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Rethinking perception and cognition in the digital environment

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Undoubtedly, the future of humanity is digital. As we transition into this new technological era, we are confronted with many uncertainties. The digital environment, a relatively recent phenomenon, differs both qualitatively and quantitatively from other natural and social environments. Its ubiquity and rapid evolution, along with the ease of automating and replicating digital code, set the stage for significant impacts on human cognition and perception. This article conceptually explores the general characteristics of the digital environment, highlights its significance and relevance to cognitive science, summarizes a range of recent findings on the effects of digital technology on our cognitive and perceptual processes, and concludes with several hypotheses about the evolution of our minds in the digital future.

KEYWORDS
digital environment, digital future, computer technology, automation, multitasking, cognitive processes, evolution, adaptation

1 Introduction

All life forms exist within the environments they inhabit. With the emergence of the fields of ecological and environmental psychology around the period of the cognitive revolution in the sixties and seventies, the focus shifted toward understanding how various environments shape the human mind and behavior. The basic premise of these fields is that psychological phenomena cannot be understood without the context of the environment (Stokols, 1978; Gibson, 1979). The word *environment* itself comes from Old French, meaning "something that encircles" (Reber et al., 2009), and it is an essential variable in all psychological research. To varying degrees, animals engage with their physical surroundings and interact among themselves, creating an additional layer of social environment on top of the physical one (Proshansky et al., 1970). Humans, endowed with large brains and complex cultures, are capable of actively modifying their environments, even creating new ones. William James, one of the founders of modern psychology, early on recognized that "minds inhabit environments which act on them and on which they in turn react" (James, 1890, p. 6) implying that minds are not passive entities molded unidirectionally by their surroundings, but they actively produce artifacts, technologies, and behaviors that, in turn, change and reshape their environment. While physical and social environments have long been studied by cognitive sciences, digital technology presents new challenges for the evolution of the human mind.

The advent of digital computers and information theory in the 1940s–1950s serves as a striking example of humanity's capacity to modify the environment through technological means. This development marks a significant shift in the Anthropocene, because humans, for the first time in their history, created a digital code. Before that, human perception was solely adapted to environments where objects, beings, and surroundings were entirely physical, analog, and mechanical. The advancement of modern digital technologies introduced new types of digital objects, such as eBooks, websites, cryptocurrencies, and NFTs, as well as new beings like avatars, artificial intelligence chatbots, and video game characters. New technological environments emerged, such as the Internet, social networks, simulations, video games, augmented and virtual realities, all generated by binary code in specific portable or wearable hardware. The proliferation of digital technologies gave rise to *The Internet of Things*, changing the nature and functionality of many physical objects and machines by equipping them with sophisticated sensors and connecting them to a vast network of other (semi)autonomous intelligent devices. It seems that we are beginning to live side by side with countless interconnected intelligent machines with the capacity "to auto-organize, share information, data, and resources, reacting and acting in face of situations and changes in the environment" (Madakam et al., 2015, p. 165). According to the Digital 2023 Global Overview Report (DataReportal, 2023), in the last 10 years, people on average have spent between six and seven hours daily using the Internet, meaning almost half of their waking life is spent online. Close to 70% of the world population use mobile phones (5.44 billion people), and ∼65% (5.16 billion people) are online. The report indicates that individuals primarily use the Internet for gathering information, maintaining contact with their relatives, and for entertainment—thereby progressively transitioning their personal and social lives into the digital realm. As digital technology becomes increasingly integrated into daily life, understanding its impact on human cognition and perception becomes essential.

For that reason, the article first conjectures the nature of the digital environment itself, then reviews a selection of findings that give us an idea of the possible effects it has or could have on our cognition and perception. It is important, however, to point out that digital phenomena are very recent and yet to be scientifically described and understood. This article aims to explore such phenomena by offering a conceptual analysis and ends with several general predictions and hypotheses about the possible evolution of our minds in the context of the future digital world.

2 Properties of the digital environment

2.1 Dynamic, symbolic, immaterial

The physical environment formed and stabilized eons ago. Relative to human and animal lifespans, it undergoes very gradual and slow changes over time. Even though artifacts, natural objects, and living beings change their states constantly, they are generally perceived as having retained their fundamental physical properties. For instance, we expect an intact wine glass to maintain its size, shape, and color. If it remains unbroken, we anticipate that it will continue to function as a glass, even though it could become a different set of objects if broken. This holds true regardless of momentary perceptual fluctuations in the mind of the observer. On the other hand, the digital environment is distinctly different—it is fast, dynamic, constantly recreated, and continually changing in real time. Almost daily, new digital technologies are patented and introduced to the general population. In addition to the digital code, the associated hardware and various autonomous devices themselves become part of the physical and social environments, slowly introducing the machines as a nonbiological species. At the same time, despite the physicality of its hardware, the digital environment feels immaterial and amorphous (Bouwhuis, 2006; Crook, 2013). The digital code cannot be touched, but it can be felt and experienced in a deeply immersive way, mostly through forms of symbolic interactivity (Thierry, 2021). The dynamic digital objects are constructed using code and manipulated through a layer of digital symbols and interfaces (text, icons, menus, pointers, etc.), creating new digital forms of immaterial environmental *affordances* (Gibson, 1979).

2.2 Hyperconnected, hypersocial, spatiotemporally uniform

Media philosophers like Marshall McLuhan hypothesized that electronic media would compress time and space, effectively reducing all human interaction to a single place referred to as the "global village" (McLuhan, 1964). Indeed, digital technologies have created a hyperconnected world, effectively rendering physical and temporal distances trivial. Today, the majority of our communication and interaction occur through electronic devices, telecommunication services, and exponentially growing social networks (Dutta and Bilbao-Osorio, 2012). Current research indicates that, in the online realm as well, humans adhere to Dunbar's estimated average of 150 personal connections (Dunbar, 2018). Perhaps, this limit arises from the information-processing capabilities of the neocortex, which has evolved to accommodate typical group sizes in primates (*The Social Brain Hypothesis;* Dunbar, 1998). It remains to be seen whether, in the future, the neocortex will adapt to the numerous social encounters in the vast digital networks.

While digital networks may not have expanded the number of our social connections yet, they have fundamentally altered the spatiotemporal context in which these connections occur. By changing the spatiotemporal context, digital technology has significant potential to transform our spatiotemporal perception. Until now, all sensory, perceptual, cognitive, affective processes, and behaviors have evolved in a specific spatiotemporal context tied to the locomotion of animals in three dimensions. To solve the problem of orienting and moving through space, our brains have developed multiple neural spatial representations and mappings (Gross and Graziano, 1995; Rizzolatti et al., 1997) and complex neuromuscular mechanisms for sensing the body's position and movement (Proske and Gandevia, 2012). The spatial information is only relevant at a particular time, and even though we lack a dedicated sense, our perceptual systems are capable of temporal processing. Mechanisms have been proposed that link time to the synchrony of external and internal rhythms (Jones and Boltz, 1989), with the cerebellum and the basal ganglia being especially crucial in the timing of events, as part of a broad distributed cortical network (Ivry et al., 2002; Merchant et al., 2013). Yet, the concepts of space and time remain elusive in the digital domain. While physical space is limited and animals can only interact with their immediate surroundings at a given moment, digital space and time are virtually limitless. Individuals can affect locations far more distant than those near their own bodies. Someone might even be virtually present as a "digitalized self" at several geographical locations simultaneously, making the spatiotemporal factor often irrelevant (Chan, 2022).

2.3 Automated, multifunctional, personalized

The digital environment is rooted in automation and multifunctionality. With advancements in computer technology, the automation process has ascended to an entirely new level. The most prominent example is autonomous vehicles, which utilize intricate machine learning algorithms and advanced network communication, demonstrating advanced perceptual ability, planning, control, and real-time adaptation in various situations and contexts. Some market studies forecast a boom in autonomous vehicle sales, with an anticipated compound annual growth rate reaching 40.6% from 2023 to 2028 (SNS Insider, 2022), leaving little doubt that the future of transportation will be automated. In relation to human activity, automation has been defined as "the execution by a machine agent (usually a computer) of a function that was previously carried out by a human" (Parasuraman and Riley, 1997, p. 231). While automation offers significant benefits by relieving humans from physical—and, with digital technology, cognitive—efforts, little is known about its long-term effects on the human mind.

Perhaps human attention will be the first cognitive process to be affected by the processes of automation in the future digital environment. Automated systems, by assuming various tasks, create repetitive, low-variability environments that reduce the need for vigilance and sustained attention, leading to multiple forms of attentional inefficiencies. These conditions have often been examined in the context of human factors research in aviation, where researchers have described the phenomenon of automation-induced *complacency*, which has been implicated as an important factor in various transportation accidents and industrial disasters (Parasuraman et al., 1993). This issue arises when pilots and flight operators become excessively reliant on automated systems, failing to recognize errors within these systems. Studies indicate that complacency sets in as attention shifts from automated processes to other manual tasks, particularly under demanding multitasking conditions (Molloy and Parasuraman, 1996; Bailey and Scerbo, 2007; Parasuraman and Manzey, 2010). In addition to complacency, monotonous automation can also hinder human decision-making by promoting various forms of attentional bias or other forms of suboptimal utilization of attentional resources relative to productive tasks, such as mind wandering (Skitka et al., 1999; Thomson et al., 2015; Sauer et al., 2016; Gouraud et al., 2018).

Automation further lays a foundation for multifunctionality and multitasking, which are unavoidable in modern digital operating systems used in computers and smartphones, bringing additional implications for perception and cognition. These systems primarily feature graphical user interfaces full of interchangeable and overlapping windows. These rectangular screen areas represent different programs and areas of interest to which users switch and focus their attention. Empirical estimates of switching behaviors, quantified as on-screen window switches within a given period, vary across populations and tasks. They range from rapid switches every minute (Yeykelis et al., 2014) to an average of switches every six minutes (Rosen et al., 2013). These findings indicate that multitasking is the dominant mode of operation on digital devices (Judd, 2013). While the prevalence and utility of multitasking on digital devices are undeniable, they are often associated with poor performance and distractibility, particularly among heavy media multitaskers. This is attributed to interruptions in attentional, memory, and cognitive control processes (Ophir et al., 2009a; Cain and Mitroff, 2011; Uncapher et al., 2017). For instance, Ophir et al. (2009a) classified participants as heavy and light multitaskers based on a questionnaire and tested them using various cognitive control procedures, including task-switching abilities. Researchers observed differences in distractibility between both categories of multitaskers. More specifically, heavy multitaskers showed larger task switching costs compared to their light counterparts. Task switching involves controlled allocation of attention and cognitive resources between different tasks, and consequently, faster shifts to the relevant task and fewer distractions from irrelevant tasks indicate better cognitive control. Heavy multitaskers seem to prefer a breadth-based cognitive control over a more focused strategy and appear to experience greater bottom-up attentional capture from stimuli, which in turn impairs their ability to effectively filter out irrelevant distractors (Lin, 2009; Ophir et al., 2009a; Cain and Mitroff, 2011).

Furthermore, studies have indicated differences in brain structure and function between heavy and light media multitaskers. Specifically, individuals with higher scores on self-reported measures of distractibility have greater gray matter density in the region of the left superior parietal cortex (Kanai et al., 2011) and exhibit increased activity in the right prefrontal areas (Moisala et al., 2016). Heavy multitaskers also show reduced gray matter density in the anterior cingulate cortex (Loh and Kanai, 2014). Given the significance of the fronto-parietal brain networks in cognitive control and executive function, differences among multitasking types in these regions are to be expected (Marois and Ivanoff, 2005). Although such differences are generally based on correlational studies and don't necessarily imply causality between multitasking and changes in brain structures, these findings are indicative of the possible effects that digital technologies might have on populations already predisposed to multitasking and distractibility. At the same time, while frontal lobe areas exhibit remarkable capabilities for processing information, they are also identified as a central bottleneck that constrains our multitasking abilities (Dux et al., 2006). This makes them prime candidates for modification and adaptation in response to the future multitasking demands of the digital environment.

However, when defined as the simultaneous processing of multiple streams of information, the concept of multitasking is complex and diverse, making it difficult to devise a single procedure to measure all its behavioral and neural aspects. Many claims about multitasking originate from self-report questionnaires such as the Media Multitasking Index (MMI, Ophir et al., 2009a,b), which has recently been criticized for failing to capture all complexities of human multitasking behavior (e.g., see Fisher et al., 2023). Moreover, when multiple studies are compared in a meta-analysis, associations between media multitasking and distractibility yield small effect sizes at best (Wiradhany and Nieuwenstein, 2017), suggesting that we might need more sensitive and accurate methodologies to measure multitasking behavior in the digital domain. Finally, some studies emphasize the role of volition, noting performance differences based on whether individuals are forced to multitask or given the freedom to decide if they want to multitask or not (Kononova et al., 2016).

As a last point, while automation may impact cognitive functions, its influence extends well beyond reshaping human cognition. The automation inherent in computer algorithms facilitates the vast collection and analysis of human behavior data, and this data is frequently used to tailor services and user experiences to individuals by profiling them, consequently crafting a unique digital microenvironment for each person. Modern algorithms can continuously monitor and update user profiles, drawing from an extensive array of parameters and employing sophisticated machine and deep learning models. These models can sometimes become self-organized and transform into inaccessible "black boxes." As a result, digital automation could easily create distinct "realities" for each individual. In other words, while we might believe we are engaging with the same social network or platform like YouTube, the experiences are significantly varied for each of us due to personalized recommendations and curated content designed to maximize user attention and engagement (Harris, 2021). Unlike the physical environment, which remains universally accessible and constant for all but subject to individual interpretation, the digital environment actively and dynamically adjusts itself to each user. In this setting, it's not so much the individual interpreting the world as it is the world reshaping itself to accommodate the individual.

3 Cognition in the digital environment

Once we have described some basic properties of the digital environment, we will have a look at numerous studies that reveal a range of effects that extend across various cognitive domains. One such obvious case is the recent transition of text from paper to screens, which already seems to be changing reading and comprehension. Although the majority of people still prefer printed text (Woody et al., 2010), there is a strong cultural shift toward reading on electronic devices. However, the perceptual and cognitive qualities of printed text seem to differ from those of text displayed on screens. Behavioral experiments show that reading text on paper offers speed advantages, with readers typically reading 10%-30% faster compared to when the text is presented on screens (Dillon, 1992; Zaphiris and Kurniawan, 2001; Kerr and Symons, 2006, but see Kong et al., 2018 for lack of differences). Moreover, printed text exhibits advantages in reading comprehension and learning due to various factors. These include the difficulty in establishing temporality and locality on screen because of the absence of physical pages as location cues, as well as varying screen specifications such as resolution, font size, aliasing, and variations in contrast (Gould et al., 1987; Mangen et al., 2013, 2019; Annisette and Lafreniere, 2017; Ben-Yehudah and Eshet-Alkalai, 2021). Additionally, printed books are physical objects that can be experienced through multiple senses, including vision, touch, audition, and olfaction. Even the act of turning pages may serve as an action cue that further aids memory and learning. For example, students generally find it easier to concentrate when reading in print (Baron et al., 2017) and are more likely to learn effectively by taking notes longhand rather than typing on their laptops (Mueller and Oppenheimer, 2014). In short, printed text may facilitate multisensory learning (Shams and Seitz, 2008) by providing a variety of physical and contextual cues that aid memory and comprehension, which may not be easily transposed into the digital domain as of yet.

Furthermore, the differences between printed and digital text are not limited to the level of physical presentation. They also extend to functionality and operability. For instance, digital text can be selected, cut and, pasted, resized, manipulated in numerous other ways, and hyperlinked to other content. Hyperlinking, in particular, introduces nonlinearity in reading, placing a higher cognitive load on readers and their working memory (Niederhauser et al., 2000; DeStefano and LeFevre, 2007). The digital environment promotes reading behavioral patterns not available in print, such as quick scanning, superficial browsing/scrolling, emphasizing keywords and tagging, "bite-size" reading, and searching for specific information while disregarding the global context (Liu, 2005). When examined through classical memory frameworks that assume different levels of processing for given information (e.g., Craik and Lockhart, 1972), it seems that the digital environment does not favor deeper analysis, at least in the context of reading. However, deeper levels are necessary for the long-term retention of knowledge and critical thought. It is possible to suspect that the fast and dynamic digital stimuli, along with perceptual and social distractions, information overload, and operational costs, may interfere with attention, long-term memory, and reasoning (Annisette and Lafreniere, 2017; Carr, 2020). A recent meta-analysis has suggested additional reasons for the shallow processing of digital text, including mind wandering during screen-based reading, difficulty in maintaining focus, and heightened susceptibility to distractions (Clinton, 2019). Thus, the digital environment has the potential to alter reading behaviors and the capacity to process and comprehend text, with implications for future literacy.

Despite its effects on specific domains like reading, digital technology has the potential to impact much broader cognitive domains. Technological influences on humans are nothing new, and historically, we have consistently relied on technology, from early stone tools to modern computers, to reduce cognitive and motor demands, making it an integral part of our evolution and culture. However, most pre-digital technologies, being mechanical and analog, had limited capacities for information storage and processing, as well as a limited scope of use. People designed mechanical calculating devices, such as the abacus, and developed numerous methods for preserving and communicating information recorded on external physical mediums. The recent advent of digital technology has far surpassed analog technology in its capacity to store, process, and output information. It offers increasing generalizability and, in many cases, even outperforms humans. In a broad sense, digital technology is taking over many of the mind's tasks and leads to externalization and "cognitive offloading" (Risko and Gilbert, 2016; Eliseev and Marsh, 2021). Such processes interrupt the encoding of new information and make human memory systems dependent on technology. For instance, digital photography has made taking photos ubiquitous and very easy, but research shows that when people take photos of things, they generally remember about 14% less information about objects and their locations (Henkel, 2014). In fact, the "photo-taking-impairment" effect persists even when people are aware that the photos will not be available later (Soares and Storm, 2018). The phenomenon of recording events on devices externally also influences the content of autobiographical memory by modulating what people pay attention to (Eliseev and Marsh, 2021).

The Internet appears to have additional effects on human memory and learning. The possibility of searching for information online at any given time primes people to memorize less and to expect that everything will always be available by accessing the Internet (generally known as the "Google effect"; Sparrow et al., 2011). The digital environment, when it comes to information foraging, produces better memory for "where to find the information" rather than memory for the content itself. Relying excessively on Internet searches conditions people to access it even when asked a set of relatively easy trivia questions. This reliance also fosters an illusion of knowledge, which involves overestimating one's actual knowledge due to constant access to online information sources (Fisher et al., 2015; Storm et al., 2017). Smartphones appear to exacerbate the sense of false knowledge even further, as research indicates cognitive self-esteem scores are ∼10% higher for Internet searches performed on smartphones compared to searches conducted on laptops (Hamilton and Yao, 2018). The externalization and cognitive offloading of our mental processes into digital technologies may not only change how much we remember but also what we remember. This shift could make it more important to remember how to operate devices or where to find information, rather than remembering facts and content. In other words, digitalization has the potential to become a completely new epistemology engine through which we understand the world (Ihde, 2000).

Finally, digital technology is a source of endless stimulation. Nobel laureate Herbert A. Simon insightfully pointed out that the abundance of information carries a cost to our attention. According to him, "a wealth of information creates a poverty of attention" (Simon, 1971, p. 40). Digital devices constantly bombard our minds with notifications, serving as attention-capturing stimuli. Devices such as smartphones are so captivating to our attention that they deplete cognitive capacity merely with their presence (Ward et al., 2017). Smartphones reinforce checking habits, initiating sets of repetitive behaviors to reach for and engage with the device, often without clear goals (Oulasvirta et al., 2012). The fragmented nature of the Internet also contributes to a reduced attentional scope with prolonged use (Peng et al., 2018). The most common forms of Internet addiction are highly correlated with attention deficit hyperactivity disorders (ADHD), especially in young age (Yen et al., 2007; Wang et al., 2017).

4 Perception in the digital environment

Cognitive systems cannot be altered without corresponding changes in the underlying processes of perception. If we accept the hypothesis that the digital environment will have a profound effect on our cognition, we must assume that it will also alter our perception. Our perceptual systems have evolved as a function of the physical environment, but they will undoubtedly also need to adapt to the digital environment we've created. The fundamental question is: which properties of this environment will be most dominant and important, and which will become inputs for our perception to tune into and adapt to? Can our brains adapt as readily as they did to the inverted world in the eccentric prism experiments conducted by Stratton (1897) over a century ago? Will digital technology create new "epistemology engines" (Ihde, 2000), as many artificial physical technologies have done before, or will it lead to something entirely different?

Recent studies offer some insights into such questions, suggesting that digital technologies might indeed be altering perceptual processes in various ways. An exciting line of research is emerging from studies on video games, which provide convenient stimuli for investigating human perception within a digital environment. Video game players represent a group of individuals who are immersed in and exposed to intensive digital content for prolonged periods of time. This makes them a valuable resource for understanding any perceptual and sensory-motor changes that may result from gaming. For example, the pixelated content on computer screens has a higher orientation anisotropy compared to real natural objects present in our surroundings (Duggan and Gerhardstein, 2023). In other words, content displayed on computer screens is more uniform, more structured, and less varied in its layout, shape, and orientation than what would be seen in nature. This is relevant because the visual systems of animals and humans already exhibit a preference toward vertical and horizontal orientations over oblique ones, a phenomenon known as the "oblique effect" (Appelle, 1972). It is generally easier for people to perceive and recognize lines and shapes that are vertical or horizontal rather than those that are slanted. The canonical features of digital stimuli could potentially strengthen the oblique effect, as already demonstrated in groups asked to play the Minecraft video game (Hipp et al., 2020). In this study, the experimental group outperformed the controls in an orientation sensitivity test. Overall, the findings revealed that participants made initial saccades to horizontal or vertical lines ∼18% faster than to oblique ones. If we are permitted to speculate on the future of human vision, the uniformity inherent in digital environments could potentially prompt a reorganization of the visual cortex. This change might allocate even more neurons to the processing of vertical and horizontal lines at the expense of oblique ones, thereby diminishing our capacity to recognize irregular shapes in the future. In addition to their enhanced orientation sensitivity detection, video game players demonstrate greater precision in processing radial motion, likely due to specific action game designs that facilitate practice in these motions (Hutchinson and Stocks, 2013). They also excel at distinguishing targets from distractors, displaying superior visual acuity at higher spatial resolutions and showing resistance to interference from crowding. Importantly, these effects are not limited to regular players; they can also be induced in individuals who do not usually play games, following relatively brief training sessions with action games (Green and Bavelier, 2007). Moreover, it has been reported that video gaming enhances visual contrast sensitivity, signal detection, and temporal processing, improves multiple object tracking and saccadic speed, makes gamers better change detectors, and aids the control and efficacy of attention (Green and Bavelier, 2006; West et al., 2008; Li et al., 2009; Chisholm et al., 2010; Donohue et al., 2010; Clark et al., 2011; Mack and Ilg, 2014, but see Murphy and Spencer, 2009 for much smaller effects of gaming and failure to replicate many of the effects).

Perceptual interactions and experiences with video games and other digital media, especially during early developmental stages, may also result in enduring functional and structural reorganizations of the brain. Experience-dependent neuroplasticity continues into adulthood, and as an increasing proportion of the adult population engages with the digital environment, we can anticipate more prevalent brain changes as a result (May, 2011). For instance, individuals who played Pokémon in their childhood possess a reorganized ventral temporal cortex (an area associated with visual recognition) that continues to be attuned to the unique attributes of digital Pokémon creatures, even in their adulthood (Gomez et al., 2019). The cortical adaptations to digital technologies do not necessarily have to originate in childhood but can easily emerge during adulthood as well. One instance is the study by Gindrat et al. (2015), who reported observable differences in the somatosensory cortex activity, evoked from the fingertips of touchscreen users, compared to non-users. Excessive exposure to digital media during childhood, however, may have negative effects on the developing brain, disrupting the normal growth of brain structures associated with language and literacy. Unlike audio narratives and illustrations, for example, digitally animated stories do not provide the best preconditions for the development of language networks in the brain (Hutton et al., 2020a,b). In short, there is some initial evidence that video games fine-tune and speed up perception, or at least stimulate various perceptual and neural adaptations (Dye et al., 2009), but naturally more studies are needed.

In addition to potential effects on visual perception, digital technologies may be altering the way we perceive and experience others and ourselves. The boundaries between the physical and digital are getting blurred via the proliferation of personal digital devices, interconnected online as social networks, that increasingly mediate our interactions (Jordan, 2009). We are experiencing new emerging forms of "digitalized self" that exist in parallel to the physical self and sometimes interfere with it, with important implications for construals like self-concept, self-esteem, and identity (Chan, 2022). For instance, the so-called "Proteus effect" demonstrates that people's online avatars (digital self-representations) change the ways we disclose information about ourselves, how we interpret social distances, and how we negotiate with others (Yee and Bailenson, 2007). Furthermore, the enormous number of people we meet online far exceeds the number of people we meet offline, which inflates the social comparison and the negative effects on our well-being associated with it (Vogel et al., 2014; de Vries and Kühne, 2015). Finally, regarding immediate social perception, such as understanding people's emotions through digitally mediated communications (e.g., video chats) or the use of social media, the research literature indicates diminished mirror neuron system responses. This suggests a lesser understanding of others' motivations, intentions, and thoughts (Doheny and Lighthall, 2023).

Taking into account the aforementioned observations, however, it is essential to remain cautious in interpreting these findings. We need to scrutinize the generalizability of the effects of video games and digital technologies further, guard against publication bias and measurement errors, and devise methodologies that control the confounds potentially arising from our interactions with the non-digital environment (Hilgard et al., 2019). Although numerous studies suggest that gaming has positive effects on cognition and perception, it is important to note that technologically advanced video games are a relatively new phenomenon. Consequently, many of the cited findings should be viewed as preliminary and approached with caution. Critical analyses of existing research caution against accepting causal claims in many of these studies (e.g., Roque and Boot, 2018) and question the generalization of cognitive benefits observed in specific games to other areas of expertise (Gobet et al., 2014).

5 Conclusion and future directions

The physical environment surrounds our bodies, while the digital environment surrounds our minds. Characterized by dynamic, automatic, repetitive, addictive, ubiquitous, and immersive qualities, the digital environment holds tremendous potential to alter our perception, cognition, and underlying neural structures. It's already reshaping our social and personal lives, along with our cognitive processes, decisions, and behaviors. Identifying and understanding the adaptive and selective pressures created by the digital environment should be one of the main goals of future cognitive science. These pressures may significantly differ from those of the natural environment in which we have evolved.

If one were to speculate and hypothesize about perception in the digital future, we might expect several adaptations. Our visual perception might need to adjust to complex and visually crowded displays that favor conjunction searches, and it could become more tuned to emitted light rather than reflected light. Various perceptual thresholds might shift, aligning more with the discrete intensities found in the digital environment, as opposed to the continuous ones found in nature. We might find ourselves adapting more to 2D scenes, favoring monocular over binocular cues for depth. Alterations in the perception of object permanence could occur, among many other potential changes. On the cognitive level, we might anticipate more externalization and offloading of memory and computation into digital hardware, alterations to the sustained attention and vigilance due to automation, as well as adaptations that are better suited for searchability rather than for memorizing content. We may observe multitasking-driven adaptations to our attention and executive control mechanisms, coupled with alterations in our spatiotemporal processing. Lastly, our brains might need to adapt to more effectively process abstractions and symbols, navigate increasingly larger social networks, and possibly evolve representations of digital objects that don't have real counterparts in nature.

In conclusion, the future of humanity depends on how we adapt physically, biologically, perceptually, and socially to the digital environment. However, due to the recency of the digital phenomena and the lack of longitudinal studies, it is currently very difficult to determine with certainty in which direction our minds will evolve in the context of the new environment. The aim of this analysis is to inspire more research on the topic and to speculate on possible future developments in light of the limited evidence we have thus far. Only through careful framing and a detailed understanding of the properties, dynamics, and impacts of the digital environment can we ensure a prosperous future for humanity.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

AK: Conceptualization, Investigation, Writing—original draft, Writing—review & editing.

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