J Am Holist Vet Med Assoc. 2023;73:11–17.
https://doi.org/10.56641/WBJT4492

A One Health Approach to Neurodiversity and Attention-Deficit/Hyperactivity Disorder in People and Dogs: Implications for Research, Treatments, and Acceptance

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Abbreviations

ADHD	**Attention-deficit/ hyperactivity disorder**
HSHA	**Hypersensitivity-Hyperactivity Syndrome**
OH	**One Health**

Abstract

The criteria for defining *neurodivergency*, brain differences in individuals compared to "neurotypical" people, and *neurodiversity*, the community of individuals with brain differences, continue to evolve. The current understanding of neurodiversity in humans could also be applied to other species, as One Health (OH) has taught veterinarians about the shared problems of animals and humans. Like humans, dogs can show neurodivergent behaviors, as seen in attention-deficit/hyperactivity disorder (ADHD), making them an animal model for human studies of this condition. Given the increase in canine behavior issues, the correlation of mental health diseases between species could be used to best treat and diagnose both humans and animals. Recognizing that the health of people, animals, and the environment are connected, the author presents a rationale for considering a OH approach to mental health and neurodiversity. By understanding the prevalence of mental health issues and neurodiversity in companion animals, the author contends that a OH strategy may uncover new ways to diagnose as well as reduce human stigmas around mental health, specifically ADHD. Addressing several interdependent factors that prevent humans from seeking help, a coordinated intervention between human health, animal health, and environmental health sectors may have a synergistic effect in the research fields for the treatment of neurodiversity and mental health. In addition, incorporating interrelated etiologies of mental health and behavior issues in all species may contribute to the breadth of understanding these issues for all patients.

Introduction

According to the National Alliance on Mental Illness, in 2020 mental health and behavior disorders affected approximately 1 in 4 people in the U.S. (1, 2). For many diagnoses, terms such as *neurodivergency* are applied to describe brain differences affecting how the brain works (3). This means that those with neurodivergency have different strengths and challenges than people whose brains do not have those differences (3). *Neurodivergent* is not a medical term; rather, it is a way to describe people using words other than "normal" and "abnormal" (3). This is important because there is no single definition of "normal" for how the human brain works (3). There are also substantial uncertainties surrounding when neurologically-based human behaviors cross the critical threshold from variations of normal (*neurotypical*) to pathology (4). The concept of *neurodiversity*, the spectrum of brain differences encompassing neurodiverse and neurotypical people, has been evolving since the 1990s due to more research and a better understanding of brain differences. The term recognizes that there are many structural and chemical differences of the brain previously characterized as "disorders," when in reality these differences represent a more diverse mental and emotional spectrum that perhaps exists outside of a "normal" paradigm. Unfortunately, such differences

can be interpreted as social and scholastic weaknesses by many. What often gets overlooked, however, are the myriad strengths that accompany a differently-abled brain from that of the average or "neurotypical" brain (1, 4).

Studies also show a significant frequency of behavior issues in our canine population. In 2019 the prevalence of canine behavior problems among 4114 dogs worldwide (3122 dogs located in the U.S. and the rest from other countries) was 85%, including a large range of problematic behaviors such as fear/anxiety, aggression, jumping, excessive barking, coprophagia, obsessive-compulsive disorder behaviors, house soiling, rolling in repulsive material, overactivity/hyperactivity, destructive behavior, escaping, and mounting (5). A 2020 Finnish study of 13,700 pet dogs found 14%–20% had separation anxiety, 20%–50% had noise sensitivity, and 20%–25% showed fearfulness (6).

The question arises: Can we bring together our knowledge of behavioral issues in humans and their best friend to make progress in research, treatments, and eventually social acceptance for individuals with behavioral diagnoses? Researchers have concluded that the domestic dog (*Canis familiaris*) is a promising animal model of human behavior and cognition. Dogs are uniquely suited from an ethological and comparative-psychological perspective to be exceptionally able and motivated to competently interact with humans, as certain adaptational processes during their domestication have shaped their behavioral and socio-cognitive skills (7). More specifically, considering the similarities in genetics, physiology, and living environment between dogs and humans, the dog can serve as a more intrinsic model in studying attention-deficit/hyperactivity disorder (ADHD) (8). By recognizing and accepting the high prevalence of mental health struggles and neurodiversity in dogs, a One Health (OH) strategy may also uncover new ways to reduce the social stigma that surrounds human mental health and neurodiversity. Further, this strategy may determine underlying etiologies for these changes and new treatments for both humans and dogs (8). Understanding the factors that affect canine hyperactivity/impulsivity and inattention can benefit not only recognition and management of these traits in dogs but also human ADHD research (8).

In order to increase awareness and find new diagnostic methods and treatments, there is a need for a coordinated collaboration among human, animal, and environmental health sectors to better understand the underlying etiologies of neurodivergency as well as increase public knowledge about neurodiversity in humans and dogs.

One Health, Defined

There are sweeping definitions and various interpretations of OH based on the organization offering the definition. The WHO categorizes OH as an approach in which multiple sectors communicate and work together to achieve better public health outcomes (9). It emphasizes the OH approach as being especially relevant to include food safety, the control of zoonoses, and combatting antimicrobial resistance (9). The CDC's understanding of OH also focuses on public health and how zoonotic diseases impact human health, but still with the main focus being management and separation of these diseases (10). This transdisciplinary approach has the "goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment" (11). The One Health Commission, a globally focused charity organization dedicated to implementing OH and OH actions around the world, encompasses not only the goals of zoonotic disease prevention and monitoring—addressing how to keep humans, animals, and the environment healthy—but also emphasizes the need for interdisciplinary information sharing and education about OH issues to support a paradigm shift in collaborations, information sharing, and active health interventions (12). Their holistic approach looks to create "a world in which the interconnectedness of animals, environment, plants and people is deeply, and systematically recognized, valued and acted upon for the benefit of all" (12).

On a local scale, veterinarians work for OH every day. The health of companion animals is closely connected to the health of their owners and other humans, as well as with the health of other animals (13). It is through a shared model of ADHD between canines and humans that this neurodiversity in both species can be better understood and better support be made available.

ADHD in Humans and Canines

According to the American Psychiatric Association, ADHD is defined as persistent symptoms of inattention and/or hyperactivity-impulsivity that interfere with development and/or functioning (14). It is characterized by dysregulated cognition and behaviors, resulting in inattention, excessive motor activity, and impulsivity (15). This very common multifactorial disorder has been shown to have genetic and biological factors playing important roles (16).

Recent surveys estimate the prevalence of ADHD among children as 1%–12% and 2.5% in adults, although this percentage is low given the current recognition that women are commonly underdiagnosed with ADHD (14, 15).

ISSN 2474-1906

Clinically significant symptoms persist into adulthood in 60% of cases, and often the diagnosis is not made until a person reaches adulthood (16). Attention-deficit/hyperactivity disorder is often associated with abnormalities in social behavior; enhanced aggression; difficulties of adapting to norms; and cognitive, language, motor, emotional, and learning impairments (14).

The diagnosis of ADHD is not exclusive to humans, as it has also been identified in canines. It is a dimension of the normal personality continuum observed across species, including humans and dogs (8). There is a growing body of work demonstrating the dog as an ideal animal model of ADHD with regard to individual differences in behavioral/neuropsychological, cognitive, and personality variables, as well as the relationship between those (7, 14, 17-20).

Barcus et al. were the first to recognize dogs as a suitable animal model for studying hyperactive children and propose a dog model for ADHD (17). Hyperactivity is a characteristic of canine ADHD, which is also a trait found in many neurodivergent humans diagnosed with ADHD. A more recent study by Puurunen et al. showed that dogs may spontaneously develop ADHD-like behavior with hyperactivity, impulsivity, and inattention (18). The French veterinary psychiatry community has proposed a precise definition of an ADHD-like syndrome in dogs, termed *Hypersensitivity-Hyperactivity Syndrome* (HSHA) (21). Dogs suffering from severe HSHA present 3 main signs: hypermotricity (an inability to stop a behavior), lack of satiety, and shorter sleep duration with normal cycles (21). Diagnosis of HSHA is based primarily on exclusion of other causes such as other developmental behavior disorders, emotional or mood disorders, organic disease (neurological disorders, pain), or overactivity in a normal dog triggered by understimulation or insufficient exercise (21).

Despite tools such as the *Diagnostic and Statistical Manual* by the American Psychiatric Association and the *International Classification of Diseases 10*, there is no general agreement on how to diagnose ADHD in humans (21). The situation is similar in veterinary medicine. Different signs with different names are used to describe ADHD-like behavior in dogs, including hyperkinesis, hypermotricity, overactivity, and impulsivity (21).

Studies suggest that 12%–15% and 20% of dogs naturally manifest high levels of hyperactivity/impulsivity and inattention, respectively, making the domestic dog a highly potential animal model for ADHD (8). In contrast to rodents, dogs naturally exhibit a great deal of ADHD-related phenotypic variability (19). These traits are mediated by the same behavioral, biological, and genetic factors in both dogs and humans, and dogs also respond to medication used to treat ADHD in humans (8, 14, 19). Like humans, dogs clinically classified as "ADHD-like" showed lower serotonin and dopamine concentrations (20). In dogs, fluoxetine was useful and well-tolerated in treating ADHD-like behaviors (21-23).

The dog is unique among other domesticated animals, as their origins in human interaction date back 15,000–20,000 years. During domestication, dogs were exposed to similar environmental factors and experienced convergent social evolution. They are also comparable to humans in many complex social cognition tasks, genetics, body size and physiology, and shared environment and lifestyle, including sociality (loyalty and attachment), emotional synchronization, social learning, and obeying behavior rules (8, 24). Finally, dogs exhibit functional impairment in relation to ADHD-like behaviors, similarly to human children (19). The latter feature makes the dog a highly intriguing model for ADHD, as despite the high heritability estimates, nongenetic factors also contribute to the etiology of ADHD (8). However, which environmental factors affect ADHD outcomes and to what extent is not well known (8).

The comorbid association in dogs between hyperactivity/impulsivity and aggressiveness, fearfulness, and compulsive behavior may refer to shared underlying neurobiological pathways and brain structures involved in these traits (8). It has also been found in humans that obsessive-compulsive disorder often co-occurs with ADHD, with both conditions characterized by impaired inhibitory control and deficit in executive function (8).

The overlap between ADHD and generalized anxiety disorder in humans has led to very productive investigations exploring both disorders and areas of intersection (25). In ADHD and generalized anxiety disorder clinical trials in humans, 25% of patients in each population had comorbid ADHD and anxiety (25). Some researchers have suggested that ADHD combined with anxiety might be regarded as a distinct ADHD subtype (25). Animal models consistently demonstrate that brain serotonin systems are critically involved in the response to stressors, as well as in fear and anxiety generation (20). Accordingly, lower serotonin concentrations have been found in dogs showing defensive forms of aggression than in other aggression

forms, and serotoninergic drugs are used to treat fear and phobias in humans and dogs (20).

Dogs have developed an evolutionarily new behavioral regulation system that organizes their social behaviors toward/with humans. This makes the dog an ideal animal model of complex cognitive, social, and human processes. Dogs have been shown to exhibit spontaneous affiliative responses to human social stimuli, including in terms of attachment as well as preferential attention to the eyes of humans and early and specific sensitivity to establishing eye contact with humans, compulsory compliance in social situations, and an ability to adapt emotionally and physiologically to humans, indicated by emotional contagion (7).

Researchers have also identified canine genes for characteristics relevant to agility, friendliness, attachment, and social behavior. It follows that identification of further phenotypic parallels, including those correlated with disinhibition of behavioral control mechanisms, may clarify the genetic basis of ADHD not only in humans but also in dogs. As dogs exhibit socio-cognitive skills that share behavioral and functional characteristics and their physical and social environment with humans, they are a suitable model for testing not only differences in ADHD but also relevant functional outcomes (eg, socio-cognitive skill deficits and social impairment) (7).

Animal-Human-Environment Linkages to the Proposed Etiologies of Neurodiversity

Attention-deficit/hyperactivity disorder is complex, and multiple factors may contribute to its etiology in which genetic and biological factors have important roles (26). Despite the high heritability estimates, environmental factors, including but not limited to nutrition and trauma, contribute to the etiology of ADHD, which are also relevant in the canine population (8, 15, 26). Multiple pre-, peri-, and postnatal environmental factors may be risk factors for ADHD (26). To date, the synergistic action between genes and environment is generally acknowledged, and in ADHD genes are thought to be expressed and cause the disorder in the presence of unfavorable environmental conditions (26).

Dogs exercising more and participating more frequently in activities and training can release their energy and frustration in a controlled manner (8). Several environmental factors in dogs that are associated with hyperactivity/impulsivity and inattention include not getting enough daily exercise and rare participation in activities and training (8). Therefore, in some cases, high levels of hyperactivity/impulsivity and inattention may be due to limited possibilities to release energy and reduce activity levels (8). Studies investigating the effects of exercise on human ADHD are sparse and have small sample sizes, but in children with ADHD, a few meta-analyses demonstrate that physical exercise alleviates hyperactivity, impulsivity, and inattention to some extent (8).

Nutritional/Environmental Links to Mental Health and Neurodiversity

Diet and food composition have been reported to influence mood and behavior in humans and animals (18, 27, 28). Modernization and its consequent changes in human as well as canine diets, including dietary patterns, habits, and food processing, have greatly influenced the gut microbiome (28). Nutrients and the influence over the gut microbiome have been shown to affect mood and cognitive function due to the microbiome-gut-brain axis (28). In humans, it has been established that the microbiome has a potential to influence the development and progression of ADHD (29). With this convincing evidence for the effect of diet and microbiome on ADHD in children, the "typical" canine diet needs to be addressed further (26). More studies on the effects of a highly processed diet on the microbiome and ADHD in dogs may show how a fresh-food diet could be a treatment opportunity.

In addition, studies exploring more specifics of micronutrients, amino acid amounts, and the processing of ingredients could help reduce unwanted behavior in dogs (28-30). A positive effect of polyunsaturated fatty acids on ADHD signs has been reported in dogs (31). Micronutrients such as magnesium and particularly zinc have proved to be important with regard to treatment of ADHD and improvement of ADHD-related symptoms (31). Dogs with at least 1 common behavioral disorder—namely, excessive activity, inappropriate elimination, fearfulness, destructiveness, or aggression toward unfamiliar people—showed a significant reduction in the median score for the severity of fearfulness, destructiveness, and inappropriate elimination with the addition of daily fish oil, magnesium citrate, and zinc sulfate (31).

Benefits of a One Health Approach: Shared Treatment Models

By using shared etiological as well as treatment models, practitioners will be better able to diagnose and treat human and canine patients. The etiology and diagnosis of ADHD in humans and dogs remain unclear, and further studies are needed. The reliability of the ADHD measurement in studies of dogs will benefit humans, as it has been established that the dog is an accurate animal model for human ADHD (19).

ISSN 2474-1906

Effective treatments for ADHD in humans may warrant consideration for dogs. Psychostimulants in humans are a first-choice pharmacological treatment and have shown beneficial short-term efficacy in children (26). However, complete normalization of behavior is rare in children taking psychostimulants, and they may still meet the ADHD criteria (26). Furthermore, medication non-adherence occurs frequently (26). Better treatments preferentially aimed at the prevention of the negative ADHD-linked behaviors in young children and targeting the underlying causes are welcome (26). Such treatments include acupuncture and herbal medicine. Acupuncture can significantly improve ADHD symptoms in human patients while also allowing for the positive aspects of a neurodivergent brain to come through more strongly (32, 33). There is also a growing body of evidence that botanical supplements, including but not limited to ashwagandha (*Withania somnifera*), medical cannabis (*Cannabis* spp), and rehmannia (*Rehmannia glutinosa*), are also beneficial for patients with ADHD (34-36).

Benefit of a Human-Animal One Health Model for Mental Health Stigma

Several studies have shown the harm of the mental health stigma. In modern society, behaviors associated with ADHD, such as fidgeting, sensory overstimulation, inability to concentrate, and hyper-focus, are not typically perceived as positive and are often met with high levels of criticism from others (37). Children with ADHD are not liked as much as their neurotypical peers and are more likely to be bullied during their school years, in part because, as in autism, those with ADHD can have difficulty reading social cues (37). In experimental studies, undergraduate students have reported lower levels of popularity and reduced willingness to interact with people demonstrating ADHD behaviors (37). High-functioning adults with ADHD report higher levels of judgment from others, as evaluations of people with ADHD tend to be negative due to their diagnosis and are not reflective of their success or abilities (37). It is also worthy to note that although individuals with ADHD can be "tone-deaf" when it comes to social situations, there are ADHD individuals with higher-than-normal emotional IQ, leading them to an over-emphasis on social norms and cues, which may contribute to the higher comorbidity of anxiety with ADHD. With companion dogs bred to be attuned to the emotional needs of their humans, it makes sense that dogs with anxiety and ADHD-like signs could be more highly attuned to the emotions of their owners.

Discussion

Normalizing neurodiversity can lead to those differences being celebrated and fully integrated into a functional unit, whether a family or society, rather than ostracized, causing

stigma. A OH model could look to natural differences in brain structure and functioning as a way to strengthen an overall system, rather than something to standardize. Studies show that neurodivergent brains have aptitude for patterns, social justice and fairness, and innovation. Many people can find the value of neurodiversity in pets, and this author proposes that doing so with humans would enrich not only the lived experience of humans but also add to overall health and acceptance of those who are neurodivergent. The increase in canine behavior issues and the correlation of the diseases between species could be used to best treat and diagnose all groups.

One Health goes beyond the practical application of antimicrobial resistance and pathogenic disease surveillance into a model that could be used to decrease social stigma that surrounds addressing mental health and neurodiversity in humans by normalizing it with pets. By exchanging the paradigm of "disability" or "illness" with a "diversity" perspective that would take into account both strengths and weaknesses of these differences, the idea emerges that variation can be positive (2).

Recognizing that the health of people, animals, and the environment are connected encourages a rationale and research agenda for considering a OH approach to mental health and neurodiversity. Sharing models of neurodiversity and mental health between human and animal practitioners will result in a better understanding of causes of neurodivergency, including low serotonin and dopamine levels, but also of nutrient deficiencies, environmental toxin exposure, and other undiscovered etiologies. Normalizing the diagnosis and treatment of behavior issues in companion animals has the potential benefit to decrease the stigma on mental health and neurodiversity in humans.

Adopting a neurodiversity perspective for ADHD will change the focus and purpose of research and how it is practiced (38). Although disorder-based and neurodiversity-inspired researchers have the same ultimate goal—to provide an evidence base to reduce any impairment experienced by neurodivergent people—they go about achieving this aim in radically different ways (23). Research conducted within the disorder-based framework, with which practitioners are most familiar, focuses on understanding the biopsychosocial basis of dysfunction within the individual so that it can be targeted, symptoms can be alleviated, and associated impairment can therefore be reduced (23). A more judicious and perhaps socially efficient approach to treating mental disorders would be to replace a "disability" or "illness" paradigm with a "diversity" perspective that takes into account both strengths and weaknesses and the idea that variation can be positive (2). By adopting a neurodiversity framework informed by studies on both animals and humans, the researcher will turn the spotlight on the neurodivergent person's or animal's physical and social environment (23). A better understanding will be attained concerning how the environment's structure constrains and limits a neurodivergent person/dog and leads to impairment (23). Such a framework will lead to better treatment outcomes for humans and dogs through the results of these studies.

The OH model supports the sharing of experience and research on humans and canines in terms of better diagnostic techniques as well as improved treatment options. Recognizing the roles of food, the environment including interactions with human and animal family members, exercise, air quality, mental stimulation, toxin exposure, and genetic changes provides a more holistic use of OH in mental health and neurodiversity.

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