (Fowler and Noyes, 2017[157]). This has been on the research agenda of bodies such as the World Health Organization (WHO) (World Health Organization, 2010[158]). The debate over risks of radiation exposure has become especially prominent, although data in adults tends to show weak or non-causal links between radiofrequency exposure and brain cancer and different head tumours (Repacholi et al., 2012[159]). There is some evidence that suggests a higher risk of certain cancers (e.g. glioma, a cancer of the glial cells in the brain or spine) with increased mobile phone use (Morgan et al., 2015[160]), especially on the side of the head that is preferred for cell phone use (Khurana et al., 2009[161]). However, there is sparse data regarding long-term use in adults (Repacholi et al., 2012[159]), and the evidence linking radiofrequency to cancer is contested by experts in the field (World Health Organization, 2015[162]).

As the proliferation of mobile phone use especially in children is a relatively recent phenomenon, the long-term health risks in this group are not clear as there has been no previous generation exposed during childhood or adolescence to this kind of radiation (Hardell, 2018[163]). As mentioned in the section focusing on sleep, radiofrequency might also impact sleep architecture (Lowden et al., 2011[130]). Due to the lack of longitudinal work documenting the effects of long-term exposure to radiofrequency from cell phones and mobile networks, as well as inconclusive literature in this field, it is difficult to state actual risks. The data is insufficient to draw conclusions about these risks from long-term and low level exposure to radiofrequency that people are exposed to in everyday environments (Röösli et al., 2010[164]).

## 2.7. Summing up

Generally speaking, the research is mixed in terms of health outcomes for children and technology exposure. If screen time is displacing other activities, such as physical activity, interacting with family and peers, or sleeping for adequate periods of time, this would be cause for concern. However, research linking moderate technology use to increased participation in sports and clubs (somewhat negating the displacement hypothesis) should provide some solace to parents and educators who are worried about children interacting with screens. As in the first section of this paper, there are a number of open questions and needs in this area of research such as:

- stress mechanisms associated with screen use – exploring stressful versus stress-preventive use of screens
- threshold limit for displacement effects
- the potential for active video games to be used as public health interventions, or incorporated into education systems to promote activity
- the real health risks (if any) of long-term, low-level exposure of children and adolescents to radiofrequency.

Timing of media use is another domain in which parents and health professionals could potentially work together to improve sleep outcomes. Thus, creating “media-free” or “media-reduced” zones such as bedrooms and restricting use right before bedtime could be beneficial for sleep, as additions to implementing healthy sleep hygiene habits. Furthermore, addressing postural concerns and reducing access to high-calorie, low-nutrient snacks to reduce mindless eating in front of the television could be of benefit.

# 3. Policy implications and where do we go from here?

Due to the ubiquity of technology in the lives of 21st century children, a concerted effort needs to be made to protect children from the risks associated with technology use, and also to promote positive habits and modes of use that are beneficial for child development. Although less of a focus in this paper, technology clearly also provides children with a number of learning and socialisation opportunities, and digital competence will likely be necessary for the next generations to enter the labour market.

Screen time guidelines from many countries, with a large focus on setting limits on exposure, might be too simplistic and fail to account for some of the nuances associated with how children and adolescents use technology – such as what they use it for, when they are using it, and the different types of screens they engage with throughout the day as well as the "screen-stacking" phenomenon. Trends in technology use have shown that children and adolescents use screens differently than they did in the past. Computers are more often used in the classroom, especially with the proliferation of "Bring Your Own Device" (BYOD) programmes, and by 2015 91% of 15-year olds who took the PISA assessment reported having access to a smartphone (OECD, 2017[1]). As these digital trends are on the rise, more nuanced recommendations that are strongly rooted in evidence and take into account the quality of the existing evidence are essential. The recently published guidelines from the RCPCH in the United Kingdom that incorporate these notions, and account for individual differences in children, may be a big step in the right direction in this regard.

## 3.1. Key findings

There are some areas of research regarding children's use of technology that have quite robust and consistent research. Yet, there are others with incoherent conclusions, or that are still in their infancy that are guiding policy and public opinion. At this time, there remain many open questions for future research.

Some results that have been quite consistent across the research, include:

- Blue light affects melatonin production and can affect sleep – in conjunction with good sleep hygiene, limiting access to blue light before bedtime or using blue light glasses can help mitigate this.
- Moderate internet use can help children build rapport with their peers, and probably does not displace engaging in physical activity or other health-promoting behaviours.
- Not all media is created equal – active versus passive engagement, violent versus entertainment versus educational content, and age-appropriateness can impact child outcomes.
- Co-viewing provides opportunities for "scaffolding", and can help children understand onscreen content; spending quality time with parents/caregivers might be more important than the type of activity engaged in together (i.e. screen versus non-screen).

Despite widespread attention in both media and policy circles, there are some areas of the research that require more clarity or agreement across scientific and policy communities, including:

- if using technology is the cause of various cognitive/behavioural outcomes (i.e. attention problems or conduct problems)
- if using technology is implicated in restructuring parts of children's brains – as mentioned in Section 1.1.2, a "total rewiring" is highly unlikely
- if extreme use of certain technologies warrants an "addiction" label, or is this a pathologising of normal childhood behaviours
- if technology does impact children's cognitive/emotional/brain development, the causal mechanisms are unclear
- if there are real health risks associated with technology use.

In order to develop healthy attitudes towards children and technology, as well as comprehensive and well-informed guidelines, there is a need for more high-quality research in this field. National policy agendas can help fill these gaps by selectively funding research in these areas. Some examples of research priorities for the future include:

- Longitudinal studies.
- Larger emphasis on how and why children use technology, and what phenomena like "screen-stacking" could mean for processes such as attention or working memory.
- Inclusion of patient-based studies, not just healthy populations, when studying mental health issues or concerns.
- Real-world implications of outcomes in this field – effect sizes published in studies are often statistically significant (albeit small), yet what do these results mean for the day to day lives of children and their peers? Does a "large effect size" translate into functional differences in a child's daily cognition, behaviour, social relationships and educational outcomes?
- Establish causal links between technology use and child outcomes, and understand underlying mechanisms.
- A deeper exploration of the benefits associated with technology use such as social capital formation, enhanced cognition (i.e. spatial processing, working memory), physical activity, and teaching and learning processes.

In light of this, there are some areas where a concerted effort can be made to protect children and adolescents from potential negative effects associated with technology use. This includes educators, parents and health practitioners assessing whether screen time is affecting engagement in certain health-promoting behaviours (e.g. physical activity, meal-times, sleep), setting timeframes for screen use (i.e. limiting blue-light emitting devices close to bedtime) and ensuring content-appropriate programming for younger children. Furthermore, individual differences are important in this field. Simply playing violent video games does not a killer make[4]; individual differences of children should be accounted for in this domain, and any limits on quantity and quality of media consumed could be assessed on a child by child basis, which national guidelines could take into account.

In addition to the issues covered in this paper, recommendations for screen time can take into account some other risks associated with technology use such as phishing,

[4] This is often speculated in the wake of tragedies such as the mass shooting in 1999 at Columbine. However, almost all adolescents in the United States engage in some kind of video game playing, making it a high base rate behaviour, whereas few engage in low base rate behaviours such as school shootings (Ferguson, 2007[168]).

cyber-bullying, accessing unsafe material or pornography, and communication with unknown persons that can open the door for grooming or radicalisation. On the other hand, potential benefits such as sustaining and making friendships, developing digital skills relevant for the 21st century labour market and access to information should also be accounted for. It is also important to assess these risks and opportunities when considering restricting or enabling screen time.

Children and technology use is a topic nowadays that potentially receives more media hype than it deserves. The research base is still a work in progress, and the existing literature points to a number of potential risks and benefits associated with using technology. There is still progress to be made on identifying "hard facts". Unfortunately, many national guidelines focus on risks rather than rewards, and media hysteria spouts a number of "neuromyths" and false associations between technology use and developmental outcomes of children. Guidelines, especially those that prescribe strict time limits on media use, need to be rooted in strong, multidisciplinary research. In order to do so, we will hopefully see a proliferation of high quality work in these fields, especially in the neuroscientific field which is still in its infancy regarding this topic.

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# Annex A. Reviews included in this paper

Evidence-based policy relies on making decisions based on the best available evidence, rather than the outcomes of individual studies. For this reason, different types of reviews or analyses of the literature are important to assess when implementing effective policies.

The systematic review is often seen as the gold standard in evidence-based policy making, requiring an exhaustive and comprehensive search of the literature. Literature reviews examine current or recent literature, and may or may not be comprehensive. Meta-analyses combine the results of quantitative studies to give a more precise effect of the reported results (Grant and Booth, 2009[165]). The below table outlines the purpose and conclusions of the different reviews and meta-analyses included in this work.

**Table A.1. Included reviews and meta-analyses**

| Reference | # of studies | Design | Purpose | Conclusions |
|---|---|---|---|---|
| (Evans Schmidt and Anderson, 2009[54]) | n/a | Literature review | Explores impact of television on cognitive development and educational outcomes | Educational television has a significant positive impact on children whereas entertainment television has a negative impact due to displacement of reading and exposure to violent content |
| (Crone and Konijn, 2018[38]) | n/a | Literature review | Use neuroscience literature to understand mutual influence of media and peers on adolescent well-being/opinion formation | Different neural systems associated with media use such as social reward processing, emotion-based processing, regulation, and mentalising about others; peer sensitivities are larger in adolescents than other age groups |
| (Kardefelt-Winther, 2017[166]) | n/a | Literature review | Examines how time spent using digital technology impacts three dimensions of well-being: mental/psychological, social and physical | Relationship with mental well-being U-shaped with most benefits associated with moderate use (too much or too little may be detrimental); neuroscience evidence challenges the notion that technology rewires children's brains |
| (Linebarger and Vaala, 2010[19]) | n/a | Literature review | Assesses whether infants and toddlers are capable of language learning from screen media through an ecological framework | Learning is facilitated through different factors including: degree to which media resembles real-life experiences (of infant or toddler) including use of familiar objects/routines or simple stories; repeated exposure; presence of a competent co-viewer |
| (Nikkelen et al., 2014[167]) | 45, studies until September 2013 | Meta-analysis | Investigating the relationship between media use and ADHD-related behaviours in childhood and adolescence | Small significant relationship between media use and ADHD-related behaviours; however, literature gaps include examining the effects of fast-paced and violent media on ADHD-related behaviours, and address questions of causality. Moderate correlation between attention problems and media use (r=0.32), small correlation between impulsivity and media use (r=0.11) |
| (Hale and Guan, 2015[128]) | 67, 1999-2014 | Systematic review | Examines the association between screen time and sleep outcomes in school-aged children and adolescents | Sleep time adversely associated with screen use in 90% of studies; results vary depending on demographic factors and type of screen used as well as day of the week; studies are not causal |
| (Norris, Hamer and Stamatakis, 2016[147]) | 22 | Systematic review | Assesses quality of evidence regarding using school active video games for physical activity and health outcomes | Some studies suggested greater physical activity in active video game sessions compared with controls (school time only); motor skills improved with games in all studies but not compared to motor skill interventions; overall, the evidence is not strong enough to recommend active video games as health interventions in schools |
| (Gao et al., 2015[148]) | 35, 1985-2015 | Meta-analysis | Assesses literature on the effects of active video games on children's health-related outcomes | Compared with sedentary behaviours, games had large effect on health outcomes such as energy expenditure (effect size, Hedge's g = 2.74); comparison between games and field-based activity had null to moderate effect size; authors concluded games can be good addition to traditional physical activity/sport in children especially in lieu of sedentary time |
| (Kostyrka-Allchorne, Cooper and Simpson, 2017[69]) | 76 | Systematic review | Assesses literature on television watching and children's cognitive and behavioural outcomes | Effects depend on individual characteristics of children (e.g. age of exposure matters - benefits of educational television may be higher in early childhood than for school-age children), type of exposure (i.e. foreground or background), amount of exposure etc.; what children watch may be more important than how much they watch |