DIGITAL COGNITION AND DEMOCRACY INITIATIVE

ATTENTION

HOW DIGITAL TECHNOLOGIES INFLUENCE WHAT WE NOTICE, WHAT WE FOCUS ON, AND HOW WE LEARN

THE DIGITAL COGNITION AND DEMOCRACY INITIATIVE

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About the Digital Cognition and Democracy Initiative

Digital technology has become a fixture in everyday life. The digital technology landscape has dramatically shifted, catering to individualized neurochemical reinforcement. Information mediation is now fast-paced, high-volume, low-friction, and extra-sensorial, garnering increasing concern about the impacts digital ubiquity is having on democracy.

Documented risks to the individual include impacts on mental health, particularly among young people; the proliferation of false information; and an overreliance on outsourced information. Impacts at the individual level cumulatively manifest in societal level concerns, such as affective polarization–defined as the tendency to distrust people from the opposite end of the political spectrum–and risks to public health as a consequence of disinformation campaigns. While digital technologies are not the sole cause of these concerns, the role they play is significant. A sound ability to update one's beliefs and to engage in constructive discourse are key elements of civic engagement and therefore healthy democracy. These skills rely on a concert of cognitive processes that are now influenced by rapid and extensive technology proliferation. The urgency of exploring this problem has grown as the risks to individual and societal well-being have become more evident.

This report is part of a series examining the effects digital technologies have on the following cognitive processes: "Memory," "Attention," and "Reasoning." The broader report series includes three additional papers looking at some of the society-level cognitive and democratic impacts of technology, titled: "Modulating Trust," "Shortcutting Critical Thinking," and "Exploiting Emotions." We have also compiled a capstone report, "Rewired: How Digital Technologies Shape Cognition," and a review of the literature on technology and cognition detailing many of the sources used for our analyses.

A note on methods

This report is informed by guidance from IST coalition members, but it is primarily derived from past and current cognitive science research findings relevant to the human relationship with digital technologies. It is not a synthesis of all available cognitive science research on technology. Rather, it is a selection of literature that best captures how digital technologies impact cognitive processes in ways that are in turn important for a healthy democracy.

The Relationship Between Digital Technologies and Cognitive Processes

Why attention & technology?

This report examines the impact that technology has on the cognitive function of attention. It provides a working definition of attention within a cognitive science context, including the distinction between overt and covert attention. It summarizes findings that elucidate how attention is affected by the passive and active consumption of technology. Two common forms of active consumption are also examined in more detail: multitasking and gaming. This review provides introductory insight into how human attention is being affected by digital technologies, and concludes with a brief discussion on the implications of this research.

Advances in computational power and networked technologies have ushered in an era of constant connectivity. The flashy and captivating design of media technologies have made our phones powerhouses of information and social connection. According to research from the Reuters Institute, the smartphone is now the primary way people access daily news.[1] Furthermore, they found that for those under 30, visual networks, such as TikTok and Instagram, are proving to be critical channels for information.[2] The bells and whistles that decorate today's technologies, and the omnipresent nature of digital media, raise questions about the ways focus is being held hostage, distracted, extracted, or enhanced. This report confirms that current research finds a strong relationship between the use of technologies and shifts in attentional behaviors.

Key findings in this report indicate that attention may be affected by digital technologies in the following ways:

- **Distraction from critical tasks:** The presence of a phone or the sound of a phone ringing distracts a driver enough to impact their performance while driving a car.[3] Immersive

[1] Nic Newman et al., "Digital News Report 2022," *Reuters Institute*, accessed August 14, 2022, 2, https://reutersinstitute.politics.ox.ac.uk/digital-news-report/2022.
[2] Ibid.
[3] Radoslaw Zajdel et al., "The Sound of a Mobile Phone Ringing Affects the Complex Reaction Time of Its Owner," *Archives of Medical Science* 8, no. 5 (2012): 892-898.

digital experiences, coupled with expanding connectivity and computational power, surround users psychologically.[4]

- **Information foraging:** Historically, the human dopaminergic system evolved around the desire-and-reward cycle of food-foraging and eating.[5] The impulse to seek information or to skim through digital content more passively is rooted in the dopaminergic feedback system, which motivates neurological and behavioral patterns that evolved around food-foraging activity.[6,7]
- **Division of attention:** Digital technologies seem to encourage and facilitate multitasking and rapid task switching, which may influence attentional resource allocation and abilities or reduce the ability to maintain focus on a single task.[8] Brasel and Gips found that subjects switched their attention between television and smartphone use at a rate of four times per minute.[9]
- **Neurological consequences:** Extensive screen time among adolescents is correlated with atrophy of gray matter areas of the brain attributed to information processing; atrophy of white matter areas attributed to communication between different parts of the brain; reduced cortical thickness attributed to impaired cognitive performance; and, in the case of gaming, brain changes similar to those caused by drug addiction.[10]

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[4] Susanne E. Baumgartner, "The Relationship Between Media Multitasking and Executive Function in Early Adolescents," *The Journal of Early Adolescence* 34, no. 8 (2014): 1120-1144; Roy Pea et al., "Media Use, Face-to-Face Communication, Media Multitasking, and Social Well-Being Among 8-to-12-Year-Old Girls," *Developmental Psychology* 48, no. 2 (2012): 327.

[5] Thomas T. Hills, "Animal Foraging and the Evolution of Goal-Directed Cognition," *Cognitive Science* 30, no. 1 (2006): 3-41, https://doi.org/10.1207/s15516709cog0000_50.

[6] Ibid.

[7] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016); Peter Pirolli and Stuart Card, "Information Foraging," *Psychological Review* 106, no. 4 (1999): 643, https://psycnet.apa.org/doi/10.1037/0033-295X.106.4.643.

[8] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016).

[9] S. Adam Brasel and James Gips, "Media Multitasking Behavior: Concurrent Television and Computer Usage," *Cyberpsychology, Behavior, and Social Networking* 14, no. 9 (2011): 527-534. https://doi.org/10.1089/cyber.2010.0350.

[10] Victoria L. Dunckley, "Gray Matters: Too Much Screen Time Damages the Brain," *Psychology Today*, February 27, 2014. See also: Yan Zhou et al., "Gray Matter Abnormalities in Internet Addiction: a Voxel-Based Morphometry Study," *European Journal of Radiology* 79, no. 1 (2011): 92-95, https://doi.org/10.1016/j.ejrad.2009.10.025; Kai Yuan et al., "Microstructure Abnormalities in Adolescents with Internet Addiction Disorder," *PloS One* 6, no. 6 (2011): e20708, https://doi.org/10.1371/journal.pone.0020708; C. B.Weng et al., "A Voxel-Based Morphometric Analysis of Brain Gray Matter in Online Game Addicts," *Zhonghua Yi Xue Za Zhi* 92, no. 45 (2012): 3221-3223; C. B. Weng et al. "Grijze Stof en Witte Stofafwijkingen bij Online Game-verslaving," *Eur J Radiol* 82, no. 8 (2013): 1308-1312; Fuchun Lin et al., "Abnormal White Matter Integrity in Adolescents with Internet Addiction Disorder: A Tract-Based Spatial Statistics Study," *PloS One* 7, no. 1 (2012): e30253, https://doi.org/10.1371/journal.pone.0030253; Soon-Beom Hong et al., "Decreased Functional Brain Connectivity in Adolescents with Internet Addiction," *PloS One* 8, no. 2 (2013): e57831, https://doi.org/10.1371/journal.pone.0057831; Anyi Yang et al., "Longer Screen Time Utilization is Associated with the Polygenic Risk for Attention-Deficit/Hyperactivity Disorder with Mediation by Brain White Matter Microstructure," *EBioMedicine* 80 (2022): 104039, https://doi.org/10.1016/j.ebiom.2022.104039; John S. Hutton et al., "Associations Between Screen-Based Media Use and Brain White Matter Integrity in Preschool-Aged Children," *JAMA Pediatrics* 174, no. 1 (2020): e193869-e193869; Yunqi Zhu et al., "Molecular and Functional Imaging of Internet Addiction," *BioMed Research International* 2015 (2015); Chih-Hung Ko et al., "Brain Activities Associated with Gaming Urge of Online Gaming Addiction," *Journal of Psychiatric Research* 43, no. 7 (2009): 739-747; Doug Hyun Han et al., "Brain Activity and Desire for Internet Video Game Play," *Comprehensive Psychiatry* 52, no. 1 (2011): 88-95; and Aviv Weinstein et al., "New Developments in Brain Research of Internet and Gaming Disorder," *Neuroscience & Biobehavioral Reviews* 75 (2017): 314-330.

- **Disordered attention:** Research has found correlations between high frequencies of checking social media and a higher likelihood of developing ADHD-like symptoms.[11]

Most research in this area is in the early stages and the findings provided here are likewise provisional. More research and study replication is needed to have confidence in the generalizability of these conclusions. However, some clear patterns are emerging that warrant deeper analysis of the broader impacts that technology exerts on individuals in democratic societies and on democracy itself.

Attention Defined

Attention is essential for learning and memory formation. Contemporary cognitive science operates with William James's 1890 definition of attention: "It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalocalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others."[12] Cognitive psychology has since systematically substantiated his early description. This report addresses two different attention functions: 1) how information is processed to perform a task, and 2) how cognitive effort is passively allocated to certain stimuli in any given environment.

According to the widely-cited 2001 Sohlberg and Mateer model, there are five types of attention: focused, sustained, selective, alternating, and divided. We focus here on selective attention because that is where most relevant research has been done. Selective attention, as Sohlberg and Mateer write, "refers to the ability to maintain a behavioral or cognitive set in the face of distracting or competing stimuli."[13] There are broadly two categories of selective attention: overt attention and covert attention. Overt attention is primarily visual and measured via eye movements. Covert attention is also visual attention but does not involve eye movement.

Overt attention is typically visual and triggered by bright or contrasting colors, movement, or other visual physical qualities. This primal form of attention evolved to be very sensitive. Overt attention can also be triggered by an already-understood deeper meaning, such as a personal preference or "scene schemas"—an observer's knowledge about what is contained in a familiar visual context.[14]

Overt attention is best understood with reference to working memory. Working memory is "the system or systems that are assumed to be necessary in order to keep things in mind while

[11] Chaelin K. Ra et al., "Association of Digital Media Use with Subsequent Symptoms of Attention-Deficit/Hyperactivity Disorder Among Adolescents," *Jama* 320, no. 3 (2018): 255-263, https://doi.org/10.1001/jama.2018.8931.
[12] William James et al., *The Principles of Psychology*, Vol. 1, no. 2. (London: Macmillan, 1890): 403-404.
[13] McKay Moore Sohlberg and Catherine A. Mateer, eds, *Cognitive Rehabilitation: An Integrative Neuropsychological Approach* (New York: Guilford Press, 2001): 129.
[14] E. Bruce Goldstein, *Cognitive Psychology: Connecting Mind, Research and Everyday Experience*, 4th ed. (Boston: Cengage Learning, 2014): 97.

performing complex tasks such as reasoning, comprehension, and learning."[15] Attention, particularly overt attention, helps to sustain working memory (think of reading visual text). Cognitive scientist Alan Baddeley developed a model of working memory that usefully highlights the interconnected nature of cognitive functions in prioritizing certain stimuli and updating information stored in short-term memory to optimize for the completion of everyday tasks. His model deems this concert of cognitive functions involved in working memory an "attentional control system" (See Figure 1).[16] Researchers Gazzeley and Rosen developed a subsequent model of cognitive control that suggests devotion of attention to any one piece of information is a process informed not just by cognitive capacity (as explained by Badeley's model), but also by higher-order desires and goals.[17] Although these two models are not perfectly compatible, they are complementary; each one is useful for understanding how external digital forces affect attention as a cognitive process. (For an analysis of digital influence on long-term memory please see the paper in this series, "Memory.")

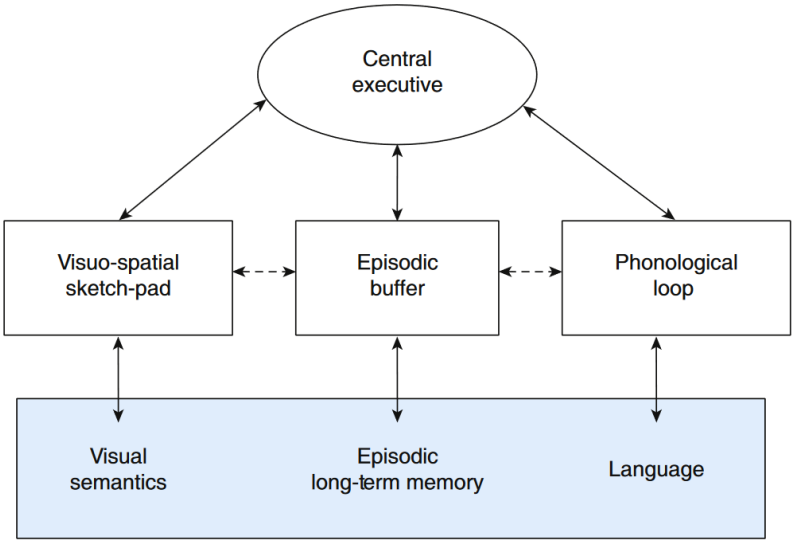

Figure 1: Baddeley's Working Memory Model. A later development of the multicomponent model. Includes links to long-term memory and a fourth component, the episodic buffer that is accessible to conscious awareness. This report will focus on long-term memory, as the use of short-term memory has strong ties to attention.[18]

Covert attention refers to visual attentional shifts without eye movement. If we understand our focus as a spotlight, how we allocate our attention to objects on the periphery of our focal point are influenced not necessarily by distance, but by whether the object exists within the object of

[15] Alan Baddeley, "Working Memory," *Current Biology* 20, no. 4 (2010): R136, https://doi.org/10.1016/j.cub.2009.12.014.
[16] Alan Baddeley, *Working Memory, Thought, and Action*, Vol. 45 (Oxford: Oxford University Press, 2007).
[17] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016): 29.
[18] Figure 1 Diagram: Short Term Memory Refers to the Visuo Spatial Sketchpad and Phonological Loop (i.e., visual and auditory short term memories). Baddeley, "Working Memory," R138.

focus.[19] If one's focal point is the center of a photograph on one's Facebook feed, one might be more likely to notice the tree on the far right side of the photo than the number of likes below the photo, despite the fact that the number of likes and the tree are equidistant from the visual focal point. The clever and deliberate use of lines and shading to draw boundaries around certain pieces of information are user experience design practices guided by such psychological principles.[20] The aforementioned models are helpful for framing the subsequent discussion around how the digital technologies we engage with every day shape our attention and therefore how we think.

How Do Digital Technologies Affect Attention?

Our senses, particularly sight, play a major role in directing attention. Dramatic technological shifts towards fast-paced, high-sensory experience with clever visual interfaces and complementary audio have made engaging with digital media and communications technologies a constant, irresistible temptation. These digital technologies pervade not just social settings but also education and work settings. The primary culprits are digital communications and entertainment technologies. The subsequent sections of this report review how digital technologies influence attention.

Cognitive scientists Adam Gazzaley and Larry Rosen point to a critical shift in technological design which set the foundation for important changes in the attentional behaviors of our time:

[19] Robert Egly et al., "Shifting Visual Attention Between Objects and Locations: Evidence from Normal and Parietal Lesion Subjects," *Journal of Experimental Psychology: General* 123, no. 2 (1994): 161.
[20] Yan Zhou et al., "Gray Matter Abnormalities in Internet Addiction: A Voxel-Based Morphometry Study," *European Journal of Radiology* 79, no. 1 (2011): 92-95; Norbi Gaal, "UX & Psychology Go Hand in Hand — Introduction to Human Attention," *Medium*, January 11, 2018, https://uxdesign.cc/ux-psychology-go-hand-in-hand-introduction-to-human-attention-a70ffd2c4289.

"It all started with the graphical user interface that took us from the flat, two-dimensional text-based environment that operated on a line-by-line basis similar to a typewriter, to a small picture depicting an operation or program. From there it was a short hop to a completely multisensory world appealing to all of our visual, auditory, and tactile or kinesthetic senses. We now see videos in high definition, often in simulated 3D. We hear high-definition stereo sounds that feel as crisp as sounds in the real world. Our devices vibrate, shake, rattle, and roll, and our attention is captured."[21]

- *Adam Gazzaley and Larry D. Rosen, "The Distracted Mind: Ancient Brains in a High-Tech World."*

In this respect, the rich sensorial experience of engaging with modern media often plays on our visual and auditory senses, enticing users incrementally, but consistently, to engage with different facets of the digital media experience. These behaviors are best encapsulated in what cultural anthropologist and DCDI coalition member Natasha Dow Schüll terms ludic loops: "the repeating cycles of action created by digital interactive media such as video games, slot machines, apps, and websites, owing to certain design characteristics."[22] "It is standard practice to strategically fine-tune a user's digital experience by adopting design features which will lead to increased engagement–the digital designer's intended behavioral outcome.[23] The commercialization of the web, otherwise known as the "attention economy," has made adopting these design practices lucrative for technology companies.[24] The subsequent sections will discuss how navigating contemporary digital media, with all its bells and whistles, influences our attention.

[21] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016).
[22] Natasha Dow Schüll, "Ludic Loops," (Skeptech Lecture Event, WFMU, New Jersey, May 24, 2016). See also: Natasha Dow Schüll, *Addiction by Design: Machine Gambling in Las Vegas* (Princeton: Princeton University Press, 2012); Natasha Dow Schüll, "Stuck in the Machine Zone: Your Sweet Tooth for 'Candy Crush,'" *NPR*, June 7, 2014, https://www.npr.org/sections/alltechconsidered/2014/06/07/319560646/stuck-in-the-machine-zone-your-sweet-tooth-for-candy-crush; and Adam L. Alter, *Irresistible: The Rise of Addictive Technology and the Business of Keeping Us Hooked* (New York: Penguin Press, 2017).
[23] Joe Leech, *Psychology for Designers* (Bristol: mrjoe press, 2017), https://mrjoe.uk/psychology-for-designers/.
[24] See IST's write-up on the attention economy: Alexa Wehsener, "Digital Threats to Democracy: Pay Attention," *Institute for Security and Technology,* July 2020, https://securityandtechnology.org/wp-content/uploads/2020/07/CNAS-Report-FTTD-Pay-Attention-3.pdf.

Passive & Active Consumption: The Dopamine System

On average, Americans check their phones 344 times a day and 74% of Americans cite unease with leaving their phones at home.[25] A common new fixture of contemporary life is passive yet habitual information "foraging."[26] Akin to walking through a hall of sales vendors seeking to tempt you to purchase their item, the various applications on our personal devices strategically employ clever design choices in an effort to capture—and hold—user attention. In passively navigating our everyday information ecosystems, digital cues are tailored to trigger our "overt attention." These "attentional capture" tactics prey on humans' innate attraction to colorful and flashy visuals.[27] Gazzaley and Rosen speak to an experience familiar to the modern smartphone users:

"As you glance at your iPhone you see little red circles with white numbers indicating that something awaits you: four unread email messages, ten Facebook notifications, and so many reminders that your mind is overwhelmed with which icon to tap first. Your iPad does the same, as does your laptop, which particularly taunts you with numerical notifications of unread messages, flashing icons telling you that you need to back up your computer files, and on and on."[28]

- *Adam Gazzaley and Larry D. Rosen, "The Distracted Mind: Ancient Brains in a High-Tech World."*

Research has found that even when someone driving a car is not actively or visually engaging with a smartphone, the mere sound of a phone ringing can significantly impact driving performance, as it attracts and harnesses attention resources.[29]

Passive consumption accounts for only a fraction of daily engagement with digital technologies. Most engagement involves active consumption, or goal-oriented behaviors. The desire to seek out information is driven by the dopamine reward system in the brain. Dopamine is a neurotransmitter that plays a major role in the experience of satisfaction, as well as many essential brain functions. Historically, the human dopaminergic system evolved around the

[25] Trevor Wheelwright, "2022 Cell Phone Usage Statistics: How Obsessed Are We?" *Reviews.Org*, January 24, 2022, https://www.reviews.org/mobile/cell-phone-addiction/.
[26] Thomas T. Hills, "Animal Foraging and the Evolution of Goal-Directed Cognition," *Cognitive Science* 30, no. 1 (2006): 3-41, https://doi.org/10.1207/s15516709cog0000_50.
[27] Brian A. Anderson et al., "Learned Value Magnifies Salience-Based Attentional Captured," *PloS One* 6, no. 11 (2011): e27926.
[28] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016): 110.
[29] Radoslaw Zajdel et al., "The Sound of a Mobile Phone Ringing Affects the Complex Reaction Time of Its Owner," *Archives of Medical Science* 8, no. 5 (2012): 892-898.

desire-and-reward cycle of food-foraging and eating.[30] Research has found that the desire to seek out information for survival and sustenance can be described much like food foraging tactics. Thoroughly "foraged" food patches will often lead to a strategic shift to a different food patch.[31] Similarly, studies show that people will move on from an information source once it has given them a justifiable amount of information relative to the effort or time they expend acquiring that information.[32] The impulse to acquire useful information, or in cases of more passive engagement, to skim or scroll for interesting or valuable information, is deeply rooted in the neuropsychological dopaminergic feedback system. Current digital technologies have thus become intimately involved with this information-seeking neurological and behavioral pattern.

Multitasking

Current technologies increasingly facilitate rapid switching between interfaces and information sources. Adam Brasel and James Gips found that subjects switched their attention between television and smartphone use at a rate of four switches per minute, totaling 120 switches over 27 minutes.[33] Within a smartphone alone there are typically many applications to choose from, many designed to vie for attention with attractive imagery, integrated audio, and the use of interstitial pop-ups.[34] Such features play on the more primal, bottom-up attentional reflexes that are rooted in the dopaminergic cycle discussed above.[35] Features often additionally engage top-down attentional logics. Top-down attention is triggered by appeals to one's prior knowledge or expectations.[36] Consider the following example:

[30] Thomas T. Hills, "Animal Foraging and the Evolution of Goal-Directed Cognition," *Cognitive Science* 30, no. 1 (2006): 3-41, https://doi.org/10.1207/s15516709cog0000_50.
[31] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016); Peter Pirolli and Stuart Card, "Information Foraging," *Psychological Review* 106, no. 4 (1999): 643, https://psycnet.apa.org/doi/10.1037/0033-295X.106.4.643.
[32] Ibid.
[33] S. Adam Brasel and James Gips, "Media Multitasking Behavior: Concurrent Television and Computer Usage," *Cyberpsychology, Behavior, and Social Networking* 14, no. 9 (2011): 527-534, https://doi.org/10.1089/cyber.2010.0350.
[34] Joe Leech, *Psychology for Designers* (Bristol: mrjoe press, 2017), https://mrjoe.uk/psychology-for-designers/.
[35] Tristan Harris, "How Your Brain Is Getting Hacked: Facebook, Tinder, Slot Machines," *Big Think,* 2017, https://www.youtube.com/watch?v=JgkvTRz_Alo.
[36] John D. Lee et al., *Designing for People: An Introduction to Human Factors Engineering* (Charleston: CreateSpace, 2017).

"As he tried to log off at 7:13 a.m. on New Year's Day last year, Josh Streeter, then an Uber driver in the Tampa, Fla., area, received a message on the company's driver app with the headline 'Make it to $330.' The text then explained: 'You're $10 away from making $330 in net earnings. Are you sure you want to go offline?' Below were two prompts: 'Go offline' and 'Keep driving.' The latter was already highlighted."[37]

- *Noam Scheiber, "How Uber Uses Psychological Tricks to Push Its Drivers' Buttons."*

Bottom-up attentional stimuli include the decision to highlight "keep driving" by changing the physical qualities of the content to visually stand out. The use of "income targeting" strategies to encourage continued driving is a prime example of top-down attentional stimuli.[38] Technology designers use both attentional capture strategies in designing digital experiences to engage and enthrall users.[39]

Digital design practices informed by psychological principles result in powerfully immersive digital experiences. When that enticing usability is coupled with expanding connectivity and computational power, users are psychologically surrounded by standing invitations to engage with various channels of information. This is now so commonplace that these technologies are at times referred to as "multitasking facilitators."[40] Concern over the prevalence of multitasking or "task switching" behaviors center around the risks these behaviors pose to one's ability to accomplish a goal with limited distraction or interference.[41] Researchers Ophir and their coauthors studied such impacts and found that high-media-multitaskers (HMMs) were less likely to suppress impulses for task switching or to ignore irrelevant representations in memory.[42] They propose that differences in information processing between high-media-multitaskers (HMMs) and low-media-multitaskers (LMMs) could be explained by

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[37] Noam Scheiber, "How Uber Uses Psychological Tricks to Push Its Drivers' Buttons," *The New York Times*, April 2, 2017, https://www.nytimes.com/interactive/2017/04/02/technology/uber-drivers-psychological-tricks.html.
[38] Colin Camerer et al., "Labor Supply of New York City Cabdrivers: One Day at a Time," *The Quarterly Journal of Economics* 112, no. 2 (1997): 407-441.
[39] Noam Scheiber, "How Uber Uses Psychological Tricks to Push Its Drivers' Buttons," *The New York Times*, April 2, 2017, https://www.nytimes.com/interactive/2017/04/02/technology/uber-drivers-psychological-tricks.html; Natasha Dow Schüll, "Stuck in the Machine Zone: Your Sweet Tooth for 'Candy Crush,'" *NPR*, June 7, 2014, https://www.npr.org/sections/alltechconsidered/2014/06/07/319560646/stuck-in-the-machine-zone-your-sweet-tooth-for-candy-crush. See also: Natasha Dow Schüll, *Addiction by Design: Machine Gambling in Las Vegas* (Princeton: Princeton University Press, 2012); Adam L. Alter, *Irresistible: The Rise of Addictive Technology and the Business of Keeping Us Hooked* (New York: Penguin Press, 2017).
[40] Susanne E. Baumgartner et al., "The Relationship Between Media Multitasking and Executive Function in Early Adolescents," *The Journal of Early Adolescence* 34, no. 8 (2014): 1120-1144, https://doi.org/10.1177/0272431614523133; Roy Pea et al., "Media Use, Face-to-Face Communication, Media Multitasking, and Social Well-Being Among 8-to 12-Year-Old Girls," *Developmental Psychology* 48, no. 2 (2012): 327, https://psycnet.apa.org/doi/10.1037/a0027030.
[41] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016); Gary W. Small et al., "Brain Health Consequences of Digital Technology Use," *Dialogues in Clinical Neuroscience* 22, no. 2 (2022), https://doi.org/10.31887/DCNS.2020.22.2/gsmall.
[42] Eyal Ophir et al., "Cognitive Control in Media Multitaskers," *Proceedings of the National Academy of Sciences* 106, no. 37 (2009): 15583-15587, https://doi.org/10.1073/pnas.0903620106.

LMMs' tendency towards top-down attentional processing and by HMMs' vulnerability towards external stimuli interference and distraction. A propensity to engage in bottom-up attentional behaviors is associated with higher distractibility.[43]

Engagement in task switching or multitasking behaviors clearly influences attentional resource allocation and abilities.[44] The causal direction, however, is still unclear: do tech-based multitasking behaviors lead to a decline in attentional capability, or does reduced attentional capability increase the propensity to engage in high-media-multitasking?[45] More research is needed here. However, one study on this topic, by Sanbonmatsu et al., found that those most capable of multitasking behaviors were the least likely to engage in multitasking, while those that do engage in multitasking behaviors exhibited traits such as impulsivity and sensation-seeking.[46] Whether it is individual traits or the technologies that drive people to multitask, it is clear that the information ecosystem supported by powerful mobile computing devices provides people with opportunities to engage in these behaviors more readily.

Despite findings that engaging with digital media may reduce a user's ability to focus on a single task, there has been research to suggest that HMMs may just be engaging in a different type of focus: breadth-biased cognitive control. Education technology researcher Dr. Lin Lin Lipsmeyer describes this form of cognitive control as "treating all of the information in front of them with equal (or almost equal) amounts of attention instead of focusing their attention steadily on a particular task."[47] Moreover, researchers Kelvin F. H. Lui and Alan C. N. Wong found that HMMs outperformed LMMs in high-sensory integration tasks which required the processing of a variety of modalities.[48] A third group of researchers led by Joaquin Anguera exhibited how neuroplasticity of the prefrontal cortex, the source of much executive cognitive control, can function in this context. They found that after a group of older adults (aged 60-85 years) received training on sign reading and concurrent driving, their ability to perform both tasks simultaneously improved.[49] In this case, multitasking behavior training in an appropriate context yielded benefits. Lin Lispmeyer; Lui and Wong; and Anguera and others' findings cumulatively

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[43] Ryota Kanai et al., "Distractibility in Daily Life is Reflected in the Structure and Function of Human Parietal Cortex," *Journal of Neuroscience* 31, no. 18 (2011): 6620-6626, https://doi.org/10.1523/JNEUROSCI.5864-10.2011.
[44] Adam Gazzaley and Larry D. Rosen, *The Distracted Mind: Ancient Brains in a High-Tech World* (Cambridge: MIT Press, 2016).
[45] Susanne E. Baumgartner et al., "The Relationship Between Media Multitasking and Executive Function in Early Adolescents," *The Journal of Early Adolescence* 34, no. 8 (2014): 1120-1144, https://doi.org/10.1177/0272431614523133; Winneke A. Van Der Schuur et al., "The Consequences of Media Multitasking for Youth: A Review," *Computers in Human Behavior* 53 (2015): 204-215, https://doi.org/10.1016/j.chb.2015.06.035.
[46] David M. Sanbonmatsu et al., "Who Multi-Tasks and Why? Multi-Tasking Ability, Perceived Multi-Tasking Ability, Impulsivity, and Sensation Seeking," *PloS One* 8, no. 1 (2013): e54402, https://doi.org/10.1371/journal.pone.0054402.
[47] Lin Lin, "Breadth-Biased Versus Focused Cognitive Control in Media Multitasking Behaviors," *Proceedings of the National Academy of Sciences* 106, no. 37 (2009): 15521, https://doi.org/10.1073/pnas.0908642106.
[48] Kelvin F.H. Lui and Alan C-N. Wong, "Does Media Multitasking Always Hurt? A Positive Correlation Between Multitasking and Multisensory Integration," *Psychonomic Bulletin & Review* 19, no. 4 (2012): 647-653; David A. Ziegler et al., "The Acute and Chronic Impact of Technology on Our Brain," *The Wiley Handbook of Psychology, Technology, and Society* (Hoboken: Wiley-Blackwell, 2015): 3-19.
[49] Joaquin A. Anguera et al., "Video Game Training Enhances Cognitive Control in Older Adults," *Nature* 501, no. 7465 (2013): 97-101, https://doi.org/10.1038/nature12486.

attest to the need to explore what positive outcomes might come from developing a different type of attentional capability, and in which contexts such capabilities are helpful or harmful to goal attainment.[50]

Gaming

Anguera and others' aforementioned training is a prime example of the use of gaming to train up on cognitive control skills.[51] C. Shawn Green and Daphne Bavelier have similarly explored the effects of playing video games (i.e. Grand Theft Auto 3, Half-Life, Counter-Strike, and Super Mario Cart) and found improvements in attention and quicker information processing.[52] A later study found that playing video games contributes to enhanced covert attentional capabilities and an ability to successfully manage dual-task performance.[53] Chisholm and colleagues built on Green and Bavelier's work by investigating whether action video game players employ more top-down or bottom-up attentional strategies.[54] They found evidence which suggests that video game players exhibit strong endogenous control, meaning they are more likely to engage in top-down attentional strategies such that they have a muted sensitivity to distractor stimuli (which are meant to trigger bottom-up attentional strategies) compared to non-video game players. As promising as these findings are, the transferability of these skills outside of a gaming setting remains to be seen.[55]

Child psychiatrist Victoria Dunckley reviewed the impacts that extensive screen time have on the developing adolescent brain. She found atrophy of gray matter areas of the brain attributed to information processing; atrophy of white matter areas of the brain attributed to communication between different parts of the brain; reduced cortical thickness contributing to impaired cognitive performance; and brain changes similar to those caused by drug addiction caused by

[50] Lin Lin. "Breadth-Biased Versus Focused Cognitive Control in Media Multitasking Behaviors," *Proceedings of the National Academy of Sciences* 106, no. 37 (2009): 15521, https://doi.org/10.1073/pnas.0908642106; Kelvin F.H. Lui and Alan C-N. Wong, "Does Media Multitasking Always Hurt? A Positive Correlation Between Multitasking and Multisensory Integration," *Psychonomic Bulletin & Review* 19, no. 4 (2012): 647-653; Joaquin A. Anguera et al., "Video Game Training Enhances Cognitive Control in Older Adults," *Nature* 501, no. 7465 (2013): 97-101, https://doi.org/10.1038/nature12486.
[51] Joaquin A. Anguera et al., "Video Game Training Enhances Cognitive Control in Older Adults," *Nature* 501, no. 7465 (2013): 97-101, https://doi.org/10.1038/nature12486.
[52] C. Shawn Green and Daphne Bavelier, "Action Video Game Modifies Visual Selective Attention," *Nature* 423, no. 6939 (2003): 534-537, https://doi.org/10.1038/nature01647.
[53] C. Shawn Green and Daphne Bavelier, "Effect of Action Video Games on the Spatial Distribution of Visuospatial Attention," *Journal of Experimental Psychology: Human Perception and Performance* 32, no. 6 (2006): 1465, https://doi.org/10.1037/0096-1523.32.6.1465.
[54] Joseph D. Chisholm et al., "Reduced Attentional Capture In Action Video Game Players," *Attention, Perception, & Psychophysics* 72, no. 3 (2010): 667-671, https://doi.org/10.3758/APP.72.3.667.
[55] E. Pasquinelli, "Are Digital Devices Altering Our Brains," *Scientific American,* September 11, 2018, https://www.scientificamerican.com/article/are-digital-devices-altering-our-brains.

gaming addiction.[56] Despite reflecting an extreme end of the behavioral spectrum, a recent meta-analysis estimated a prevalence of worldwide gaming addiction at 2.8% (accounting for the 28 studies which adhered to representative sampling methods), thus potentially accounting for over 220 million people globally.[57]

Gaming addiction is but one area of concern when it comes to technology use. In a two-year study of 2,587 adolescents who did not initially exhibit significant symptoms of attention deficit hyperactivity disorder (ADHD), researchers found correlations between higher frequency in checking social media and a higher likelihood of developing ADHD-like symptoms.[58] Noting a very interesting relationship, Andreassen et al. explored whether ADHD or obsessive compulsive disorder (OCD) symptoms could explain variance in social media or video game addiction.[59] They ultimately found that ADHD explained more variance in social media addiction than in video gaming, proposing that the omnipresence and high-sensory experience of social media platforms potentially lead to compulsive use. In conducting a meta-analysis of 48 studies, scientists Nikkelen and their coauthors found a small significant relationship between media use and ADHD-related behaviors but called into question the variability in how ADHD was defined across studies.[60] It is critical to note that in most studies, parent or self-report surveys on ADHD-related behaviors were used as the primary source of data. Furthermore, most studies conducted were largely correlational. Greater variety in data sources, clarifying the causal relationship of potential confounding variables (e.g. OCD, depression, anxiety) and attempts to

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[56] Victoria L. Dunckley, "Gray Matters: Too Much Screen Time Damages the Brain," *Psychology Today*, February 27, 2014. See also: Yan Zhou et al., "Gray Matter Abnormalities in Internet Addiction: A Voxel-Based Morphometry Study," *European Journal of Radiology* 79, no. 1 (2011), https://doi.org/10.1016/j.ejrad.2009.10.025; Kai Yuan et al., "Microstructure Abnormalities in Adolescents with Internet Addiction Disorder," *PloS One* 6, no. 6 (2011): e20708, https://doi.org/10.1371/journal.pone.0020708; C.B. Weng et al., "A Voxel-Based Morphometric Analysis of Brain Gray Matter in Online Game Addicts," *Zhonghua Yi Xue Za Zhi* 92, no. 45 (2012): 3221-3223; C.B. Weng et al., "Grijze Stof en Witte Stofafwijkingen bij Online Game-Verslaving," *Eur J Radiol* 82, no. 8 (2013): 1308-1312; Fuchun Lin et al., "Abnormal White Matter Integrity in Adolescents with Internet Addiction Disorder: A Tract-Based Spatial Statistics Study," *PloS One* 7, no. 1 (2012): e30253, https://doi.org/10.1371/journal.pone.0030253; Soon-Beom Hong et al., "Decreased Functional Brain Connectivity in Adolescents with Internet Addiction," *PloS one* 8, no. 2 (2013): e57831, https://doi.org/10.1371/journal.pone.0057831; Anyi Yang et al., "Longer Screen Time Utilization Is Associated with the Polygenic Risk for Attention-Deficit/Hyperactivity Disorder with Mediation by Brain White Matter Microstructure," *EBioMedicine* 80 (2022): 104039, https://doi.org/10.1016/j.ebiom.2022.104039; John S. Hutton et al., "Associations Between Screen-Based Media Use and Brain White Matter Integrity in Preschool-Aged Children," *JAMA Pediatrics* 174, no. 1 (2020): e193869-e193869; Yunqi Zhu et al., "Molecular and Functional Imaging of Internet Addiction," *BioMed Research International* (2015), https://doi.org/10.1155/2015/378675; Chih-Hung Ko et al., "Brain Activities Associated with Gaming Urge of Online Gaming Addiction," *Journal of Psychiatric Research* 43, no. 7 (2009): 739-747, https://doi.org/10.1016/j.jpsychires.2008.09.012; Doug Hyun Han et al., "Brain Activity and Desire for Internet Video Game Play," *Comprehensive Psychiatry* 52, no. 1 (2011): 88-95, https://doi.org/10.1016/j.comppsych.2010.04.004; and Aviv Weinstein et al., "New Developments in Brain Research of Internet and Gaming Disorder," *Neuroscience & Biobehavioral Reviews* 75 (2017): 314-330, https://doi.org/10.1016/j.neubiorev.2017.01.040.

[57] Hee Sun Kim et al., "Prevalence of Gaming Disorder: A Meta-Analysis," *Addictive Behaviors* 126 (2022): 107183, https://doi.org/10.1016/j.addbeh.2021.107183.

[58] Chaelin K. Ra et al., "Association of Digital Media Use with Subsequent Symptoms of Attention-Deficit/Hyperactivity Disorder Among Adolescents," *Jama* 320, no. 3 (2018): 255-263, https://doi.org/10.1001/jama.2018.8931.

[59] Cecilie Schou Andreassen et al., "The Relationship Between Addictive Use of Social Media and Video Games and Symptoms of Psychiatric Disorders: A Large-Scale Cross-Sectional Study," *Psychology of Addictive Behaviors* 30, no. 2 (2016): 252, https://doi.org/10.1016/j.addbeh.2016.03.006.

[60] Sanne W.C. Nikkelen et al., "Media Use and ADHD-Related Behaviors in Children and Adolescents: A Meta-Analysis," *Developmental Psychology* 50, no. 9 (2014): 2228.

pinpoint causal relationships will provide a richer understanding of the relationship between media use and addictive behaviors. Research thus far indicates a strong relationship between the use of technologies and shifts in attentional behaviors.

Conclusion

Digital dings and timely, tailored push notifications have become the ambient sounds of day-to-day life. Digital devices are loaded with features designed to elicit rewarding sensations with every minute engagement.[61] Users are thus enticed into ludic loops, those "repeating cycles" of stimulus and reward. With such a rich and engaging ecosystem driven by digital systems, it is important to scrutinize how it influences the basic cognitive process of attention.

Digital technologies pose three risks to our attention:

1. They interrupt our ability to complete everyday tasks.
2. They nurture addictive behaviors.
3. They affect cognitive processes that generate healthy democratic discourse, such as decision-making and reasoning.

These findings point to two areas for further exploration: 1) how digital systems and online content are designed in regards to their flashiness and visual attractiveness; and 2) how content is messaged to invoke strong personal feelings based on one's prior knowledge or experience. These two areas of exploration speak to our susceptibility to top-down versus bottom-up attentional stimuli.

There is also much more room for further exploration regarding the potential positive impacts digital technologies can have on human attention. Beyond the context of gaming, for example, it would be valuable to gain a deeper understanding of the situations in which "breadth-biased cognitive control" might be a superior cognitive strategy to that of the traditional notion of "cognitive control."

The ability to focus is a prerequisite for absorbing relevant signals for long-term information storage, judgment formation, and goal-aligned decision-making. Attention plays a key role as our cognitive traffic director. Compromising this cognitive function can affect other cognitive processes, including—critically—cognitive processes that more directly impact civic engagement: e.g. reasoning, judgment, and decision making. The importance of this cannot be overstated, and must be understood in the context of the additional papers in this series,

[61] Trevor Haynes, "Dopamine, Smartphones & You: A Battle for Your Time," *Science in the News* (blog), May 1, 2018. https://sitn.hms.harvard.edu/flash/2018/dopamine-smartphones-battle-time/; Simon Parkin, "'Has Dopamine Got Us Hooked on Tech?" *The Observer*, March 4, 2018, https://www.theguardian.com/technology/2018/mar/04/has-dopamine-got-us-hooked-on-tech-facebook-apps-addiction.

"Memory" and "Reasoning." Findings from these reports frame the current understanding of how digital technologies influence these cognitive mechanisms. This information can inform how policymakers, technologists, and academics might be able to devote their energy towards both bolstering individual cognitive resilience and strengthening pro-social technological design practices during an age of systemic disinformation and affective polarization.

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