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REVIEW ARTICLE

Digital Environment's Potential to Modulate Altered Decision-Making Pathways and Processes in Autism Spectrum Disorder

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ABSTRACT: Autism spectrum disorder (ASD) is characterized by atypical cognition and behavioral patterns, including atypical decision-making, risk processing, and moral reasoning. The digital age is expanding, and so are its impacts, especially on individuals with ASD. Research suggests that digital environments can alter the expression of genes and the connectivity of brain regions associated with decision-making tasks in individuals with ASD. This limited review highlights some of the potential of digital environments to act as external modulators that could either intensify or mitigate the atypical decision-making patterns in ASD by influencing the genetic and neural pathways involved in decision-making. This paper reviews decision-making, ASD, and digital environments from a neurogenetic and epigenetic perspective. Understanding connections between digital environments and biological mechanisms behind decision-making in individuals with ASD can uncover new directions for therapy, education, and technological intervention for neurodivergent individuals.

KEYWORDS: Cellular and Molecular Biology, Genetics, Neuroscience, Autism Spectrum Disorder, Decision-Making, Prefrontal Cortex, Digital Environment.

Introduction

The digital world is rapidly expanding, and so is its integration into our everyday lives. This increasingly virtual, fast-paced, and cognitively demanding environment has raised the importance of understanding how digital environments impact human cognition, specifically decision-making. This is especially important for neurodivergent populations like individuals with autism spectrum disorder (ASD), a neurological disorder characterized by its effects on communication, learning, and behavior.[1] There is an ample literature base regarding the neurogenetic pathways underlying the typical decision-making process and how digital environments alter behavior,[2,3] and similarly, ample information exists regarding the decision-making susceptibilities of people with ASD.[4–6] Still, there is a lack of knowledge on how digital environments specifically influence these neurogenetic pathways to modulate decision-making in individuals with ASD. Understanding how digital environments interact with underlying biological mechanisms of decision-making in individuals with ASD is ripe for exploration.

Decision-making involves the interaction of cognitive, emotional, and reward-based mechanisms.[7] Research has shown that individuals with ASD differ in their decision-making process from neurotypical individuals.[8] In a small study of 78 adults, individuals with autism spectrum conditions frequently experienced several problems in decision-making and were more likely to avoid decisions.[9] These difficulties may be exacerbated by the unpredictability of social situations and the fact that individuals with ASD struggle with social cue processing.[8] This is further illustrated by ASD individuals' association with emotional signals having less impact upon their decision-making capabilities.[5] In another example, the decisions of neurotypical and neurodivergent individuals differed depending on the type of decision and the context of the situation. For instance, individuals with ASD, compared to neurotypical peers, were less averse to ambiguity in gain situations and more risk-averse in loss contexts, and they showed reduced sensitivity changes in different situations.[4] In this context, gain situations involve positive outcomes, while loss scenarios are negative contexts involving adverse consequences.

While many genes are involved with decision-making pathways, this review's focus examines catechol-o-methyltransferase (*COMT*), dopamine receptors D2 and D4 (*DRD2* and *DRD4*), and serotonin transporter solute carrier family 6 member 4(*SLC6A4*). Variations in these genes have been linked to ASD and other neurodevelopmental disorders. The expression of these genes plays a role in the functioning of the prefrontal cortex (PFC), a brain region involved with higher-order executive functions (including planning, judgment, and flexible thinking).[10] This highlights the PFC's role in decision-making.[11] Exploring these genes and these PFC pathways provides new insight into the decision-making process and how it can be modified.

Digital environments and their increasing pervasiveness create novel cognitive conditions that normalize rapid information processing, immediate rewards, consistent and constant stimulus, and desensitization to content.[12] These environments have the potential to influence reward sensitivity, attention allocation, and emotional regulation.[3] These functions are already heavily altered in individuals with ASD, lending plausibility to the notion that digital landscapes modulate certain decision-making tendencies in individuals with ASD.[2] Moreover, ASD individuals are especially susceptible to increased media use due to the highly appealing nature of digital devices.[13]

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People spend a significant amount of time immersed in digital technology, such as VR headsets and video games. Individuals with ASD, compared with neurotypical peers, demonstrate neurogenetic and neuroanatomical differences in decision-making pathways.[8,9] Examining the interaction of the digital environment with neurogenetic and neuroanatomical pathways increases the understanding of technology's impact on cognitive development and its impact on neurotypical and neurodivergent populations. In particular, it raises the question: how do digital environments influence the *COMT, DRD2, DRD4*, and *SLC6A4* genes and the prefrontal cortex in individuals with autism spectrum disorder?

This paper explores the possibility of digital environments modulating changes, neurogenetically or epigenetically, leading to further atypical alterations in the PFC of individuals with ASD. These alterations could further differentiate the decision-making capabilities of people with ASD. Future research could examine how these differences can be altered through exposure to digital environments. Understanding the interaction of digital environments and the underlying pathways in decision-making can provide new insight into the decision-making process of individuals with ASD and others with neurodevelopmental disorders. These perspectives offer profound implications for future therapy of ASD.

Neurogenetic pathways underlying decision-making:

Decision-making can be defined as the process of evaluating available information to consider potential outcomes and selecting the outcome that most closely aligns with a person's goal. Decisions, big or small, are made every day. This review looks into aspects of decision-making, namely cognitive control, risk evaluation, and reward processing of individuals with ASD, and now considers some genetic influences. Understanding typical decision-making helps with differentiating atypical decision-making, providing additional insight into ASD and how digital environments may influence associated mechanisms.

The prefrontal cortex (PFC) is the most forward (anterior) brain region, and it plays a significant role in several processes. The brain matures from the back to the front; thus, the PFC does not fully develop until early adulthood, around age twenty-five.[14] The PFC plays a central role in decision-making by controlling short-term behavior in pursuit of a long-term goal. Additionally, the PFC is involved in other executive functions, including working memory, planning, judgment, and flexible thinking.[15] These are complex cognitive functions, so the PFC is unlikely to be the sole brain region responsible for them; nevertheless, the PFC has a critical role. Furthermore, damage to the PFC can cause people to jump to conclusions and inhibit their ability to consider alternative possibilities.11 Studying digital media's connection with this brain region has strong potential for understanding how decision-making is modulated in ASD.

The *COMT* gene creates the COMT enzyme, which is crucial to the breakdown of dopamine and influences cognitive, executive, memory, and attentional functions.[16] DRD2 and DRD4 influence reward processing and risk evaluation. Variations in the density of DRD2 and DRD4 influence dopamine levels, influencing impulsivity.[17] Another study found a correlation between a polymorphism and poor executive functioning.[18] A different study found a lack of conclusive evidence that DRD variations hinder executive functions in a financial risk-taking setting.[19] Further study is required to examine these differences and add to the scarce literature base. The *SLC6A4* gene regulates serotonin reuptake, influencing emotional regulation and impulse control, two functions critical to decision-making. It is important to note that these are not the only genes and processes involved in decision-making. Genes such as the *BDNF*,[20] *DARPP-32*, and *5-HT2A* include associations with general decision-making.[21]

Let's look at particular details. The *COMT* gene influences the decision-making pathways in the brain by regulating dopamine levels in the prefrontal cortex.[22] Dopamine influences decision-making through dopaminergic signaling between the PFC and other brain regions, allowing for goal-oriented behavior.[22] A polymorphism is two or more common genes or DNA sequences within individuals. The *COMT* gene has a Val158Met polymorphism, meaning there is a substitution of a guanine with an adenine base at codon 158, which causes the amino acid to become a methionine (Met) instead of a valine (Val).[16] Studies have shown that individuals possessing the Met/Met version of this polymorphism made worse decisions than individuals with the Val/Val variant.[16] This polymorphism also correlated with worse emotional decision-making.[20]

Two other genes involved in dopamine regulation are the dopamine D2 and dopamine D4 receptors (*DRD2* and *DRD4*). The *DRD2* gene controls the density of D2 receptors in the PFC, and people with lower D2-receptor density tend to make impulsive decisions, to have reduced reward anticipation, and to be susceptible to addictions.[23] This suggests that the *DRD2* gene influences decision-making by increasing a preference for instant gratification. The *DRD4* gene's influence on dopamine contributes to risk-taking, novelty-seeking, addictive behavior, and impulsivity.[17] A common polymorphism in this gene is the 7-repeat allele of the exon 3 variable number tandem repeats (VNTR) alleles. This polymorphism is believed to influence dopamine transmission, decreasing the performance of executive functions by increasing impulsive actions.

Serotonin is another neurotransmitter that impacts decision-making. The *SLC6A4* gene (5-HTT) facilitates serotonin reuptake, the transportation of serotonin from synaptic spaces into presynaptic neurons. Serotonin is associated with decision-making, particularly learning from negative outcomes and positive reward signals, facilitating dopamine reward processing, and influencing attentional capacity.[21] A common genetic variation is the 5-HTTLPR polymorphism with a short (S) allele in the region. This polymorphism is associated with increased emotional reactivity and a heightened response to negative stimuli.[24] This association appears to amplify risk aversion and create more negative reactions to a decision due to increased fear.

Together, *COMT, DRD2, DRD4,* and *SLC6A4* genes influence decision-making through their modulation of the neurotransmitters dopamine and serotonin in the PFC. These genes significantly impact risk evaluation, reward sensitivity, impulsivity, and emotional regulation. I believe that a combination of these genes, and possibly others, has a significant influence on decision-making capabilities. Examination of these genetic mechanisms helps us grasp how the PFC regulates decision-making and how individuals with ASD experience deviations in these pathways. Understanding the neurogenetic pathways behind decision-making helps us explore the paper's purpose by allowing us to understand differences in function caused by ASD and points to the importance of researching how digital environments' interaction may change these pathways.

Neural and Genetic Pathways in Decision-Making Altered by ASD:

Autism spectrum disorder (ASD) is known to affect brain development and cognitive processes of impacted individuals from an early age, leading to differences and difficulties in learning, communication, and behavior.[25,26] These neurogenetic deviations in decision-making are shaped by irregular gene expression and atypical patterns of neural connectivity. Understanding these deviations helps us to comprehend the cognitive characteristics of individuals with ASD. This helps attribute results to digital environments and removes some potential confounding variables.

Individuals with ASD have abnormal dopamine transmission and activity in the PFC. The structure and the function of decision-making pathways are often disrupted. Parts of the brain communicate with each other inefficiently, impeding the integration of information and reducing intra-cortical connectivity.[26] This was further examined and supported by functional magnetic resonance imaging.[27] Reward-circuitry differences are also noticed in individuals with ASD.[25] Such atypical activation and connectivity in the PFC during decision-making tasks contribute to challenges in thinking flexibly and evaluating consequences. Acknowledging this atypical interaction helps when evaluating the digital landscape's impact on decision-making outcomes.

Given the decreased interconnectivity in the PFC of individuals with ASD, some changes in dopamine regulation, such as those affected by the *COMT, DRD2*, and *DRD4* genes, can enhance decision-making. Let's look at these studies of the *COMT* gene. Two studies reveal no significant difference between individuals with ASD and control groups for the Val/Val, Met/Val, and Met/Met genotypes.[28,29] The first study examined the relationship of the genotypes with other neurodevelopmental disorders, including anxiety and tics,[28] while the other study investigated hyperactivity.[29] They found no significant associations between individuals with ASD and the Val158Met polymorphism. However, the second study discovered that the association with hyperactivity and impulsivity was higher in the Val/Val genotype.[29] This finding suggests the possibility of certain genotypes in the *COMT* gene correlating with alterations in decision-making for individuals with ASD. Therefore, this is an important genetic mechanism to consider while examining how digital environments affect ASD.

One study of *DRD2* genes found that the gene correlated with susceptibility to ASD behaviors in affected male families and with the possibility of predicting ASD in families.[30] Another study found that individuals at high risk of developing ASD and who possessed *DRD4* and *DRD2* genotypes associated with less efficient dopaminergic functioning experienced more ASD behavior.[31] Since results varied, there is no conclusive evidence that the *DRD2* and *DRD4* genes are risk factors for ASD. However, this calls for further study. A meta-analysis of the 5-HTTLPR polymorphism of the SLC6A4 gene showed that the polymorphism does not have a statistically significant effect on ASD risk.[32] Multiple studies in the meta-analysis did find a correlation, but the studies lacked enough consistency to support causation. Thus, the *DRD* and *SLC6A4* genes are important genes to consider when studying how digital landscapes could influence decision-making in individuals with ASD.

COMT, DRD2, DRD4, and *SLC6A4* all appear plausibly related to decision-making mechanisms because of their effect on the PFC through dopamine and serotonin signaling. Mixed results fail to provide genotypic evidence tying these genes directly and consistently to ASD. The influence of these genes on decision-making lies mainly in their impact on behavior within individuals with ASD. Further research might explore the connection between these genes and ASD and their possible impacts on genetic circuits. This section provides a baseline for the decision-making effects in ASD populations, enabling the results of how decision-making is altered to be attributed to digital environments.

Epigenetic Regulation of ASD:

Epigenetics is the study of how molecular factors, such as behavior and environment, influence genetic activity without altering the DNA sequence.[33] While genetic polymorphisms in *COMT, DRD2, DRD4,* and *SLC6A4* genes have the potential to shape neurotransmitter signaling and decision-making and require further research to discover a consistent link with ASD, epigenetics has demonstrated a more coherent connection with ASD. Therefore, epigenetic changes provide a possible explanation for how environmental exposures can influence the neurogenetic mechanisms behind ASD risk, symptoms, and decision-making.

DNA methylation is a commonly used epigenetic marker. DNA methylation occurs when a methyl group attaches to the cytosine of a CpG dinucleotide.[34] This alters gene expression without changing the DNA sequence.[33] Numerous studies have found that dysregulation of DNA methylation has a strong relationship with ASD and other neurological disorders.[33–36] "Therefore, epigenetic alterations may significantly affect the function of autism-related genes," and such alterations show that the PFC is one of the brain regions most susceptible to environmental influences.[35] Furthermore, emerging evidence indicates that mild internet use is correlated with alterations in DNA methylation of *OXTR, DAT*, and other genes.[37] This highlights the importance of utilizing epigenetics to understand how digital environments regulate genes like *COMT, DRD*, and *SLC6A4*.

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Another common epigenetic biomarker is histone modifications. There are two types of modifications: acetylation and methylation. Acetylation occurs when the nucleosome dissolves, releasing genes that alter DNA composition. Histone tail methylation occurs when the nucleosomes tighten, inactivating the gene, preventing DNA from being altered.[36] Either way, histone modifications change the availability of DNA. Individuals with ASD showed an increased rate in cis-regulatory elements, an irregular connection between genes and ion channels, and reduced acetylation.[36] Thus, histone modifications serve as a biomarker for ASD. Research on how digital environments influence histone modifications remains limited, but such work could offer valuable insight into how digital landscapes shape decision-making genes.

These two processes show that dysregulation of histone acetylation and DNA methylation in genes associated with synaptic plasticity and neuronal differentiation is linked with ASD. This suggests that epigenetic regulation is important in understanding the environment's influence on genetic predisposition in individuals with ASD. Many of these studies focused on perinatal time periods, so future studies could explore the impact of the environment in later developing years after birth. Additionally, future research might examine changes in these biomarkers in decision-making genes for individuals with ASD. Epigenetic changes in ASD highlight how environmental factors can influence neurogenetic pathways, providing insight into atypical decision-making differences caused by digital environments.

Digital Environments' Influence on Decision-Making & ASD:

Digital environments (including video games, virtual reality, and social media) create unique experiences of sensory, cognitive, and social stimuli that influence neural mechanisms involved in decision-making. Addictive digital environments such as social media and video games have been associated with reduced activity in the prefrontal cortex.[3] This leads to addictive behaviors through the release of dopamine, activating the brain's reward system. Additionally, people "who frequently engage in media multitasking exhibited reduced reward self-control, leading to impulsive decision-making."[3] While digital environments can provide people with access to information, allowing for informed decisions, they can create cognitive overload, impairing decision-making skills.[3] Additionally, digital marketing has been shown to alter decision-making by creating cognitive biases through the integration of tailored options.[38] These cognitive biases can also be created through recommender systems, which prompt consumers to purchase items based on nudging mechanisms.[12] Lastly, digital environments have normalized automation, diminished attentional capabilities, promoted new biases, altered perception, and reduced cognitive abilities.[2] This information signifies just how important understanding digital environments is for not only ASD individuals but also the general population. Digital environments' ability to influence decisions signifies how important understanding this variable is for decision-making capabilities in ASD.

In addition to digital environments influencing decision-making, they have been associated with causing atypical neurodevelopment and impacting behaviors in individuals with ASD. Excessive screen time at a young age is correlated with developmental and behavioral problems, including the onset of ASD and other neurodevelopmental disorders.[39] Additionally, early digital media exposure was shown to create atypical sensory processing similar to that of autistic individuals.[40] Due to individuals with ASD's unique sensory characteristics, it is plausible that they are at increased risk of problematic media use and the implicated negative impacts.[13] This highlights how crucial understanding digital environments is for youth and ASD individuals.

On the other hand, digital environments are increasingly being tested for interventive methods, specifically in ASD samples. Serious games, games focused primarily on an educational function, show significant potential in positively impacting social skills in ASD.[41] While other mental processes aren't tested, serious games have promising implications for enhancing other cognitive outcomes, especially when considering how other executive functions influence social interactions. A small sample test of VR systems found a correlation between planning and social skills and associated the VR with improved social skills.[42] Furthermore, a meta-analysis suggested VR improves cognitive functions.[43] However, the analysis noted that the number of available studies was limited, and VR creates new problems with affordability, accessibility, and other important considerations. Another analysis found digital health interventions have optimistic results for all individuals with ASD.[44]

An alternative method being tested is applied behavioral analysis (ABA). Other treatments include "diets and vitamins, floor time, holding, medication, sensory integration, speech and music therapy, special education, and visual schedules."[45] These treatments lack conclusive evidence supporting their effectiveness in treating ASD. The meta-analysis of ABA did find associative outcomes between the therapy method and ASD symptoms. However, the effects were correlated with socialization and communication abilities, and there were no significant differences in adaptive behavior, cognition, or other ASD behaviors.[45] This illustrates the need for future study to show a significant connection between current ASD treatments and executive functions like decision-making. Additionally, literature could examine combining digital interventions with current therapy.

Overall, digital environments impair decision-making pathways by overloading cognitive processes and exacerbating conditions such as impulsivity. These environments are also associated with neurodevelopmental conditions and symptoms. However, these environments, implemented in interventive measures, show promising results in reducing ASD symptoms, especially in social contexts. Alternative methods for treating ASD symptoms lack associations with alleviating decision-making hindrances like impulsivity. Overall, future research is needed to understand how digital environments impact the *COMT, DRD2, DRD4*, and *SLC6A4* genes in neurotypical and neurodivergent populations. This research would

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also provide new insights into how decision-making is affected and help create effective interventions.

Conclusion

This paper underscores the possibility that the interaction of ASD-linked genetic and neural variations with digital environments reshapes mechanisms of decision-making. Research is currently limited. This review exposes a) the need for understanding how digital environments impact the cognitive abilities of individuals with neurodevelopmental disorders, b) the possibility of utilizing digital tools to enhance and ease the experiences of these individuals, and c) the possibility of therapeutic methods. These are especially important concerns due to the heightened risk factors and susceptibility of individuals with ASD, in the context of digital landscapes, to addiction.

Future research could explore how these new ubiquitous environments modulate dopaminergic and serotonergic genes. Focusing on how digital environments impact pathways/ processes of decision-making in development is crucial for understanding their effects on individuals.[46] Studies could also review the neurogenetic mechanisms underlying the interaction between ASD development and vulnerabilities to certain media. Future research would provide a more comprehensive understanding of the variations in the decision-making of individuals with ASD. Current literature associating digital interventions with decision-making is scarce. Furthermore, the potential for the combination of digital environments with current ASD treatment provides a novel avenue of study. Ultimately, leveraging digital environments to modulate decision-making in ASD could transform both research and therapy by bridging molecular, neural, and behavioral insight.[13]

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