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THEORETICAL ARTICLE

Distractibility and Impulsivity in ADHD as an Evolutionary Mismatch of High Trait Curiosity

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition characterized by symptoms that include inattention, hyperactivity, and impulsivity. Recent research suggests that individuals with ADHD might exhibit higher levels of curiosity, which may be linked to their tendencies toward distractibility and impulsivity. This paper proposes an evolutionary mismatch hypothesis for high trait curiosity in ADHD, positing that 'hypercuriosity', which may have been adaptive in ancestral environments characterized by scarce resources and unpredictable risks, has become mismatched in industrialized societies where environments are more stable and information rich. The theory predicts that individuals with ADHD will demonstrate heightened levels of novelty-seeking and exploratory behaviors, manifesting as symptoms labeled as distractibility and impulsivity in modern environments. The paper explores the potential evolutionary benefits of high trait curiosity, the consequences of an evolutionary mismatch, and the implications for research and practice. The limitations of the theory are addressed, such as the need for more targeted research on curiosity in ADHD and potential differences among ADHD subtypes. Future research directions are proposed to refine and test the hypothesis, ultimately contributing to a more nuanced understanding of ADHD and informing the development of strength-based interventions. This theoretical framework offers a novel perspective on the adaptive value of ADHD traits and their manifestation in modern societies.

Keywords Curiosity · ADHD · Evolutionary mismatch

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition characterized by a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with typical functioning (American Psychiatric Association, 2013). ADHD is thought to affect 5% of children and adolescents and 2.5% of adults worldwide, and while the exact causes are still being researched, current evidence suggests genetics, environment, brain structure and chemistry all contribute to its development (Faraone et al., 2015). The core symptoms of ADHD include inattention (e.g., distractibility, difficulty sustaining focus, forgetfulness), hyperactivity (e.g., excessive fidgeting and constant motion), and impulsivity (e.g., interrupting others, rushing through tasks, engaging in unsafe behavior). Different subtypes of ADHD exist depending on which is the predominant symptom: predominantly inattentive presentation, predominantly hyperactive/impulsive presentation, or combined presentation (Chhabildas et al., 2001). These symptoms can lead to impairments in daily life functioning including difficulties with work, school, relationships, and self-regulation (Holst & Thorell, 2019; Kosheleff et al., 2023; Pitts et al., 2015). While ADHD is often viewed through the lens of its challenges, recent research has begun to explore potentially adaptive traits associated with the condition, such as heightened creativity, energy, and curiosity (Schippers et al., 2022).

This paper examines the relationship between curiosity and ADHD from an evolutionary perspective. Curiosity is a multifaceted construct that encompasses several related but distinct aspects, such as epistemic curiosity, defined as the desire for knowledge, and diversive curiosity, the fleeting desire for novel stimulus (Berlyne, 1954; Litman & Spielberger, 2003). Trait curiosity in particular is conceptualized as the general tendency to seek out new information or experiences, a definition adapted from the state-trait curiosity

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inventory which includes statements such as "new situations capture my attention", "I enjoy exploring new places" and "I like to experience new sensations" (Naylor, 1981). Curiosity plays a crucial role in determining what information is attended to and processed (Loewenstein, 1994; Modirshanechi et al., 2023). Research has shown that curiosity influences attention at both the perceptual and cognitive levels. At the perceptual level, curiosity increases the salience of novel and surprising stimuli, making them more likely to capture attention (Gottlieb et al., 2013). This attentional bias towards unexpected information serves an adaptive function, enabling individuals to rapidly detect and respond to changes in their environment (Gottlieb & Oudeyer, 2018). At the cognitive level, curiosity drives the allocation of attentional resources towards acquiring new knowledge, acting as an intrinsic motivation to seek information, driving attention towards stimuli that offer the potential for learning and reducing uncertainty (Gottlieb & Oudeyer, 2018; Von Stumm et al., 2011). This view is supported by neuroimaging studies showing that curiosity enhances activity in brain regions associated with attention and learning, such as the prefrontal cortex and the hippocampus (Gruber et al., 2014; Kang et al., 2009). When an individual is curious about a particular topic, they are more likely to engage in sustained and focused attention, dedicating cognitive resources to learning and problem-solving (Kidd & Hayden, 2015). This link between curiosity and attention raises the question of whether high trait curiosity may contribute to some of the cognitive and behavioral difficulties observed in ADHD.

Distractibility is listed as a sub-symptom of inattention in the DSM-V, and "being easily distracted" is frequently reported in adults with ADHD (Wilens et al., 2009). While "distraction" can be triggered by both external and internal sources, ADHD research has traditionally focused more on external sources of distraction leading to substantial evidence connecting external distractibility and ADHD (Osborne et al., 2023). For instance, external distractors such as unrelated auditory and visual stimuli more strongly disrupt task performance in ADHD groups compared to controls (Forster & Lavie, 2016; Gumenyuk et al., 2005; Schneidt et al., 2018). For those with ADHD, such diversive curiosity—which has been defined as the the fleeting desire for stimulus variation (Litman & Spielberger, 2003)—can lead to distraction when it constantly shifts from one locus of attention to another (Steglich-Petersen & Varga, 2023; Stein et al., 2007). However, internal distractions can disrupt performance in ADHD as well, even without external stimuli present (Franklin et al., 2017; Osborne et al., 2023). Specifically, mind-wandering in ADHD can shift attention away from a task toward unrelated thoughts (Lanier et al., 2021; Seli et al., 2015; Smallwood & Schooler, 2006). Research indicates that individuals with more ADHD symptoms experience greater spontaneous, but not deliberate, mind-wandering, and suggests that spontaneous mind-wandering might be central to ADHD symptomatology (Seli et al., 2015).

On the other hand, individuals with ADHD also experience periods of intensive concentration on interesting, non-routine tasks, accompanied by a temporarily diminished perception of one's environment where they are "locking on" to some absorbing activity where they have difficulty shifting their attention away from activities of interest (Conner, 1994; Ozel-Kizil et al., 2013, 2016). The term 'hyperfocus' has been used to characterize this heightened, focused attention (Ashinoff & Abu-Akel, 2021). It has been reported that ADHD individuals can become deeply engrossed in activities they find compelling, continuing these pursuits for hours while losing interest in their surroundings (Brown, 2005; Conner, 1994). During hyperfocus episodes, people with ADHD describe feeling unaware of the passage of time and cannot abandon the object of their curiosity (Ashinoff & Abu-Akel, 2021; Brown, 2005; Conner, 1994; Groen et al., 2020). In summary, hyperfocus can be seen as a specific and extreme type of sustained attention (Sklar, 2013). The interplay between hyperfocused and distracted behavior in ADHD likely depends on several factors, such as the motivational salience of the current stimulus compared to incoming stimuli, the frequency of new information arising, and the individual's inherent interest in the current stimulus. When the current stimulus is highly engaging, curiosity may drive hyperfocus, increasing productivity on the specific task but causing difficulties in transitioning to other tasks or attending to important external stimuli (Ashinoff & Abu-Akel, 2021; Hupfeld et al., 2019). Conversely, when the current stimulus is less engaging, or when other motivationally salient stimuli are present, curiosity may lead to increased distractibility as the individual is impulsively drawn to explore these new potentially rewarding sources of information (Forster & Lavie, 2016).

Impulsivity is considered another core symptom of ADHD (American Psychiatric Association, 2013; Winstanley et al., 2006). The study of impulsivity and in particular impulsive choice, which means choosing sooner rewards even if they come with a cost, is often conducted in relationship to delayed gratification, which implies choosing smaller rewards sooner against larger rewards later (Green & Myerson, 2004; Mischel, 1974; Wulfert et al., 2002). In this sense, impulsivity is the urgent desire to act. In delay-discounting tasks, individuals with ADHD tend to impulsively choose the smaller but more immediate rewards to the larger more delayed rewards (Schweitzer & Sulzer-Azaroff, 1995; Solanto et al., 2001; Sonuga-Barke et al., 1992, 1996). However, if choosing the quicker reward does not actually shorten total time engaged with the task, ADHD subjects can wait for bigger rewards (Sonuga-Barke et al., 1992, 1996).

This pattern suggests that impulsivity in ADHD—as well as hyperactivity and inattention—might functionally manifest an underlying drive to avoid delays (Sonuga-Barke, 2003).

Impulsivity has been posited as a central feature of curiosity (Loewenstein, 1994). Already at the end of the nineteenth century, philosopher and psychologist James (1899) referred to curiosity as "the impulse towards better cognition." Recent research has further examined curiosity as the urgent desire to know. For instance, studies suggest a willingness to pay for advance information, even when this information is not useful and does not affect the outcome, and even when the expected delay periods are merely on the order of seconds (Brydevall et al., 2018; Cabrero et al., 2019). Moreover, numerous studies have established a link between impulsivity and frontostriatal networks, as well as the role of midbrain dopamine inputs to both the striatum and the prefrontal cortex (Dalley & Robbins, 2017; Scheres et al., 2013; Smith et al., 2016). Similarly, neuroimaging studies suggest that heightened curiosity boosts activation in parts of the prefrontal cortex, striatum, and dopaminergic midbrain areas (Gruber et al., 2014; Kang et al., 2009; Lau et al., 2020), indicating that both impulsivity and curiosity may involve overlapping neural pathways. As such, modern research seems to confirm William James' intuition, leading researchers to describe curiosity as "the impulse to know" based on common behavioral and neural mechanisms underlying both curiosity and impulsivity in relation to reward and information-seeking (Marvin et al., 2020). In fact, emerging evidence suggests that individuals with ADHD themselves relate their curiosity with their tendency toward impulsivity and distraction (Redshaw & McCormack, 2022; Schippers et al., 2022). As noted by psychiatrists Edward Hallowell and John Ratey reflecting on their lived experience of ADHD: "If we weren't so dreamy and curious we could stay on track and never get distracted." (2021, p. 21).

The 5-Dimensional Curiosity Scale (5DC) identifies five distinct dimensions: Joyous Exploration, Deprivation Sensitivity, Stress Tolerance, Social Curiosity, and Thrill Seeking (Kashdan et al., 2018). The novelty-seeking and exploration behaviors often observed in ADHD align closely with the Thrill Seeking dimension of curiosity (Grimm et al., 2020; Sedgwick et al., 2019). Individuals with ADHD might exhibit heightened Deprivation Sensitivity, driven by the need to quickly resolve uncertainty and accompanied by a sense of discomfort until the information is acquired (Litman & Jimerson, 2004). Furthermore, the Five Factor Model personality trait Openness, which includes aspects of intellectual curiosity and a need for variety, has been found to be associated with neurocognitive characteristics of ADHD (Van Dijk et al., 2017). Openness involves a preference for novelty and variety, which might drive the intense, impulsive information-seeking behaviors seen in ADHD. For instance, inattentive children with ADHD tend to be high on approach behaviors, "characterized by eagerness and readily seeking new experiences with curiosity and openness but reacting impulsively" (Chauhan et al., 2019, p. 61).

Although there has been considerable work exploring evolutionary accounts of ADHD (Esteller-Cucala et al., 2020; Jensen et al., 1997; Swanepoel et al., 2017; Thagaard et al., 2016; Williams & Taylor, 2006), few attempts have been made to offer a theoretical framework integrating the evolutionary mechanisms of distractibility and impulsivity in ADHD. While previous theories have focused on novelty seeking and vigilance as key traits in evolutionary accounts of ADHD (Jensen et al., 1997; Thagaard et al., 2016), curiosity offers a distinct construct that integrates these traits and provides a more comprehensive understanding of the relationship between exploratory tendencies, distractibility, and impulsivity in ADHD. Novelty seeking involves the pursuit of new and varied experiences (Costa et al., 2014), while vigilance is characterized by heightened awareness and monitoring of the environment (Beauchamp, 2015; Herrera et al., 2011). Curiosity can drive both novelty seeking and vigilance by motivating individuals to explore their surroundings and attend to potentially informative stimuli (Gottlieb et al., 2013; Kidd & Hayden, 2015). By encompassing both the pursuit of new experiences and the monitoring of the environment, curiosity provides a unifying framework for understanding the evolutionary origins and modern challenges associated with ADHD-related traits.

This theoretical paper proposes that 'hypercuriosity', defined as the heightened and impulsive desire to know, is an evolutionary adaptation that has become mismatched under modern environmental conditions, resulting in what the DSM-V describes a being "easily sidetracked" and "easily distracted by extraneous stimuli" in ADHD (American Psychiatric Association, 2013). An evolutionary mismatch occurs when the environment that a species currently lives in is different from the environment to which a specific trait evolved to be adaptive (Cofnas, 2016; Manus, 2018; Tooby & Cosmides, 2015). Rapid changes in factors such as social structures, diet, activity levels, and sleep patterns can create a mismatch between what humans are adapted for and their current environment. This mismatch can occur not only due to changes in environmental requirements but also when previously adaptive mechanisms become dysfunctional or dysregulated in new conditions regardless of any specific environmental demands (Cofnas, 2016; Li et al., 2018) and can lead to increased risk for physical and mental health difficulties (Montgomery, 2018). This paper explores the potential evolutionary benefits of hypercuriosity, environmental changes that may render it maladaptive in the modern world, as well as implications for research and practice.

Explanatory Scope of the Theory

The hypercuriosity hypothesis posits that high trait curiosity, prevalent among individuals diagnosed with ADHD, represents an evolutionary adaptation beneficial for environments characterized by scarce resources and unpredictable risks, where this trait promoted behaviors that enhanced survival at the individual and group level. However, high trait curiosity has become an evolutionary mismatch in industrialized societies where environments are predominantly resource-rich with fewer unpredictable risks. This mismatch manifests as increased distractibility and impulsivity, with implications for well-being and performance.

Evolutionary Benefits of High Trait Curiosity

Curiosity drives the motivation to obtain information, which functions as a reward, supporting the idea that exploration tendencies have evolved as an adaptive trait by treating information as an independently sought-after currency to enhance chances of survival (Marvin & Shohamy, 2016). Dall and colleagues (2005) emphasize the crucial role of information in animal behavior and evolution, stating that "the better informed an individual, the better it can develop and adjust its behavior to meet the demands of a variable world" (p. 187). The drive to explore and learn about one's environment is also a fundamental aspect of human development that is thought to have evolved as an adaptation to the learning demands of our species' foraging niche (Gopnik, 2020; Kaplan et al., 2000). The extended childhood period in humans, characterized by high levels of curiosity and exploration, likely evolved to facilitate the acquisition of knowledge and skills necessary for survival in such environments (Gopnik, 2020; Kaplan et al., 2000). In hunter-gatherer societies, children's curiosity is a key driver of their learning process, as they are often allowed to freely explore and engage in self-directed learning (Gray, 2011; Lew-Levy et al., 2017). For instance, among the BaYaka hunter-gatherers of Congo, children learn subsistence skills through play and participation in foraging activities (Salali et al., 2019). Building on the role of curiosity in the drive to learn and explore, researchers have categorized different modes of curiosity as 'hunters' who pursue information methodically, 'busy-bodies' who take a scattered and broad approach to seeking information, and 'dancers' who engage with information in a fluid and adaptive manner (Zurn, 2019; Zurn & Bassett, 2023). The busy-body mode of curiosity, characterized by attentional shifts and "never-dwelling anywhere" behavior (Heidegger, 1996, p. 161), might be more aligned with the characteristic attentional shifts, novelty seeking, and exploratory behaviors observed in ADHD that would have facilitated the discovery of new resources and information in environments where such behaviors were critical for survival (Lydon-Staley et al., 2021).

A proclivity to explore has also been linked to better foraging outcomes in various species, including humans. Resource acquisition in hunter-gatherer societies is often unpredictable, with success varying across time and location (Hawkes et al., 2001; Hill & Hurtado, 1996). Curiosity and a higher tolerance for novelty may have been advantageous in this context, as these traits would have facilitated the discovery of novel food sources. Novelty seeking is characterized by the pursuit of new and varied experiences, a trait advantageous for identifying new food sources and habitats (Costa et al., 2014; Gören, 2016). These exploratory tendencies enhance learning and adaptation to new environments, contributing to the accumulation of ecological knowledge and skills necessary for survival (Mettke-Hofmann, 2014). The dispersed nature of resources may also have favored a greater propensity for exploration, as it would have led to covering larger areas and acquiring knowledge about the distribution and availability of resources (Kaplan et al., 2000). In contrast, the benefits of high trait curiosity may be less pronounced in agricultural societies and non-human primate groups that rely on more predictable and localized resources such as cultivated crops or fruit trees (Kaplan et al., 2000; Stevenson, 2004). A recent study investigated the relationship between ADHD attributes and foraging decisions in humans using an online task where participants had to decide whether to continue collecting rewards from a depleting resource patch or to replenish the patch by moving to a new one (Barack et al., 2024). The results showed that participants whose scores on the ADHD scale met the threshold for a positive screen not only departed resource patches sooner than those who did not meet this criterion but also achieved higher reward rates. These findings suggest that high trait curiosity in ADHD may have evolved as an adaptive trait, conferring foraging advantages by favoring exploration over exploitation and improving survival in various environments.

The nomadic lifestyle, characterized by frequent movement and exploration of new environments, may have also favored individuals with higher levels of curiosity, as they are more likely to seek out and adapt to novel situations. The dopamine D4 receptor (DRD4) gene, also known as the "wanderlust gene" (Realo et al., 2023), has been associated with novelty seeking, impulsivity, and a proclivity for exploration (He et al., 2018; Munafò et al., 2008). The frequency of the DRD4/7R allele, which is associated with decreased receptor functioning, has been found to be higher in nomadic populations compared to sedentary populations (Eisenberg et al., 2007). This suggests that high trait curiosity may have

been advantageous in nomadic societies, where the unpredictability of resource availability necessitates a greater reliance on curiosity-driven exploration to discover new food sources and navigate unfamiliar landscapes (Berbesque et al., 2014). It was also observed that among nomadic Ariaal men in northern Kenya, those with one or two DRD4/7R alleles had higher body mass index (BMI) compared to those without the allele, suggesting a potential adaptive advantage in their environment (Eisenberg et al., 2007). Further research found support for the association between ADHD and the DRD4 gene (Faraone et al., 2001), and it was noted that carriers of the DRD4/7R allele are more likely to show ADHD symptoms and exhibit novelty seeking, impulsivity, and exploratory behavior (Swanepoel et al., 2017). These traits may have been well-suited to the demands of a nomadic lifestyle, where individuals need to be ready to move frequently and explore new environments in search of resources (Potts, 2014). For instance, nomadic Mbendjele BaYaka hunter-gatherers tend to discount the future more heavily than their sedentary farmer neighbors (Salali & Migliano, 2015), suggesting a preference for immediate rewards that aligns with a more impulsive form of curiosity. Furthermore, a significant difference was found in the 7R allele frequency between recent past hunter-gatherer and agriculturalist populations in South America, with the allele being more prevalent in hunter-gatherers (Tovo-Rodrigues et al., 2010). It was proposed that the DRD4/7R allele originated as a rare mutation that increased in frequency due to positive selection (Ding et al., 2002). These findings suggest that the DRD4/7R allele and its associated behaviors may have conferred adaptive advantages in the context of our evolutionary past.

Vigilance, associated with high-scanning behavior, allows for better monitoring of surroundings (Beauchamp, 2015; Herrera et al., 2011). Curiosity can drive vigilance as individuals monitor their environment, especially in the absence of fear (Beauchamp, 2017). In situations where the potential rewards of further exploration outweigh the perceived risks, curiosity might take precedence and lead to increased information-seeking and learning (Lima & Bednekoff, 1999). In fact, risk-taking in ADHD has been found to be associated with exaggerated views of the benefits of positive outcomes (Shoham et al., 2016). The impulsive curiosity to attend to extraneous stimuli, often associated with ADHD, has been linked to higher vigilance (Hegerl & Hensch, 2014), which may have increased the chances of survival in our evolutionary past (Hartmann, 1999). Jensen and colleagues (1997) propose that ADHD traits, such as hypervigilance and high-scanning behavior, may have been adaptive in ancestral hunter-gatherer environments characterized by novel and rapidly changing conditions. They argue that such traits may have allowed for better monitoring of threats and danger in these environments. In situations where the presence of a minor stimulus could signal the possibility of a predator, the ability to quickly shift attention to the stimulus would have been crucial for early humans to be aware of potential danger and react accordingly (Zorya, 2023). Research suggests that neural circuits in the superior colliculus, a midbrain structure involved in orienting behaviors and attentional shifts, are involved in initiating orienting and exploratory movements related to curiosity-driven exploration (Modirshanechi et al., 2023) and that the superior colliculus serves functions in predator avoidance (Allen et al., 2021). Interestingly, it has been hypothesized that the superior colliculus is overly responsive in ADHD (Dommett et al., 2009; Overton, 2008). This heightened awareness of environmental cues and impulsive form of curiosity may have been a valuable adaptation in the past. Finally, morbid curiosity—being "curious about threats" or the desire to learn about potential threats—has been hypothesized to derive from an evolved cognitive architecture for predator management (Scrivner, 2021), supporting the notion that high trait curiosity in the context of high predation risks may have had adaptive value in our evolutionary past.

The captivity effect in non-human primates, where captive animals exhibit higher levels of curiosity compared to their wild counterparts (Damerius et al., 2017; Forss et al., 2015), provides an interesting parallel to the impact of modern environments on human cognition and behavior. The heightened curiosity in captivity is hypothesized to be due to reduced risk and increased free time (Forss & Willems, 2022). In nature, curiosity-driven exploration can be risky, as it may expose individuals to potential threats such as predators or environmental hazards (Byrne, 2013). As a result, it is plausible that in wild populations, high trait curiosity would be limited to a subset of individuals to balance the potential benefits of exploration with its inherent risks, while the majority of the population exhibits lower levels of curiosity (Sih et al., 2004). This is analogous to the concept of neurodiversity in humans, where neurodivergent traits, such as those associated with ADHD, autism, or dyslexia, are present in a smaller portion of the population compared to the neurotypical majority (Armstrong, 2015). Other evolutionary theories propose that certain traits associated with mental health conditions such as schizophrenia may have had group-level benefits in ancestral contexts (Polimeni & Reiss, 2003). For example, some symptoms of schizophrenia such as hallucinations and altered perceptions have been suggested to provide benefits to the group in ancestral environments through the spiritual leadership and healing practices of shamanism (Brewerton, 1994; Maslowski et al., 1998; Polimeni & Reiss, 2002). Similarly, despite its potential risks at the individual level, high trait curiosity in ADHD could have conferred group advantages in ancestral environments by promoting exploration and discovery of new resources. In addition, for high trait curiosity to persist

in ADHD, the individual-level benefits such as more effective foraging strategies and better monitoring of threats might have outweighed the potential risks (O'Gorman et al., 2008). This perspective aligns with multilevel selection theory, which suggests that evolutionary processes can act at both individual and group levels (Wilson & Wilson, 2007). Migliano and Vinicius (2022) argue that exploratory tendencies contributed to the development of cumulative culture in human societies, particularly within the hunter-gatherer foraging niche. This view is consistent with research on the evolution of prosocial traits in humans, which proposes that uniquely human characteristics such as cooperation and information sharing might have evolved through a combination of individual and group selection pressures (Bowles & Gintis, 2011). However, it is important to note that multilevel selection theory remains controversial in evolutionary biology and sociobiology (Kramer, & Meunier, 2016; Okasha, 2001). Many researchers argue that selection at the individual level is generally much stronger than selection at the group level, making group selection unlikely to be a significant force in evolution (West et al., 2007) and critics point out that for a trait to evolve through group selection, the benefit to the group would need to outweigh any potential costs to individuals, which is often considered unlikely in natural populations (Pinker, 2015). Therefore, while multilevel selection offers an intriguing perspective on the evolution of high trait curiosity in ADHD, these theories should be interpreted with caution.

In summary, the evidence suggests that high trait curiosity and its associated behaviors as observed in ADHD may have conferred various adaptive advantages in ancestral environments. By promoting exploratory behaviors, novelty seeking, and information acquisition, high trait curiosity likely enhanced survival in contexts characterized by resource scarcity, unpredictability, and dispersed information. This perspective extends previous evolutionary theories of ADHD (Jensen et al., 1997; Swanepoel et al., 2017) by highlighting the specific role of curiosity-driven exploration in shaping the adaptive value of ADHD traits in ancestral environments.

Evolutionary Mismatch of High Trait Curiosity

Certain ADHD traits that were once valuable for survival in ancestral environments may have become maladaptive in modern contexts. Genomic analyses support the presence of long-standing selective pressures acting against ADHD-associated alleles, with a decrease in the frequency of these variants observed since Paleolithic times. Investigations of the evolution of ADHD-associated alleles in European populations using archaic, ancient, and modern human samples found that the frequency of variants associated with ADHD has steadily decreased since Paleolithic times, suggesting a long-term evolutionary trend (Esteller-Cucala et al., 2020). This negative selection may have occurred as changes in the environment or human lifestyle during this period made certain ADHD traits less advantageous for survival and reproduction.

The ubiquity of technology in today's world may have further exacerbated the mismatch between high trait curiosity and the environment. The internet provides higher levels of information richness, which refers to the amount and complexity of information available in an environment (Grosse, 2021; Lurie, 2004; Röttger & Vedres, 2020). Despite a potential "digital advantage", high trait curiosity in ADHD can create challenges in the context of modern technology with the constant presence of distractions and the requirement to sustain attention in a stimuli-rich online environment (Adelantado-Renau et al., 2019; Sonuga-Barke & Kostyrka-Allchorne, 2023). As such, the heightened sensitivity to new information and stimuli observed in ADHD, beneficial in resource-scarce environments for rapid adaptation, might have become maladaptive in today's information-rich environments (DeYoung, 2013; Geary, 2008; Schneidt et al., 2018). The Differential Susceptibility to Media Effects Model (DSMM) proposed that media response states, including cognitive, emotional, and excitative states, mediate the relationship between media exposure and various outcomes (Valkenburg & Peter, 2013). Fast-paced media may lead to increased arousal, and, with frequent exposure, baseline arousal levels may decrease, potentially contributing to ADHD-related behaviors (Beyens et al., 2018). Digital media introduces an abundance of novel stimuli which reinforces novelty-seeking behavior, fostering curiosity but also potentially leading to cognitive fatigue due to information overload (Shanmugasundaram & Tamilarasu, 2023). Researchers have suggested that sustaining concentration in a stimuli-rich digital setting, processing novel information, and constructing a coherent narrative across various tasks and contexts are expected to pose even greater challenges for people with ADHD compared to non-digital situations, given the omnipresent availability of potential distractions (Hanin, 2021).

Beyond distractions, research has found that ADHD symptoms are associated with problematic digital media use (Dekkers & van Hoorn, 2022; Sibley & Coxe, 2018), and that addiction-like social media use increases ADHD symptoms (Boer et al., 2020). These findings are supported by a meta-analysis which suggests a significant association between problematic internet use and ADHD-related symptoms (Augner et al., 2023). Another meta-analysis revealed a moderate correlation between internet addiction and ADHD among adolescents and young adults (Wang et al., 2017). Moralist perspectives have consequently characterized modern digital environments as encouraging an "addiction to novelty" in which curiosity is perceived as

an uncontrollable vice (Littlejohn, 2017). Adolescence in particular is characterized by heightened curiosity associated with novelty seeking and risk taking (Defoe et al., 2022; Jovanović & Gavrilov-Jerković, 2014). While these traits promote exploration and the acquisition of new skills and knowledge, they can lead to maladaptive behaviors in industrialized contexts, such as substance abuse or reckless driving (Jovanović & Gavrilov-Jerković, 2014; Steinberg, 2017; Wills et al., 1994). These developmental patterns suggest that traits promoting exploration and skill acquisition can become disadvantageous in environments abundant with novel stimuli.

Lastly, the modern educational system and work environment often prioritize the ability to remain stationary and concentrate on predetermined tasks, which can be a mismatch for individuals with high trait curiosity. Modern education has been based on the premise that "the purpose of the schools is to transmit knowledge, skills, and standards of good conduct" (Powell, 2009, p. 13). In this setting, students are not granted the freedom to explore various subject areas and activities based on their natural curiosity (Lail, 2017). As such, Swanepoel et al. (2017) have argued that "there is a mismatch between the strengths of children with ADHD—their tendency to explore, to challenge and to try out new ways of doing things—and their environment (today's schools)." A systematic review found that ADHD adversely affects long-term academic outcomes, with both achievement test outcomes and academic performance outcomes being worse in individuals with untreated ADHD compared to non-ADHD controls, even when IQ differences were controlled for (Arnold et al., 2020). The mismatch between high trait curiosity and modern learning environments is particularly evident in childhood. While curiosity-driven learning and autonomous exploration are encouraged in hunter-gatherer societies, modern educational systems often prioritize structured learning over self-directed exploration (Chaudhary & Swanepoel, 2023; Lew-Levy et al., 2017; Swanepoel et al., 2017). This mismatch can lead to challenges for children with high trait curiosity, such as those with ADHD, who may struggle to adapt to the constraints of modern classrooms (Lail, 2017; Swanepoel et al., 2017). Consequently, the discrepancy between the modes of learning that were adaptive in our evolutionary past and the demands of modern educational settings may contribute to the challenges faced by individuals with high trait curiosity and related ADHD traits (Geary, 2008; Swanepoel et al., 2017). Beyond school, the modern work environment with its rigid structure, administrative tasks, and settings that discourage movement have also been found to pose a challenge for individuals with ADHD traits (Adamou et al., 2013; Fuermaier et al., 2021; Oscarsson et al., 2022). These constraints may lead to restlessness, difficulty staying still, and what is considered excessive movement—the hyperactive behaviors observed in ADHD (American Psychiatric Association, 2013). It was proposed that hyperactivity might be a self-stimulatory mechanism to maintain optimal arousal levels (Zentall & Zentall, 1983), which could be linked to a heightened need for novel information and experiences. Hyperactivity and hypercuriosity in ADHD might thus represent two facets of the same underlying drive for environmental interaction and information gathering, and the modern emphasis on conformity, predetermined curricula, and extended periods of stationary work can be a mismatch for evolved exploratory behaviors that were previously adaptive.

In summary, high trait curiosity associated with ADHD may have become mismatched to the demands of industrialized, information-rich environments typically characterized by a higher density and diversity of stimuli compared to ancestral environments. The constant presence of potentially rewarding experiences combined with the structured demands of educational and occupational settings in industrialized societies might lead to behaviors characterized as maladaptive in individuals with ADHD. This perspective expands upon previous evolutionary theories of ADHD (Jensen et al., 1997; Swanepoel et al., 2017) by emphasizing the role of curiosity and information processing in the maladaptive manifestation of ADHD traits in modern contexts.

Theoretical Model

High trait curiosity, prevalent among individuals diagnosed with ADHD, may represent an evolutionary adaptation beneficial for earlier environments characterized by varied, scattered, and unpredictable resources. This trait promoted exploratory behaviors, enhancing survival and reproductive success. However, in industrialized societies, the environments are predominantly stable, information-rich, and feature clearer risk/reward ratios, reducing the adaptive benefits of novelty seeking and exploration and leading to an evolutionary mismatch which manifests as symptoms labeled as distractibility and impulsivity in ADHD (Fig. 1).

The hypothesis predicts that individuals diagnosed with ADHD will exhibit higher levels of curiosity in response to motivationally salient stimuli (Berridge & Robinson, 2016) compared to those without ADHD. Motivationally salient stimuli are stimuli that have high incentive value and perceived potential for reward as demonstrated by studies showing that animals, including humans, are more likely to attend to and explore such stimuli (Fowler, 1965; Öhman et al., 2001; Taylor, 1971). These can include novel objects, potential threats, unexpected changes, and unfamiliar information (Gable & Harmon-Jones, 2010; Kim et al., 2021). This trait, while beneficial in ancestral, information-scarce environments where motivationally salient stimuli were fewer and more dispersed, may lead to maladaptive distractibility

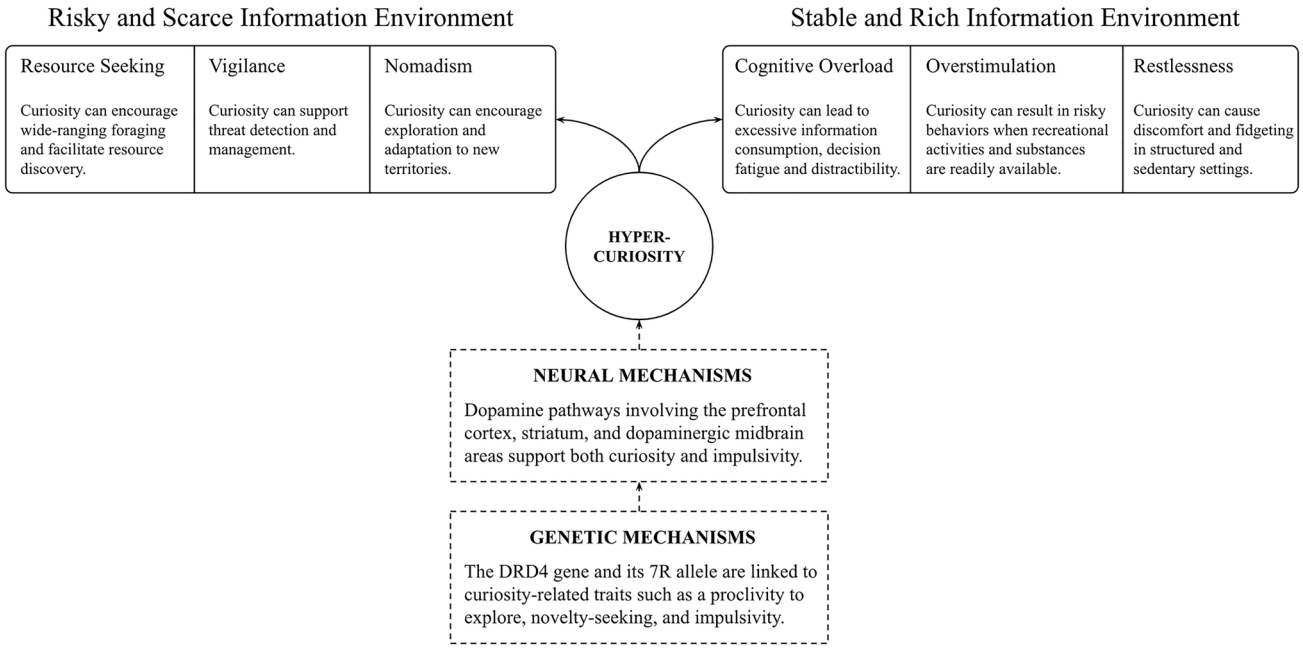


Fig. 1 Theoretical model of the relationship between high trait curiosity and environmental information-density levels

and impulsivity in the context of modern society's structured tasks and demands. The theory predicts that measures of trait curiosity, such as self-report questionnaires and behavioral tasks assessing information-seeking behavior, will be positively associated with measures of distractibility and impulsivity in ADHD, including attentional capture by irrelevant stimuli and difficulty sustaining attention on a low-curiosity task.

Building on previous work by Marvin and colleagues (2020), neuroimaging studies might explore common neural substrates during tasks that elicit curiosity, distractibility, and impulsivity in individuals with ADHD. Neurocognitive and neurophysiological measures of curiosity, distractibility, and impulsivity will show significant overlap in all individuals, suggesting shared underlying mechanisms, but these neural processes may lead to higher levels of these traits in individuals with ADHD compared to those without ADHD. Establishing these relationships would provide support for the idea that high trait curiosity in ADHD is linked to the core symptoms of the disorder and may represent a key factor in the proposed evolutionary mismatch described in this paper. Cognitive modeling could also be employed to simulate how different levels of curiosity affect attention allocation in environments with varying density of information, comparing outcomes for ADHD and non-ADHD models (Hanin, 2021). Investigating whether curiosity-driven exploration leads to better outcomes (e.g., learning, problem-solving) in ADHD individuals in open-ended tasks compared to structured tasks would further test the hypothesis (Barack et al., 2024; Jensen et al., 1997).

Falsifiability is a crucial aspect of any scientific theory, as it allows for the theory to be tested, refined, and potentially refuted (Popper, 1959). The evolutionary mismatch hypothesis for high trait curiosity in ADHD, as presented in this paper, is open to falsification through various empirical investigations. For instance, assessing distractibility using attention tasks with individuals with varying levels of curiosity and ADHD could provide insights into the relationship between curiosity, distractibility, and ADHD (Marvin & Shohamy, 2016; Swanepoel et al., 2017). Cross-cultural research examining the variance of ADHD symptoms and their impact on individuals in societies with different levels of environmental predictability and technological advancement could test the theory's predictive power regarding the mismatch in different societal contexts (Eisenberg et al., 2007; Realo et al., 2023). Longitudinal studies observing the developmental trajectory of ADHD symptoms in children with high trait curiosity, focusing on environmental interactions, could help in understanding how modern educational and social settings influence the manifestation of distractibility over time (Arnold et al., 2020; Lail, 2017). To potentially falsify the theory, researchers should aim to (1) find no difference in curiosity between ADHD and non-ADHD individuals; (2) demonstrate that curiosity is not related to distractibility and impulsivity in ADHD; or (3) show that high trait curiosity is equally adaptive or maladaptive irrespective of unpredictability and information richness of a given environment. If any of these findings were to emerge consistently across studies, the evolutionary mismatch hypothesis

for high trait curiosity in ADHD would need to be revised or rejected.

Implications for Research and Practice

While ADHD has traditionally been studied from a deficits-based perspective, recent research has begun to explore the potential advantages associated with ADHD traits, with high trait curiosity as a possible strength. For instance, a qualitative study investigating the positive aspects of ADHD from the perspective of successful adults with ADHD found that curiosity was consistently reported as a positive trait, with participants describing themselves as naturally curious (Sedgwick et al., 2019). Redshaw and McCormack (2022) reported that participants in their qualitative study ascribed an exceptional level of curiosity to their ADHD. Furthermore, an international qualitative study identified hyperfocus as a self-reported strength in ADHD, provided that the activity or topic of attention elicited curiosity (Mahdi et al., 2017), and a high degree of curiosity was found to be associated with a sense of adventurousness (Nordby et al., 2023; Schippers et al., 2022). Steglich-Petersen and Varga (2023) argued that a heightened tendency for individuals with ADHD to become curious and engage in exploratory behavior, along with a lower inclination to inhibit curiosity despite cognitive and practical challenges, can be justified and beneficial, especially when the knowledge gained from exploration can be shared within a social group. As such, future research and practice should aim to explore ways to harness the positive aspects of curiosity in ADHD while developing strategies to mitigate the potential challenges it may pose in mismatched environments.

Given the potential benefits of high trait curiosity in ADHD, educational interventions might aim to nurture this curiosity by designing environments that leverage its advantages while addressing the mismatch with modern educational demands. For instance, AI-assisted tools have been successfully used to improve education for individuals with neurodevelopmental conditions, including ADHD (Barua et al., 2022), and researchers have highlighted the transformative potential of AI in education for students with ADHD, emphasizing its capacity to offer personalized learning experiences, virtual tutors, and its positive impact on student engagement, critical thinking, and problem-solving skills (Rapti, 2023). Another promising approach is the use of game-based learning, which has been shown to have a positive effect on engagement and interest in subjects such as mathematics among students with ADHD (Sullivan-Carr, 2016). The classroom structure itself may play a role in nurturing curiosity and promoting on-task behaviors in students with ADHD. A study comparing on-task and off-task behaviors in students with ADHD indicated that students in a Montessori classroom setting designed to foster curiosity exhibited more actively engaged on-task behaviors, while those in the traditional classroom demonstrated a higher prevalence of passively engaged on-task behaviors (Lail, 2017). It was also found that students who engaged in outdoor socially-oriented activities reported higher levels of curiosity compared to those who did not (Zhang et al., 2024). Future research should continue to investigate the effectiveness of these interventions and explore new approaches to support the learning needs of students with ADHD.

Finally, curiosity is not a unitary construct, and different types of curiosity have been proposed (Berlyne, 1954; Le Cunff, 2024; Litman & Spielberger, 2003). In the context of this paper, curiosity was conceptualized as the impulsive desire to know, which aligns with the definition proposed by Marvin et al. (2020) based on common behavioral and neural mechanisms underlying both curiosity and impulsivity in relation to reward and information-seeking. Understanding the relationship between distractibility, impulsivity, and various conceptualizations of curiosity in the context of ADHD may provide valuable insights into its underlying mechanisms and inform the development of evidence-based interventions. In particular, while maintaining curiosity throughout life has been associated with better cognitive functioning, well-being, and resilience in the general population (Kashdan & Steger, 2007; Swan & Carmelli, 1996), little is known about how curiosity influences outcomes for individuals with ADHD as they age. Evidence suggests that aging may be associated with reductions in novelty seeking, openness, risk taking, and exploratory behavior (Mata et al., 2013), and a negative association between age and curiosity has been found in the general population (Chu et al., 2021). Longitudinal studies examining the developmental trajectory of curiosity and its impact on cognitive, social, and emotional functioning in individuals with ADHD could provide valuable insights into the long-term implications of the evolutionary mismatch hypothesis for high trait curiosity in ADHD.

Limitations

While the evolutionary mismatch hypothesis for high trait curiosity in ADHD presents a novel perspective on the relationship between curiosity, distractibility, and impulsivity, it is important to acknowledge its limitations. First, the theory is based on limited research. Although there is emerging evidence suggesting heightened curiosity in individuals with ADHD and a potential relationship between curiosity, distractibility, and impulsivity (Hallowell & Ratey, 2021; Marvin et al., 2020; Osborne et al., 2023; Redshaw & McCormack, 2022; Sedgwick et al., 2019), more studies are

needed to establish the robustness of this association and its underlying mechanisms.

In particular, translating findings from animal studies to humans has limitations. Although primate models have provided valuable insights into the mechanisms of curiosity (Sánchez-Amaro & Rossano, 2023; Wang & Hayden, 2019) and ADHD (Funahashi & Shimizu, 2007) separately, there is currently no research directly examining the intersection of curiosity and ADHD in non-human primates. Of note, research has found no effect of methylphenidate, a common ADHD medication, on prefrontal cortex activity in monkeys, contrasting with its known effects in humans (Tremblay et al., 2019). More targeted comparative research is needed to clarify the evolutionary basis of high trait curiosity in ADHD and its potential relationship to the captivity effect observed in non-human primates.

The present theory also does not consider the potential differences in curiosity across subtypes of ADHD, such as predominantly inattentive, predominantly hyperactive-impulsive, and combined presentations (American Psychiatric Association, 2013). Future research should explore whether the evolutionary mismatch hypothesis applies equally to all ADHD subtypes or if there are distinct patterns of curiosity and its associated challenges in modern environments across these subgroups.

Despite these limitations, the present paper offers a valuable basis for investigating the shared mechanisms of curiosity, distractibility, and impulsivity in ADHD. By exploring the potential links between these traits, researchers can gain insights into the cognitive processes that underlie the challenges faced by individuals with ADHD in modern environments. Moreover, the focus on curiosity as a central feature of ADHD provides an avenue for developing strength-based approaches to interventions and support. By recognizing and nurturing the positive aspects of high trait curiosity, such as its potential to drive learning and innovation, practitioners could help individuals with ADHD harness this strength and mitigate the impact of distractibility and impulsivity on their daily lives.

Conclusion

This paper proposes that high trait curiosity, which may have been adaptive in early environments characterized by scarce resources and unpredictable risks, has become mismatched in industrialized societies where environments are more stable, predictable, and information rich. As a result, the once-beneficial impulsive desire to know and hyperactive need to explore may now contribute to the challenges faced by individuals with ADHD, such as difficulties in sustaining attention on low-curiosity tasks. By examining the potential evolutionary origins and modern implications of high trait curiosity in ADHD, this paper lays the groundwork for future research to test the theory's predictions and develop targeted interventions that harness the strengths associated with high trait curiosity while mitigating its challenges in mismatched environments. The evolutionary mismatch hypothesis presented in this paper builds upon and extends previous evolutionary theories of ADHD by emphasizing the role of curiosity in shaping the adaptive value of ADHD traits across different environments. By introducing the concept of hypercuriosity, this theory offers a novel framework for investigating the evolutionary origins and modern implications of ADHD, contributing to the growing body of literature on the evolutionary basis of neurodevelopmental conditions.

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Declarations

Ethics Approval This article does not contain any studies with human or animal participants and ethics approval is no required.

Consent to Participate This article does not contain any studies with human or animal participants and informed consent is not required.

Consent for Publication This article does not contain any studies with human or animal participants and consent for publication is not required.

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