Digital Technology and Brain

Mehdi Tehrani-Doost, M.D.

Professor of Child and Adolescent Psychiatry &

Cognitive Neuroscience

Tehran University of Medical Sciences

Digital Technologies

- In recent years, the proliferation of digital tools, such as smartphones, social media platforms, and artificial intelligence technologies, started a significant paradigm shift in our interaction with information

Digital Technologies

- The impact of digital tools on brain function and cognition is a complex and interesting area of study that has prompted extensive research by researchers.
- There has been found several cognitive areas influenced by digital technologies

Attention

- The rapid rise of digital tools has brought about new challenges in maintaining sustained focus and have made it easier than ever to be constantly and perpetually distracted.
- Excessive smartphone use is associated with poorer attentional control (De-Sola Gutiérrez et al., 2016).

Attention

- The constant notifications, updates, and scrolling feeds can draw individuals' attention away from important tasks and create a state of perpetual partial attention.
- A study by Kross et al. (2013) revealed that passive use of Facebook predicted decreased wellbeing and increased feelings of distraction and inattention.

Attention

- One of the most significant challenges of digital tools is attentional overload.
- Attentional overload occurs when the demands of the environment exceed the capacity of an individual's attentional resources.
- The digital world presents a wide range of stimuli, all of which compete for an individual's attention (Shanmugasundaram 2023)

Attention

- One factor that contributes to attentional overload is the huge volume of information available.
- Research shows that notifications and alerts from digital tools can disrupt attention and impair cognitive performance (Iqbal and Horvitz, 2007).
- An average person checks their phone at least 85 times per day (Andrewsetal.,2015)

Attention

- The phenomenon of "continuous partial attention" is a symptom of attentional overload in the digital world (Stone, 2007).
- Continuous partial attention refers to the state of continuously dividing and shifting one's attention across multiple tasks or stimuli and only partially engaging in any one of them.
- This practice can lead to a superficial understanding of information

Attention

- This can be characterized by the constant urge to stay connected and keep up with various sources of information, often driven by the "fear of missing out" or FOMO (Przybylskietal.,2013).
- Continuous partial attention is closely related to the influence of digital technologies (Oulasvirta et al., 2012).

Attention

- In addition to continuous partial attention, the digital world can also contribute to attentional overload through multitasking.
- Multitasking involves the simultaneous performance of two or more tasks, which can reduce the efficiency and accuracy of attentional processing (Rosen et al., 2013).

Attention

- Heavy multi taskers performed worse on a task that required sustained attention than those who were light multi taskers (Ophir et al., 2009).
- Children who used digital tools for more than 2h per day had lower scores on cognitive tests than those who used them less (Firth et al., 2019).

Attention

- Moreover, the constant urge to stay connected and respond to notifications can lead to distracted real-life in person conversations and create a diminished sense of presence even in face-to-face interactions
- thereby making difficult deep engagement and empathy in interpersonal relationships (Turkle, 2011).

Attention

- One of the most significant factors is the intentional design of digital devices and platforms.
- Many digital devices and platforms are designed specifically to be highly engaging, using features such as notifications, alerts, personalized content, reminders and gamification to capture, retain and maintain users' attention (Dabbish et al., 2011).

Attention

- The reason for the link between technology use and attention problems is uncertain, but might be attributed to repetitive attentional shifts and multitasking, which can impair executive functioning (Nikkelen SW, 2014)
- Moreover, when people are constantly using their technology, they have fewer opportunities to interact offline and allow their brain to rest in its default mode (Greicius MD, 2003)

Attention

- A 2014 meta-analysis indicated a correlation between media use and attention problems (Anderson M, Jiang J. Teens 2018)
- A survey of adolescents without symptoms of ADHD at the start of the study indicated a significant association between more frequent use of digital media and symptoms of ADHD after 24 months of follow-up (Ra CK, Cho J, 2018)
- This association has been identified in people at any age (Schou Andreassen C, 2016)

Attention

- A reciprocal relationship, with higher digital media use predicting increased ADHD symptoms,
- and higher ADHD symptoms predicting increased digital has also been reported (Sibley and Coxe, 2018; Adelantado Renau et al., 2019)
- suggesting that excessive digital media use and ADHD symptoms may reinforce each other in a complex manner.
- Correlations have also been observed between screen media use and ADHD symptoms in children and adolescents (Ra et al., 2020).

Attention

- Cain et al.(2016) reported an association between increased media multitasking and poorer working memory performance and lower academic outcomes.
- In addition, college students with increased levels of Facebook usage demonstrated worse outcomes on cognitive tasks such as free recall activities (Frein et al., 2013).

Attention

- Although video games can improve certain aspects of attention, such as selective attention and visual-spatial processing,
- excessive use may also lead to attentional difficulties, such as reduced sustained attention and increased distractibility, particularly in children (Bavelier et al., 2010).

Decision-making

- Increasing internet usage has led to more informed decision making due to a broader range of accessible data.
- However, the overwhelming volume of information available can lead to information overload, complicating the decision-making process and potentially causing decision paralysis (Eppler and Mengis, 2004).

Decision-making

- In one study, participants who spent more time on social networking sites showed a higher level of cognitive overload, leading to a decrease in their ability to make decisions (Junco and Cotten, 2012).
- This finding highlights the importance of limiting digital use to avoid cognitive overload, which can impair decision making skills.

Decision-making

- Digital distractions are another aspect of technology that can impact decision making.
- Continuous digital distractions might reduce the cognitive capacity for careful deliberation, leading to more impulsive decisions (Duke and Montag, 2017).
- Participants who were interrupted by a text message while performing a decision-making task showed a decrease in the quality of their decisions, (Mark et al., 2017)

Decision-making

- In addition, digital use can lead to a decrease in critical thinking skills, which can further impair decision-making abilities.
- Participants who were exposed to social media posts with misleading information showed a decrease in their ability to critically evaluate the information presented, leading to impaired decision-making skills (Aïmeur et al., 2023).

Decision-making

- Smartphone addiction has been associated with reduced activity in the prefrontal cortex, which is responsible for decision-making and impulse control (Lin et al., 2015).
- Internet addiction was associated with reduced gray matter density in the brain's frontal cortex (Chen et al., 2023).

Impaired emotional and social intelligence

Impaired emotional and social intelligence

- Kirsh and Mounts (2007) explored the hypothesis that playing videogames would interfere with the ability to recognize emotions conveyed through facial expressions.
- They examined the effects of playing videogames on recognition of facial expressions of emotions in 197 students (ages 17 to 23 years).

Impaired emotional and social intelligence

- Participants played violent videogames before watching a series of faces expressing either angry or happy faces.
- Then participants were asked to quickly identify the emotion while the facial expression changed.
- The authors found that happy faces were identified faster than angry faces,
- and that playing violent videogames delayed happy face recognition time (Kirsh and Mounts, 2007) .

Impaired emotional and social intelligence

- Internet addiction is associated with decreased empathy, which is an important component of social cognition (Tao et al., 2010).
- Excessive use of social networking sites is associated with decreased social skills and a decreased ability to recognize facial emotions (Błachnio et al., 2016).

Impaired emotional and social intelligence

- Individuals who frequently engage in media multitasking have reduced gray matter density in the anterior cingulate cortex,
- a brain region associated with cognitive and emotional regulation (Loh and Kanai, 2014).
- Participants who reported using Facebook more frequently also had lower gray matter density in the anterior cingulate cortex, (Kanai et al., 2012).

Impaired emotional and social intelligence

- Neuroimaging have shown that individuals with problematic internet use exhibit structural and functional changes in the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC).
- These areas of the brain are critical for higher cognitive functions such as decision-making,
- impulse control, and emotion regulation

Impaired emotional and social intelligence

- a study found that heavy social media use was associated with decreased gray matter volume in the amygdala, a brain region involved in emotion regulation (Montag et al., 2017).
- Another study found that participants who were heavy users of video games had smaller gray matter volume in the hippocampus,
- a brain region involved in emotional memory (Kühn and Gallinat, 2014).

Impaired emotional and social intelligence

- People with internet addiction show impairment of white matter fibers in the brain connecting regions involved in generations of emotions and cognitive control as well (Zhou et al., 2011).
- Furthermore, frequent exposure to emotionally arousing content, such as social media posts or online news, can disrupt emotional regulation processes
- and contribute to heightened stress, anxiety, and depressive symptoms.

Impaired emotional and social intelligence

- Excessive social media use is associated with increased emotional reactivity and decreased emotional recovery,
- indicating difficulties in regulating emotional responses (Puukko et al., 2020).

Neural responses to online social rejection

- Using functional MRI (fMRI), researchers have observed increased activity in the orbitofrontal cortex and insula after participants experienced exclusion, possibly signaling increased arousal and negative affect (Cacioppo, S. et al. 2013)
- whereas spending more time with friends reduced ACC response in adolescents to social exclusion *(Masten, C. L., 2012)*

Neural responses to online social rejection

- Neuroimaging studies revealed that, being rejected resulted in increased activity in the medial frontal cortex, in both adults *(Achterberg, M., 2016)*
- and children *(Achterberg, M. et al. 2017)*
- the studies suggest that adolescents show stronger rejection expectation than adults,
- and ACC and medial frontal cortex are critically involved when processing online exclusion or rejection.

Neural responses to online social acceptance

- Likewise, being socially accepted through likes in the chat room task resulted in increased activity in the ventral striatum in children *(Achterberg, M. et al. 2017),*
- adolescents *(Gunther Moor, B., 2010)*
- and adults *(Achterberg, M., 2016)*

Neural responses to online social acceptance

- This response is blunted in adolescents who experience depression *(Silk, J. S. et al.2014)*
- or who have experienced a history of maternal negative affect *(Tan, P. Z. et al. 2014)*

Neural responses to online social acceptance

- In a controlled experimental study, adolescents showed more activity in the ventral striatum when viewing images with many vs. few likes,
- and this activation was stronger for older adolescents and college students compared to younger adolescents *(Sherman, L. E. 2017)*

Impaired emotional and social intelligence

- Spending extensive periods of time with digital media translates to spending less time communicating face to face
- The American Academy of Pediatrics has recommended that parents limit screen time for children aged 2 years or younger, when the brain is particularly malleable (American Academy of Pediatrics 2001)

Adverse impact on cognitive and brain development

Adverse impact on cognitive and brain development

- Increased screen time (and less reading time) has been associated with poorer language development and executive functioning, particularly in very young children (Horowitz-Kraus T, 2018)
- as well as poorer language development in a large cohort of minority children (Duch H, 2013)
- In infants, increased screen time was one of several factors that predicted behavioral problems (McDonald SW, 2018)

Adverse impact on cognitive and brain development

- For infants 6 to 12 months, increased screen time was linked to poorer early language development (Tomopoulos S, 2010)
- In children of preschool age and older, digital media directed toward active learning can be educational, but only when accompanied by parental interaction (Radesky JS, 2016)

Adverse impact on cognitive and brain development

- In a study of children aged 8 to 12 years, more screen and less reading time were associated with decreased brain connectivity between regions controlling word recognition and both language and cognitive control (Horowitz-Kraus T, 2018)

Adverse impact on cognitive and brain development

- Structurally, increased screen time relates to decreased integrity of white-matter pathways necessary for reading and language (Hutton JS, 2019)
- A recent review on brain development simply noted that DM's effects can be both positive and negative (Wu, D., 2023).

Impact on cognitive and brain development

- This inconsistency in findings can be attributed to several factors:
- First, the general term '**digital media**' encompasses a wide range of activities,
- Therefore, it is crucial to differentiate between various digital activities (Nivins, 2024)

Impact on cognitive and brain development

- the age of the participants is a significant factor.
- For example, research by Orben et al. in 2022 showed that social media use could negatively affect psychological well-being during particular developmental stages (Orben, A., 2022).

Impact on cognitive and brain development

- In another study, Soares et al. found that boys who spent more time watching television or playing video games at 11 years old,
- and more time using computers at 11 and 15 years old, showed improved working memory performance at 22 years old (Soares, P. S. M., 2021).
- However, this association was not observed in girls

Impact on cognitive and brain development

- Third, is the conflation of evidence from cross-sectional and longitudinal studies in reviews.
- Cross-sectional studies can identify correlations but cannot establish causality.
- Whereas longitudinal studies may even yield opposite results.
- For example, a longitudinal study found a negative correlation between time spent playing video games and intelligence (Sauce, B., 2022).

Impact on cognitive and brain development

- However, when controlling for baseline cognition and other background variables, the longitudinal analysis revealed that playing video games positively influenced changes in intelligence.

Impact on cognitive and brain development

- In one cross-sectional study of healthy children ages 8–12, time spent reading was positively correlated with higher functional connectivity between the Brodmann Area 37 and left-sided language, visual, and cognitive control regions,
- but screen time was related to lower connectivity between the left visual word form area and regions related to language and cognitive control (Horowitz-Kraus and Hutton, 2017).

Impact on cognitive and brain development

- In one study to find the relationship between Social Media Activity (SMA) and brain structures (the Adolescent Brain Cognitive Development Study)
- there was little evidence that SMA contributes to brain structure characteristics that can be related to internalizing behaviors (Paulus et al 2019)

Impact on cognitive and brain development

- However, the authors found a strong relationship to externalizing psychopathology.
- Thinner occipital cortices and smaller volume in orbitofrontal areas as well as thinner hippocampi and smaller inferior-temporal cortical volumes, showed greater levels of externalizing psychopathology (Paulus et al 2019)

Impact on cognitive and brain development

- In 2023, Miller et al. assessed the impact of Digital Media on functional connectivity over 2 years in a cohort of over 4000 children (Miller 2023).
- They reported no effects exceeding a size of 0.2, the predetermined threshold for significance.

Impact on cognitive and brain development

- In a large prospective cohort study, Nivins (2024) studied the long-term effects of DM usage on the development of the cortex, striatum, and cerebellum across three time points in children aged 9 to 11 years (Nivins 2024).
- Despite the initial hypothesis, they found that DM usage did not significantly alter the development of the global cortical surface area or striatum volume

Impact on cognitive and brain development

- However, children who devote more time to playing video games had a weak increase in cerebellum volume during the critical developmental window of development
- while those who spent more time using social media had a subtle decrease in cerebellum volume (Nivins 2024).

Impact on cognitive and brain development

- The cerebellum is a core component of the neural circuitry underpinning many cognitive deficits including
- working memory, response inhibition, attention shifting, and processing of rewards and temporal information (Durston 2011,; noreika 2013).

Impact on cognitive and brain development

- The cerebellum is sensitive to environmental exposures both prenatally, as demonstrated by studies of maternal alcohol, maternal diabetes, hypoxia, and postnatal glucocorticoid exposure (Nivins 2023),
- and postnatally (Cavanagh, J. et al. 2013)

Impact on cognitive and brain development

- In conclusion Nirvins (2024) found that individual DM usage did not alter the development of cortex or striatum volumes.
- However, high social media usage was associated with a statistically significant change in the developmental trajectory of cerebellum volumes (Nivins 2024)

Technology Addiction

Technology Addiction

- Internet addiction has been associated with reduced attention span and working memory as well as impaired decision-making, specifically in the area of risk assessment (Dong et al., 2013).
- Smartphone addiction is associated with decreased cognitive function (Lee et al., 2017)
- and deficits in attention and executive function such as inhibition and working memory (Lin et al., 2015).

Technology Addiction

- Addictive behaviors have been tied to changes in the brain’s reward system.
- The brain’s reward system plays a crucial role in regulating motivation, decision-making, and self-control.
- Digital technology, can hijack this reward system,
- leading to potential challenges in self-control and psychological regulation.

Technology Addiction

- Research has shown that excessive digital use, particularly related to activities such as social media and gaming, can trigger addictive behaviors by activating the brain's reward circuitry.
- This activation is mediated by the release of dopamine, a neurotransmitter associated with pleasure and reward (Báez-Mendoza and Schultz, 2013).

Technology Addiction

- Excessive online gaming has been linked to increased activation of the reward system, (Kuss et al., 2014).
- Studies have demonstrated that heavy digital media use is associated with lower levels of reward self-control.

Technology Addiction

- Individuals who frequently engage in media multitasking exhibited reduced reward self-control,
- leading to impulsive decision-making and decreased academic performance (Wilmer et al., 2017).

Technology Addiction

- Adolescents with internet addiction exhibited decreased gray matter density in several brain areas, including the dorsolateral prefrontal cortex (DLPFC) and the rostral ACC (Yuan et al., 2011).
- The DLPFC is implicated in executive functions such as decision making and cognitive control, whereas the ACC is involved in emotion processing and regulation

Technology Addiction

- In one study with 18 year-old college students, individuals with internet gaming addiction showed less gray matter volume in bilateral anterior cingulate cortex, precuneus, supplementary motor area, superior parietal cortex,
- left dorsal lateral prefrontal cortex, left insula,
- and bilateral cerebellum than matched controls (Wang et al., 2015).

Technology Addiction

- Among young adult female habitual internet users, more gray matter volume of bilateral putamen and right nucleus accumbens (subcortical)
- and lower gray matter volume of orbitofrontal cortex (cortical) were associated with more frequent use (Altbacker et al., 2016).

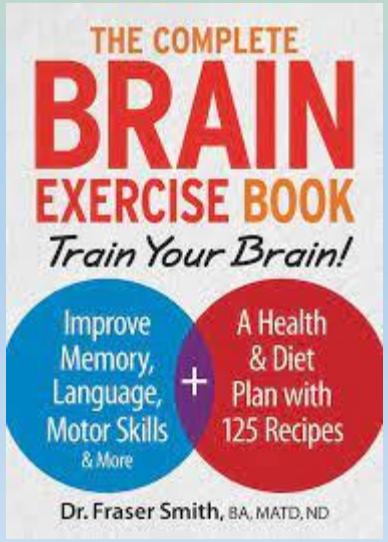
Technology Addiction

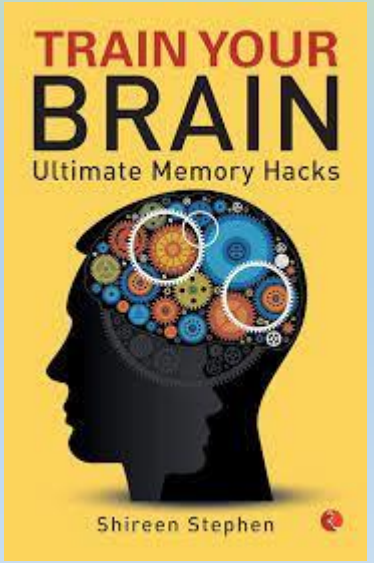
- Apart from structural and functional changes, alterations in the functional connectivity between these brain regions have also been observed.
- Individuals with internet gaming addiction showed altered resting-state functional connectivity between several regions, including the ACC and the PFC which is implicated in cognitive control and emotional regulation (Hong et al., 2013).

Brain-health benefits of digital technology

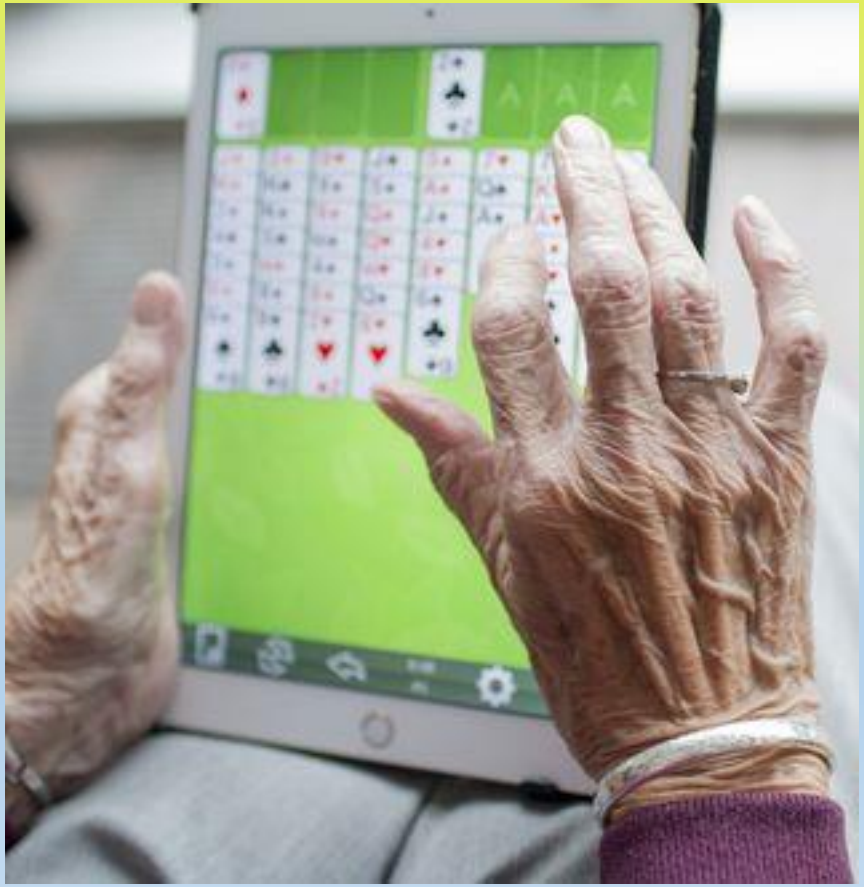
Brain-health benefits of digital technology

- Despite these potential harmful brain-health effects of digital technology, emerging evidence points to several benefits for the aging brain in particular,





- including opportunities for brain-strengthening neural exercise, cognitive training,
- and the online delivery of mental-health interventions and support (Small, 2020).



STRATEGIES	BRAIN-HEALTH PROMOTING TARGETS
Online searching	Neural activation of circuits controlling decision-making and complex reasoning
Cognitive training games	Global cognition, memory (immediate, delayed, and working), attention, learning abilities
Racecar videogames with distracting road signs	Multitasking skills
N-back task training games	Working memory, fluid intelligence
Action videogames	Visual attention, reaction time, task-switching abilities
Monitoring apps	Heart rate, breathing patterns
Psychotherapy, educational apps	Mood, sleep, social support

Table I. Health-promoting digital technology strategies for the aging brain.

Thank You for Your Attention