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Problematic Behavior of Companion Dogs: Significant for Humans, Significant for Society

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Abstract

The relationship between a dog and a person as a predictor of the occurrence of behavioral disorders. Currently, the issue of problematic behavior of companion dogs is becoming particularly relevant. The most important reason for the insufficient adaptation and socialization of dogs in society, ineffective training, and a decrease in the quality of life of animals is the lack of a scientifically based concept for identifying the causes of behavioral disorders and their elimination. It is noted that it is necessary to study early socialization, the formation of the type of attachment between the dog and the owner as a predictor of possible anxious or aggressive behavior. **The purpose of the study.** The study of behavioral disorders in domestic companion dogs. The article provides an analysis of 132 modern studies on various aspects of problematic behavior. **The occurrence and impact of behavioral disorders in dogs.** There is a correlation between aggressive and anxious behavior of dogs with the type of attachment and the way of communication with the owner. The neuroticism of the owner and the avoidant type of attachment are one of the key factors in the formation of behavioral signs of anxiety in a dog. For animals with anxiety disorders, a decrease in life expectancy, an increase in the frequency of aggressive manifestations, and a violation of communication with the owner are shown, which ultimately leads to a decrease in the quality of life in the "owner-dog" dyad. **Identification of behavioral problems in dogs.** Biochemical methods for the diagnosis of behavioral disorders are based on the analysis of the concentration of serotonin, cortisol, oxytocin and dopamine in biological fluids and dog hair. Physiological methods of diagnosing behavioral disorders are based on the assessment of ECG and thermometry. Surveys of dog owners and instrumental and behavioral test samples are also used.

Keywords

companion dog, problematic behavior, anxiety of dogs, aggressiveness of dogs, behavioral problems of dogs, identification of behavioral problems, zoopsychology

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Introduction

Behavioral difficulties in pets, their causes, assessment of well–being and prediction of animal behavior are important problems for humans and society that are relevant in modern research. The complexity of assessing the welfare of pets is determined by the context of human and animal life and interaction, the possibility of its changes and response to social and cultural norms.

Consideration of these factors – primarily aggressive and impulsive behavior – is necessary both to assess the possibility of transferring a dog to a family and to predict the possibility of animal abandonment, disruptive behavior, etc.

Determining the level of well-being of companion pets in research is considered as a complex multifactorial interdisciplinary task. Since the behavior of pets, their level of adaptability and attitude towards them is a direct marker of the level of well-being (human welfare & animal welfare), the increase in the number of news about dog attacks on people may be a sign of destabilization of society. In the Russian Federation, more than 330000 human dog bites are registered annually, and the percentage of bites by domestic dogs prevails. An uncontrolled aggressive dog poses one of the biggest threats from animals in urban agglomerations. This aspect of behavior is especially relevant for human-dog interaction, since it is aimed at maintaining social contacts. The development of approaches to the assessment and prediction of behavioral problems of dogs and their impact on human well–being, taking into account the social context, is a problem that needs to be solved as soon as possible.

In addition to studying behavioral disorders, research is devoted to modeling various psychopathologies and neurodegenerative diseases (Zhu et al., 2019; Zhvania et al., 2021; Zwierzyńska, Pietrzak; 2024). Parkinson's disease and Alzheimer's disease, schizophrenia, and cognitive impairment in aging are most often modeled (Zurkovsky et al., 2013; Zugno et al., 2014, 2017; Zurawek et al., 2018; Zhvania et al., 2021; Zuo et al., 2023). A large layer of developments is associated with the use of rodents as models of various behavioral and cognitive disorders. The knockout model of the gamma-aminobutyric acid transporter gene of subtype 1 (GAT1) (ko) (gat1-/-) in mice shows impaired memory, attention, coordination of movements and increased impulsivity (Yang et al., 2013). Major reviews provide a comprehensive analysis of the possibility of using animals in modeling ADHD-like disorders (Lee, Yoon, 2023; Kim et al., 2024).

In addition to the study of behavioral disorders themselves, a considerable amount of research is devoted to the animal model development of various psychopathologies. A large stratum of research is related to the use of rodents as animal models of behavioral and cognitive disorders, including attention deficit hyperactivity disorder. It should be taken into account that for rodents, these disorders occur only in a simulation situation, and not under conditions of natural behavior. Most often, animal model of single disorder is reconstructed, which does not allow analyzing the comorbidity of the complex disorders. This kind of model does not allow direct extrapolation of the obtained data for the humans. Consequently, more and more research is devoted to modeling phenotype of the behavioral, cognitive, and neurochemical correlates of human psychopathologies in a pet dog model (Bunford et al., 2019; Chen et al., 2023). In both humans and dogs, a high level of arousal is associated with a violation of top-down cognitive control, which mediates the occurrence of anxiety (Chen et al., 2023).

The purpose and article's methodology

The purpose of this review is to summarize information related to the causes and consequences of behavior disorders in domestic dogs (*Canis familiaris* L.), as well as their physiological and neurochemical mechanisms. Almost 130 articles submitted to Pubmed, Crossref, and Google Scholar databases have been analyzed. The selection of articles was carried out for sources published between 2000 and 2024. Full-text scientific articles published in English were selected. The keywords for the selection were determined on the basis of the most commonly used scientific terms in the developments known to the authors of this article: impulsivity, anxiety, aggression, cognitive learning, behavioral disorders, companion dog, cortisol, oxytocin, vasopressin, etc. During the initial selection, 221 sources were selected. After excluding articles with an unavailable full-text version that did not meet the objectives of the analysis, 130 articles were selected. The inclusion of the article in the analysis was carried out because of the expertise of at least two authors of the article. As a main result of the analysis, possible methods are presented to investigate the physiological correlates of behavioral disorders in dogs.

The dog-human relationship as a predictor of behavioral disorders

The uniqueness of the domestic dog lies in the adaptation of its psychological processes (because of domestication) primarily for the establishment of strong and effective communication with humans (Topál et al., 2009; Bunford et al., 2019. Dreschel, 2010). This is a fundamental difference between dogs and wolves as their closest relatives. First, wolves' behavior focuses on in-group interactions between conspecifics (Marshall-Pescini et al., 2015), whereas dogs focus on interactions with their owners. At the same time, when analyzing the behavior of dogs, it is necessary to distinguish between problematic behavior associated with the manifestation of anxiety or aggression, and undesirable behavior. Undesirable behavior is the natural behavior of a dog that is unpleasant to the owner (Boyd et al., 2018; Kimura et al., 2022; Miller et al., 2022).

The unique behavior of domestic dogs, their acquisition of social interaction skills and adaptation to humans (e.g., staring, gesturing, and certain behaviors), is to some extent regulated by the endocrine system, in particular glucocorticoids and oxytocin (Thielke & Udell, 2017; Kikusui et al., 2019). In a number of studies, reliable evidence for a specific attachment style between humans and dogs, based primarily on social interaction and life experience, is the change in oxytocin concentrations in bodily fluids (Nagasawa et al., 2015; Thielke & Udell, 2017; Wirobski et al., 2021). Wirobski et al. (2021) showed a positive correlation of oxytocin concentration in the urine of domestic dogs after physical contact with the owner, but none in domesticated wolves.

A study by Nagasawa et al. (2015) found an increase in oxytocin concentration in owners' urine after staring at a dog. This, in turn, correlates to an increase in the concentration of oxytocin in the dog's urine (Nagasawa et al., 2015). In addition, even for socialized wolves, interaction with humans through the exchange of stares is not shown to decrease performance on cognitive tests (Miklósi et al., 2003; Bentosela et al., 2016). This proves the existence of a positive feedback relationship between species and may be one of the mechanisms of coevolution between humans and dogs. It is also assumed that this mechanism works as a way of forming social attachment (Miklósi et al., 2003; Nagasawa et al., 2015; Bentosela et al., 2016)., separation anxiety (Tilke, Udell, 2017) and regulation of social behavior (Keys et al., 2017; Banford et al., 2019).

Due to the presence of high emotional attachment between humans and animals, as well as complex social interaction, it is likely that the probability of behavior disorders (not only ADHD behavior) in a dog is related to the characteristics of the psychological profile of the owner. According to the work of Gobbo E, Zupan M. (2020), aggressive behavior toward humans correlated with low sociability of the animal, and high levels of neuroticism of their owners. Human neuroticism, as an analogue of insecurity in dogs, correlated with anxiety and restlessness (Salonen et al., 2022). Fearfulness, as a personality trait, on the other hand, has been closely correlated with sensitivity to noise (Tiira et al., 2016; Salonen et al., 2022).

The occurrence of separation anxiety is also determined by the relationship between the owner and the dog. An avoidant attachment style, in which the owner does not provide the dog with an appropriate level of attention to its basic needs, leads to an increase in the animal's neuroticism and the emergence of separation anxiety. Hence, the key factor, according to the authors, is not the owner's neuroticism, but the avoidant attachment style (Konok et al., 2015). In addition, avoidant attachment style may be the cause of the dog's aggressive behavior already towards the owner (Gobbo, Zupan, 2020). The importance of separation as a stressor is evidenced by a smaller increase in a dog's heart rate during contact with a dangerous stranger in the presence of the owner compared to separation and loneliness (Gácsi et al., 2013).

Dogs of emotionally unstable owners are characterized by a high frequency of manifestations of signs of separation anxiety, fear of a stranger. The main reason for this is the lack of socialization of dogs. Owners with an increased level of anxiety and neuroticism limit the socialization of the dog, reducing the possibility of obtaining new information and contributing to an increase in the frequency of aggressive behavior (including towards the owner himself). Another factor of the owner's influence on behavioral problems of dogs, is the use of aversive or confrontational training methods associated with, among other things, negative reinforcement (Dodman et al., 2018). As a result, the dog has a low level of socialization, a weak connection with the owner is formed, which leads to a lack of understanding of commands, incorrect behavior from the point of view of the owner and an increase in stress levels. If the owner does not specify the requirements and does not allow the dog to adapt to the situation, this leads to increased stress in the dog and aggravation of undesirable behavior (Miller et al., 2022).

Based on Ainsworth's classification system, Solomon J. et al. (2019) identified four main patterns of dog-owner attachment.

- Secure: finding and initiating contact, striving to get closer to the owner, maintaining contact for at least 10 seconds. The dog actively interacts with the owner after separation.
- Avoidant: the dog's lack of desire for contact and interaction, refusal to invite owner to play, lack of search for the owner when parting for at least 30 seconds.
- Ambivalent: the mismatch of the actions of the dog and the owner to maintain contact, the owner's misunderstanding of the dog's current motivation; physical contact is accompanied by significant efforts on the part of the dog.
- Disorganized: violation of the search for contact and interaction, avoidance or resistance to the interaction of the dog and the owner when initiating human contact.

An increase in owner attentiveness to the pet led to a decrease in the likelihood of aggressive or hyperactive behavior (Solomon et al., 2019). In turn, in the classic strange situation test, less aggressive dogs showed greater attention and attachment to their owner compared to dogs that avoided such contact and exhibited aggressive behavior (Riggio et al., 2020). In addition, a modified strange situation test revealed that dogs with a secure attachment type sought to initiate contact with their owner while solving the test; whereas, dogs with an avoidant attachment type did not attempt to initiate contact (Riggio et al., 2020). Therefore, the owner-dog relationship is identified in many studies with the parent-child position (Konok et al., 2015; Dodman et al., 2018; Solomon et al., 2019; Riggio et al., 2020 et al.)

Dysfunctional relationships between dogs and owners, which are usually detected already at the stage of occurrence of behavioral problems (primarily anxiety and aggression), will have negative consequences for both sides. In particular, in dysfunctional dyads, owners are more likely to report injuries of various origins to their dogs. Therefore, timely provision of medical care and a safe lifestyle by the owner of the dog are considered as a sign of a functional dyad (Canejo-Teixeira et al., 2019).

Non-medicinal causes of behavioral disorders in dogs living in families

Because of the special role of companion animals in modern life, the stress factor takes on a special role in assessing the prediction of behavioral problems. In addition to the classical and most obvious markers of well-being, which include health status, longevity, growth traits, occupational manifestations, etc. (Sonntag, Overall, 2014), behavioral markers play an important role, primarily the presence of fears, anxiety, and impulsive behavior. Any behavioral markers can be classified as unwanted for the owner (but normal for the animals), and are a sign of true behavior disorders (Sonntag, Overall, 2014). The manifestations of such disorders can range from mild to disabling, leading to euthanasia or owner abandonment of the animal (Masson, Gaultier, 2018).

The simultaneous accounting of fear and aggression in dogs is due to a similar neurochemical and physiological nature with different behavioral manifestations (Hydbring-Sandberg et al., 2004; Gobbo, Zupan Šemrov, 2021; Mikkola et al., 2021). Fear is regarded as one of the most common reasons for aggressive behavior in dogs, even though owners may not interpret aggression as fear (Tiira, Lohi, 2014; Tiira et al., 2016). Furthermore, it is for fear that fear has been shown to have the strongest comorbidity with aggressive behaviors, lack of early socialization, and aging (Tiira et al., 2016; Mikkola et al., 2021).

As a basic emotion that determines an organism's survival, fear can become a pathological character trait when present for a long time (Tiira et al., 2016; Hakanen et al., 2020). Fear associated with various stimuli has been shown to be closely related to neuroticism (also called indecision) in dogs (Salonen et al., 2022). Moreover, the manifestation and degree of indecision in dogs is directly influenced by his or her interaction style with the owner (Dodman et al., 2018). Another factor influencing the owner's behavioral problems of dogs is the use of aversive or confrontational training methods, including those associated with negative reinforcement (Dodman et al., 2018). Most often in this situation, the authors noted aggression toward the owner and strangers, compulsive barking, separation anxiety, and urination and defecation in the house.

The initial stage of socialization has a significant impact on the development of the voluntary attention system in dogs. A common behavioral problem is social fear - fear of strangers or dogs (Puurunen et al., 2020). The basis for social fear, according to the authors, is insufficient socialization at an early age; in addition, a significant correlation with small body size and castration has been shown. Non-social fear is characteristic of dogs deprived of sufficient socialization in puppyhood, socialization with kin, and adequate training (Hakanen et al., 2020).

In addition, signs of ADHD behavior were more pronounced in male dogs, young dogs, and medium-sized dogs; lack of training and prolonged exposure to loneliness were also risk factors (Sulkama et al., 2021). ADHD behavior in dogs was significantly influenced by training (trained dogs were less likely to exhibit behavioral disorders due to developed self-control skills) and age (as older animals generally experience a decrease in motor activity) (Vas et al., 2007; Sontag et al., 2010).

Similar data are presented in Foraita M, et al (2021), where early quality socialization, good housing conditions, human contact, training and the presence of stress are noted as key factors in the development of attention. Solvable tasks and mild stress have a positive effect on attention functions, while insurmountable difficulties and severe stress have a negative effect. However, the effect of prior training was not a reduction in the number of erroneous responses, but a shortening of reaction time, which, according to the authors, was a reflection of response confidence and focus on human interaction (Bunford et al., 2019).

The causes of behavioral disorders in dogs

In the current literature, there is an evidence that 72-85% of dogs living in families have some kind of behavioral disorder (Salonen et al., 2020; Powell et al., 2021). These behaviors may be normal but undesirable to the host, or they may actually represent a behavioral pathology. Drastically negative impact on both dog and owner quality of life lead to the importance of investigating and correcting such behaviors in pets (Masson, Gaultier, 2018; Bleuer-Elsner et al., 2019 Fux et al., 2021; Mikkola et al., 2021). Those problems include aggressive and disruptive behavior, impulsivity, hyperactivity, separation anxiety, excessive barking, etc. (Lit et al., 2010; Mikkola et al., 2021). Many studies repeatedly cite behavior disorders as a reason for refusing to further keep of an animal, placing dogs in a shelter, and/or euthanizing it (Vas et al., 2007; Masson, Gaultier, 2018; Bunford et al., 2019; Salonen et al., 2020; Fux et al., 2021; Mikkola et al., 2021; Powell et al., 2021; etc.). As a result, there is an increase in the number of stray dogs due to the rejection of maladjusted pets (having an increased level of anxiety and aggression).

According to Dinwoodie I. R. et al. (2019), 85% of dogs (data based on the analysis from at least 17 countries) have some kind of behavioral problem, with 44% of these disorders being related to fear and/or anxiety. The second most common problem (30%) is aggressive behavior (Dinwoodie et al., 2019). The incidence of ADHD behavior in domestic dogs is also quite high, ranging from 12% to 34%, according to various data (Fux et al., 2021; Salonen et al., 2021). According to Salonen et al. (2021), on average, 20% of dogs have clear attention deficits and 15% have hyperactivity/impulsivity. According to K. Tiira et al (2016), general fearfulness is characteristic for 26.2% of dogs, noise sensitivity for 39.2%, and separation anxiety for 17.2%. Similar data are presented in the study of Dinwoodie I. R. et al. (2019).

The literature suggests common physiological mechanisms of human and canine ADHD. Similar to humans, ADHD in dogs is the result of disfunctional interaction between the frontal cortex and striatum (Winstanley et al., 2006; Genro et al., 2010; Sontag et al., 2010), as well as disruption in interactions between mesocortical and mesolimbic regions (Sonuga-Barke, 2003; Oades et al., 2005). These interactions are mediated by dopaminergic, serotoninergic (Oades, 2008) and noradrenergic systems (Oades et al., 2005). Therefore, it has been suggested that functional disorders of the aforementioned mediator systems play a major role in the development of the disease (Oades et al., 2005; Russell, 2007; van der Kooij, Glennon, 2007; Sontag et al., 2010).

In a study by Chen et al. (2023) a violation of the formation of the brain connectome in anxious dogs has been shown, which leads to a decrease in the level of motor control, deterioration of learning ability and adaptability.

A key aspect is the possible similarity of the molecular and neurobiological mechanisms of this disorder in both dogs and humans (Puurunen et al., 2016). For dogs, horses, and chimpanzees, a tandem repeat polymorphism of the DRD4 gene in exon 3 of the dopamine receptor D4 gene, which is thought to be associated with ADHD, has been identified similar to humans (Hejjas et al., 2007). Specifically, German Shepherds and Siberian Huskies that exhibit ADHD phenotype (especially impulsivity and lack of attention) have been shown to be characterized by short alleles of the dopamine receptor D4 (DRD4) exon 3 and tyrosine hydroxylase intron 4 repeat polymorphisms (Wan et al., 2013). This fact is the basis for the use of drugs that affect the function of the dopamine transporter in ADHD (Fernandez et al., 2021).

One possible approach to uncovering the biological pathways of ADHD is to use animal models, such as dogs, that spontaneously exhibit ADHD-like behaviors such as hyperactivity, impulsivity, and inattention (Lit et al., 2010; Wright et al., 2012; Puurunen et al., 2016). These behavioral disorders are phenotypically similar to a number of psychopathologies in humans, which may be an indication of homology of biological mechanisms of such disorders in dogs and humans. (Lit et al., 2010). In addition, behavior consistent with psychopathological disorders in dogs is spontaneous in dogs, whereas in standard laboratory animals it is usually induced (Salonen et al., 2022). Consequently, the domestic dog is a suitable model for investigating the mechanisms underlying mental disorders in humans (Lit et al., 2010; Salonen et al., 2022).

Vitamin D deficiency may also be a factor provoking behavioral disorders. This is due to its ability to regulate brain development in early ontogenesis, the formation of synaptic plasticity, neuroprotection, and the dopaminergic neuronal system (Bivona et al., 2019; Gáll, Székely, 2021). In addition, vitamin D deficiency is associated with impaired regulation of dopamine and serotonin neurotransmission (Gáll, Székely, 2021). Early vitamin D deficiency is a contributing factor to impulsivity and decreased inhibitory control (Turner et al., 2013).

The disruption of the sleep-wake cycle that leads to disruptions in serotonergic, dopaminergic, and noradrenergic systems (Mogavero et al., 2018) and synaptic homeostasis (Frank, 2020) is another important factor in behavioral disorders in dogs, particularly in ADHD behavior and violent aggression attacks.

Chronic pain is a separate and important factor (Mills et al., 2020), and new behavioral problems may arise, reinforce or exacerbate existing problems. Aggressive behavior and sensitivity to noise are the most common due to chronic pain (Lopes Fagundes et al., 2018; Mills et al., 2020), which is associated with higher levels of anxiety in the animal (Mills et al., 2020).

The Covid-19 pandemic contributed to the exacerbation of behavioral disorders in dogs. For owners, keeping an animal in the house in forced isolation seemed to reduce stress (Bowen et al., 2020; Grajfoner et al., 2021). However, the unfavorable social environment, limited walks and lack of access to veterinary care have led to a sharp increase in tension, aggression and fear in animal behavior, exacerbating existing problems and creating new ones (Bowen et al., 2020; Parente et al., 2021).

However, it is important to keep in mind that it is not uncommon to underestimate the severity of behavioral problems and their causes, or to misinterpret them, due to lack of knowledge about the possibility of such situations and the signs of behavioral disorders (Mikkola et al., 2021; Powell et al., 2021). Competent analysis and interpretation of the causes and consequences of behavioral problems in dogs will allow the owner to recognize problems, identify contributing factors and take corrective actions timely.

Using owner questionnaires to identify behavioral problems in dogs

The questionnaires for dog behavior assessment by their owners can be adapted versions of similar methods for assessing ADHD in children. Undoubted advantages of using specialized and adapted questionnaires are the possibility of obtaining quick results - also with large groups of animals under study - as well as good owner awareness of the behavioral features of the dog and a positive attitude towards this kind of testing (Vas et al., 2007). The validity of behavioral testing of dogs and owner interviews is determined in several ways: the repeatability of the result after a certain period of time, the comparison of the result obtained with a known benchmark, and the ability to compare the result of the questionnaire and the behavioral tasks (Tiira, Lohi, 2014). In particular, the owner's responses to the questionnaire regarding fear of noise, a persistent response of the dog that changes with age, correlated significantly with behavioral parameters in the animal's response to the appearance of a stranger and interaction with him (Tiira, Lohi, 2014).

In Segurson S. A. et al (2005), based on a questionnaire aimed at identifying reasons for abandoning and placing a dog in a shelter, revealed a curious effect of the ability to make test results public on their validity. The key questions in the analysis were the presence of aggression or fear of a stranger. The prospect of publicly releasing the test results – including for further dog placement – significantly reduced the likelihood of detecting signs of aggressive behavior or fear of a stranger or other dog, as well as impaired social adjustment and separation from the owner.

Vas J. et al (2007) presented a 13-item questionnaire based on a similar one for children to assess ADHD-like behavior in domestic dogs. The questionnaire allows analyzing the development of attention-holding skills, impulsivity and motor activity in attention, impulsivity and motor activity in domestic dogs.

In a large series of studies (over 13000 dog) (Tiira, Lohi, 2014; Puurunen et al., 2016, 2020, Tiira et al., 2016; Hakanen et al., 2020; Junttila et al., 2021; Mikkola et al., 2021; Salonen et al., 2020, 2021, 2022) a survey test was developed and validated to analyze a set of behavioral problems. These include ADHD behavior (inattention/impulsivity, aggression, anxiety, social and non-social anxiety, noise sensitivity, separation anxiety and compulsive behavior. In addition, a separate section of the questionnaire is devoted to an analysis of the dog's early socialization and current circumstances.

That series of studies described a high comorbidity of behavioral disorders. In a study by Salonen et al (2021), based on an analysis of questionnaires administered to Finnish dog owners regarding the frequency of some signs of ADHD behavior (as well as aggression, anxiety, noise sensitivity, separation anxiety and several others), it was found that in 32% of cases the probability of behavioral disturbances correlated with high sensitivity to noise. The highest comorbidity was shown between hyperactivity/inattention, separation anxiety, fear and aggression behaviors and separation compulsion, and between fear and aggression. High comorbidity has been shown for fearfulness and aggressive behavior: aggressive dogs were more than three times more likely to be fearful than non-aggressive dogs (Salonen et al., 2020). Sulkama et al (2021) reported similar results: high levels of hyperactivity/impulsivity were accompanied by high levels of aggressive fearfulness and inattention.

In general, according to the authors, fear and sensitivity to noise are the most important concomitant disorder in dogs exhibiting behavior. In particular, when separation anxiety was detected, signs of ADHD behavior were 4.1 times more frequent, inattention was 3.4 times more frequent, and fear was 2.8 times more frequent than in dogs without separation anxiety. The gender of the animal also appeared to be an influencing factor. Aggression and hyperactivity/impulsivity were more frequently detected for males, while fearfulness was predominant for females. The likelihood of aggressive behavior increased with age - older dogs were more aggressive than younger dogs (which may be related to the presence of chronic pain) (Mikkola et al., 2021).

In terms of breed differences, the most pronounced traits on the hyperactivity/impulsivity index were shown for the Cairn Terrier, Jack Russell Terrier, German Shepherd, and Staffordshire Terrier, while the least pronounced were shown for the Chinese Crested Dog, the Hardy Collie, and the Chihuahua (Sulkama et al., 2021).

A number of personality traits such as neuroticism for example can be a precursor to behavioral and psychopathological problems in dogs. Salonen M. et al (2022) correlated seven personality traits with ten undesirable behaviours, based on the analysis of questionnaire data from 1,360 dog owners. It is noteworthy that a trait similar to neuroticism in humans was positively correlated with the majority of undesirable behaviors extracted.

The use of the described questionnaires for owners of dogs exhibiting ADHD symptoms has the significant disadvantage of subjectivity of the information obtained, as well as the owner's initial misjudgment of the animal's behavior. This implies a distortion of the actual results (Bleuer-Elsner et al., 2019; Fux et al., 2021); consequently, such questionnaires are often not applicable in clinical practice. In a study by Lit L. et al. (2010), when evaluating the validity of a modified test aimed at assessing ADHD in humans, validity was found only for the inattention and hyperactivity/impulsivity scales.

Instrumental and behavioral tests

Impulsivity as a typical trait closely related to human and animal ADHD (Sulkama et al, 2021) manifests as the ability to act without first assessing the situation (Oades, 2008), and the inability to suppress ineffective behavior (Junttila et al, 2021). Two main manifestations are suggested for impulsivity: impulsive action (inability to suppress unproductive, unwanted action) and impulsive choice. The former is more common in male dogs and the latter in females (Winstanley et al., 2006; Wright et al., 2011; Weafer, de Wit, 2014; Junttila et al., 2021). In humans, excessive motor activity and inability to concentrate for a long time are considered key manifestations of impulsivity, whereas in dogs – inattention, impulsivity and aggression (Vas et al., 2007; Bleuer-Elsner et al., 2019; Bunford et al., 2019).

Impulsivity is based on deficits in inhibitory control and inhibition of behaviors. It has been argued that in dogs, impulsivity is inherited and is a predictor of behavioral problems, including aggression (Mongillo et al., 2019; Junttila et al., 2021). In addition, so-called cognitive impulsivity in dogs, which is associated with the choice of immediate or delayed rewards, does not change as they mature (Riemer et al., 2014). Because behavioral inhibition deficits are a key risk factors for psychiatric disorders of various genesis (Bunford et al., 2019), an assessment of inhibitory control must come to the forefront when assessing the nature of behavior problem. Inhibitory control is a cognitive skill that has been extensively studied in humans and other animals. It is defined as the ability to inhibit immediate, ineffective behavior in favor of more beneficial behavior. In contrast, a lack of inhibitory control - impulsivity - is often seen as a tendency to act prematurely, without forethought or consideration of consequences (Junttila et al., 2021).

The literature considers three interrelated phenomena as behavioral manifestations of inhibitory control: suppression of the primary reaction to an event, halting the current action and lengthening the decision-making time, and interference tolerance as a lack of reactions to external stimuli (Bunford et al., 2019). Animals with good inhibitory control exhibit high interference tolerance, whereas those with poor control are easily distracted from the task by external stimuli and extraneous actions (Müller et al., 2016).

For animal's behavior tests in laboratory, impulsivity can be measured using computerized tests aimed at assessing behavioral paradigms. Such testing can be based on both an assessment of the likelihood of premature response, the difficulty of inhibiting unwanted actions, and the lack of consideration of the possibility of multiple correct response options (Dalley, Roiser, 2012). In addition, a good method of assessing inhibitory control in dogs is the cylinder test, in which the dog must bypass a transparent barrier (cylinder) rather than reaching across it to receive a reward (Junttila et al., 2021). Inhibitory control is better represented in females, hence, they perform target tests more efficiently; in addition, females are more attuned to interacting with humans during complex tasks (Junttila et al., 2021). This is especially important in view of the opinion that dogs do not transfer the existing experience of a complex task to similar ones, but rather perceive them as new situations (Müller et al., 2016).

When evaluating ways analyze indicators of behavior disorders, we were able to find several studies in which the probability of impulsive choice is assessed using delayed discounting tasks. This test trial is regarded as the most valuable for measuring the probability of impulsive choice (Winstanley et al., 2006) and involves choosing between receiving a small reward after a short time interval and a more substantial reward after a longer time interval. These studies have unequivocally found that for both humans and animals in behavioral disorders there is a choice of immediate minor reinforcement and rarely a choice of major delayed rewards (Winstanley et al., 2006; Dalley, Roiser, 2012 Sjoberg et al., 2021). The probability of choosing immediate reinforcement is an indicator of impulsivity (Sjoberg et al., 2021). It has also been shown that for animals no effect of the inter-stimulus interval on the choice of options in the delayed reward test has been shown (Sjoberg et al., 2021), whereas for humans a significant effect of the length of the inter-stimulus interval on the probability of choice has been shown (Sjoberg et al., 2021). The results of The Dog Impulsivity Assessment Scale (DIAS) owner test and behavioral tests related to delayed or immediate reward choice were closely correlated with each other, allowing these research methods to be used together (Riemer et al., 2014).

In dogs, an increase in the number of erroneous reactions in the Go/No-Go test is regarded as a correlate of hyperactivity and/or impulsivity (Bunford et al., 2019). At the same time, sufficient cognitive inhibition has not been shown for dogs as a delayed reward ability (Bunford et al., 2019). A method for assessing behavioral stability is the stability of solving tasks involving behavioral inhibition; however, these test trials have been developed and applied only to children. For animals, the authors (Tiira, Lohi, 2014) have not found similar studies.

A common and rather significant disadvantage of survey and behavioral analysis methods in dogs is the lack of validity, repeatability and objectivity of these techniques, as well as the great influence of the testing environment and the promising publicity of the results. Specifically, owners compared to abandoned dogs; and based on the Canine Behavioral Assessment and Research Questionnaire (C-BARQ) scale results rated behavioral problems in dogs living at home more loyally, behavior disorders were present in both cases. Consequently, abandoned dog owners tended to provide more accurate information (Powell et al., 2021). This may be due to both an underestimation of the complexity of the situation and a reluctance to publicly voice problems.

At the same time, it is the behavioral tests that allow obtaining objective results of behavior in the natural environment due to the absence of exogenous interferences (Gobbo, Zupan, Šemrov, 2021) A common disadvantage of behavioral tests is the possibility to record and analyze short fragments of activity in strictly defined, standardized situations (Magula et al., 2019).

A series of papers (Bleuer-Elsner et al., 2019; Fux et al., 2021) have proposed a method for the automatic tracking and video recording of a dog's voluntary movements in consultation with a veterinarian or zoopsychologist. The hypothesis of the study is the presence of specific motor patterns in dogs with ADHD behavior, which can be recorded and analyzed by applying specialized algorithms based on machine learning. This cycle of work proposes 12 main indicators of motor activity, of which the key ones are high movement speed, large coverage of space and constant changes in the direction of movement. Notably, these indicators showed no correlation with the gender, weight, breed, or castration of the animal (Bleuer-Elsner et al., 2019). According to the authors, the differences in movement patterns between healthy dogs and dogs with ADHD behavior averaged 81% (Fux et al., 2021).

A dog's movement patterns are seen as a reflection of its behavioral traits (Bleuer-Elsner et al., 2019; Fux et al., 2021), whereas sonic behaviors (barking, growling, howling) are seen as markers of emotional states (Faragó et al., 2014; Pongrácz, 2017; Kim et al., 2018; Jégh-Czinege et al., 2020). The integrated assessment of movements and vocalizations allows objective results of behavior in the natural environment due to the absence of exogenous disturbances (Gobbo, Zupan Šemrov, 2021).

Based on the literature, this confirms the identified correlation of ADHD behavior with increased intensity of motor activity, lack of response to stop cues, and low sensory homeostasis threshold (Bleuer-Elsner et al., 2019). The high frequency of change of direction was also associated with inattentiveness of the animal and an increased response to mild stimuli.

Application of biochemical and physiological parameters

Comprehensive analysis of behavioral, physiological and biochemical indicators will allow a more correct assessment of animal behavior, the causes of adverse reactions, as well as to predict further developments. Due to the need to address this problem, we analyzed the literature regarding the use of a number of objective methods for assessing behavioral and physiological markers. Both methods used for animals and methods for humans, which with proper adaptation could be applicable for animals or become a promising method, were analyzed. The analysis of physiological and biochemical parameters is necessary to obtain a complete picture of the reaction to undesirable behavior in real time.

Biochemical indicators of behavioral disorders

A study by Puurunen J. et al. (2016) proposed the study of metabolites contained in blood plasma by liquid chromatography and mass spectrometry as an objective method for studying ADHD behavior in German shepherds. This revealed a negative correlation of ADHD behavior with the plasma concentration of phospholipids and the tryptophan metabolite, 3-indolepropionic acid; a positive correlation, however, was found for another tryptophan metabolite, kynurenic acid. More intense ADHD-like behavior was associated with decreased plasma phospholipid levels but increased fatty acid content. In total, the authors suggest 27 tryptophan and phospholipid metabolites as possible markers of ADHD-like behavior that correlate with attention deficits and/or impulsivity (Puurunen et al., 2016). Lower cholesterol and bilirubin concentrations, as well as low levels of omega-3 fatty acids, may also influence the increase in aggressive behaviors (Re et al., 2007).

Impulsivity in domestic dogs was assessed by owner surveys, the Impulsivity Assessment Scale (DIAS), a delayed reward test, and urine dopamine and serotonin concentrations (Wright et al., 2011, 2012). High impulsivity scores on the behavioral and questionnaire tests correlated with low serotonin concentration and low serotonin/dopamine ratios. Low levels and poor regulation of serotonin and dopamine are associated with disruptive and/or aggressive behaviors exhibited by ADHD in dogs (Fux et al., 2021).

High levels of anxiety correlated with an increase in cortisol and serotonin concentrations in saliva, whereas aggressive behavior correlated with a decrease. This, according to the authors, can be explained by the fact that an increase in cortisol levels reflects emotional arousal, while a decrease in serotonin reflects a fear response (Gobbo, Zupan Šemrov, 2021). Similar data were shown in the work of M. León et al. (2012), where the analysis of serotonin concentration in serum, blood plasma and platelets also revealed an inverse correlation between the activity of the serotonergic system and the level of aggression in dogs (serotonin concentration was significantly lower in aggressive dogs).

An indirect method of measuring fear of noise exposure is an increase in cortisol in the hair (Siniscalchi et al., 2013, Roth et al., 2016). Social contact with humans correlated with decreased cortisol concentrations in the hair, reflecting reduced stress levels (Roth et al., 2016). Consequently, cortisol levels in the hair reflect a dog's chronic state of emotional reactivity or temperament (Siniscalchi et al., 2013). In addition, the rate of change in cortisol concentration in saliva correlated with a dog's attachment to its owner: dogs with high levels of attachment had a higher rate of change in this index than disorganized dogs (Schöberl et al., 2014).

Attempts to correct aggression by applying intranasal oxytocin modulated not so much behavioral disorders (where no significant difference was shown compared to placebo) (Hernádi et al., 2015), but rather an increase in social interaction with humans (Romero et al., 2014; Hernádi et al., 2015). In addition, the effect of oxytocin was influenced by the relationship with humans and the dog's individual level of aggression (Hernádi et al., 2015).

Similar data were obtained when attempting to correct aggressive behavior in shelter dogs by consuming olive oil containing 5% cannabidiol. Pure olive oil was used as a control to assess the severity of the placebo effect. As a result, although there was a decrease in aggression toward humans in dogs that took cannabidiol, there were no significant differences compared to the control group. Also cannabidiol had no significant effect on the manifestation of stress (Corsetti. Et al., 2021).

Increased oxytocin concentrations in saliva and plasma after human contact (MacLean et al., 2017). this effect in saliva appears with a significant delay (at least 10 minutes) compared to plasma, and persisted longer. In addition, saliva intake does not lead to increased stress levels and pain effects, and is not contaminated by interferences similar to plasma. In addition, saliva contains oxytocin in the free state, whereas plasma contains it in the bound state, which is more difficult to detect with the test systems used in these studies.

Physiological indicators of behavioral disorders

The importance of considering autonomic regulation indices when assessing behavioral disorders in animals is also related to the available data on the correlation of cardiac cycle indices and the ability to regulate activity (Staton et al., 2009; Wickramasuriya, Faghih, 2019; Adelhofer et al., 2020; Al et al., 2020). Cardiac cycle metrics and central regulation are linked by intercorrelated relationships, and are a source of information about attention (Cuevas, Bell, 2011). From this perspective, accounting for the physiological correlates of the psychoemotional state of animals as well as the activity performed allows for a more accurate assessment of the degree of adaptation to the current situation (Luque-Casado et al., 2016; Fan et al., 2020).

The most sensitive indicator is heart rate variability (HRV) (Maros et al., 2008; Gácsi, et al., 2013; Solhjoo et al., 2019), as it is the central mechanism of cardiovascular regulation (Hjortskov et al., 2004). This occurs due to reflection in HRV indices of the upward modulation of cerebral function with changes in baroreceptor activity (Duschek et al., 2009). This is associated with increased perfusion of brain tissues with blood, which suggests the presence of unified mechanisms of synchronization of cardiac and CNS activity (Park et al., 2015). Hence, HRV is one of the reliable noninvasive methods of measuring the mammalian organism response, including to stressogenic influences (Amaya et al., 2020).

High HRV values are indicators of adequate adaptation to the new environment and effective CNS functioning, whereas low values are the signs of inadequate adaptation (Nagendra et al., 2015). As a result, a quantitative assessment of adaptability is possible based on HRV values (Thayer et al.,20 09; Gianaros et al., 2015; MacNeil et al., 2017; Mulcahy et el.,2019). The high-frequency component of heart rate variability (HF) is considered to be the most sensitive marker for assessing stress levels (MacNeil et al., 2017) as well as heart rate control by the parasympathetic part of the vagus nerve (Mulcahy et al., 2019). A decrease in HF values is observed with an increase in task difficulty (Hjortskov et al., 2004; Duschek et al., 2009; Luque-Casado et al., 2016), and an increase with a decrease in erroneous reactions (Gianaros et al., 2015). For heart rate and high-frequency component of HRV, the opposite dynamics has been shown with increasing difficulty of the load, the increase in HR is accompanied by a decrease in HF (Yu et al., 2009).

An inverse correlation between measures of voluntary attention and HF has been shown (Duschek et al., 2009; Luque-Casado et al., 2016): individuals with high baseline HF values perform better on tasks involving the attention and inhibitory control system (Mulcahy et al., 2019). Consequently, HRV HF can be used as an early marker of impairment (Forte et al., 2019; Spangler, McGinley, 2020)

To explain this relationship, the literature suggests a model of neurovisceral integration linking a particular set of neural structures - primarily the prefrontal cortex, limbic system, and brainstem - to heart rate variability and cognitive function (Thayer et al., 2009; Yu et al., 2009; Zhang et al., 2010; Gianaros et al., 2015; Mulcahy et al., 2019). The ability to self-control in emotionally colored activities correlates with the balance of autonomic processes on measures of cardiac regulation, suggesting a common neuroanatomical basis for both processes (Tonacci et al., 2019).

There are several works concerning the analysis of overexcitation of the autonomic nervous system and reflection of this condition in HRV parameters in domestic dogs. At the same time, all the works we analyzed were related to the correction of the state of stress or undesirable behavior. The study by Wormald D. et al. (2017) based on HRV parameters confirms the view of the peculiarities of the physiology of the cardiovascular system in dogs with behavioral disorders, namely the influence of anxiety on the indicators of standard deviation of R-R-intervals, the increase in the spectrum of the low-frequency component of the heart rhythm LF and HF.

A study by M. Amaya et al (2020) proposed a method to reduce stress in shelter dogs by sensory enrichment of the environment. Of the options offered, musical stimulation was the most effective. This exposure led to the activation of the sympathetic and parasympathetic parts of the ANS, which was reflected in higher HRV indices. An increase in HRV was also shown when receiving positive reinforcement (the dog's preferred toy) (Maros et al., 2008). In contrast, aggressive behavior and inadequate adaptation were accompanied by a decrease in HRV and deterioration of autonomic regulation (Craig et al., 2017). Similar studies have shown a direct correlation between a decrease in behavioral signs of anxiety, cortisol concentration in saliva, the LF/HF ratio and the duration of the RR interval values in dogs with improved conditions (Bergamasco et al., 2010; Palestrini et al., 2015; Bowman et al., 2017). According to the authors, this is also evidence of the positive impact of human communication on the well-being of dogs (Maros et al., 2008; Bergamasco et al., 2010; Palestrini et al., 2015; Bowman et al., 2017; Craig et al., 2017; Amaya et al., 2020).

A study by Gobbo E. and Zupan Šemrov M. (2021) showed a correlation of neuroendocrine regulation, HRV and aggressive behavior in dogs. Notably, this study used infrared thermography of the body surface to assess ANS activation, which allows us to analyze the influence of the animal's emotional states on vascular activity and heat output without behavioral restrictions. Aggressive behavior showed a direct correlation with an increase in muzzle temperature, and reflected specifically vascular responses (and not neuroendocrine responses) (Gobbo, Zupan Šemrov, 2021).

Since mydriasis is an indirect sign of stress and hyperactivity in humans (Sonntag & Overall, 2014; Hall & Chilcott, 2018; Hamrakova et al., 2020), the pupil's response to a light stimulus can be used as one of the markers of anxiety in animals. The linear change in pupil diameter before and after exposure to light and its percentage constriction, rate of constriction and dilation (average and maximum) were proposed as sensitive parameters. These differences are determined by reduced activation of the parasympathetic system and dominance of the sympathetic part of the autonomic nervous system. Accordingly, with proper adaptation, this method can also be applied to assess the correlation of behavioral disorders and imbalances in autonomic regulation in animals. An example of its use can be the swinging flashlight test (Hall, Chilcott, 2018).

Behavioral disorders and the gut microbiota

A separate big question is the correlation of the features of the gut microbiota and manifestations of ADHD disorders (brain-gut axis). Such a correlation may be related to impaired metabolism of neurotransmitters produced by gut bacteria (Wan et al., 2020; Sukmajaya et al., 2021). According to a literature review by Shirvani-Rad S. et al. (2022), children and adults diagnosed with ADHD were found to have increased enterococci, bifidobacteria, and odoribacteria, resulting in an imbalance of dopamine in the CNS. A study by Wan L. et al (2020) states that children with ADHD may have an abnormality of the gut flora in the form of a decrease in *Faecalibacterium*; a reduction in this group of bacteria can cause allergic reactions by altering the brain-gut axis. In turn, the allergic reaction affects the release of neurotransmitters and induces manifestations of ADHD. This is due to the ability of *Faecalibacterium* to regulate the level of inflammatory cytokines, the increase of which plays a role in the pathogenesis of ADHD.

Although the question of the correlation between ADHD behavior and the gut microbiota has been considered in great detail for children, no similar studies for dogs have been found in the open literature. We analyzed the study (Kirchhoff et al., 2019) on the relationship between aggressive behavior and intestinal microbiota in fighting dogs using the example of a small population of pit bulls participating in dogfights (21 dogs). It was found that aggressive dogs had a higher prevalence of bacteria of nine (or twelve) clades of the genus Lactobacillus, and a lower prevalence of bacteria of some clades of the genus *Fusobacterium* in the fecal microbiota. The authors conclude that gut microbiome data could potentially be used in the future not only to diagnose canine aggression, but also to predict it. It should be noted that these results echo the data obtained by Kubinyi et al. (2020), which showed a decrease in the number of Fusobacterium in older dogs.

The similar correlation of disorders have been found in ADHD diagnosed humans and ADHD behavior in dogs, where is was related to alterations tryptophan and lipid metabolism (Puruunen et al., 2016; Bleuer-Elsner et al., 2019). Works devoted to the analysis of this issue in dogs are currently sparse. In particular, the association of behavioral problems in dogs with impaired tryptophan metabolism and, consequently, the effect of the gut microbiome on the serotoninergic system has been shown (O'Mahony et al., 2015).

In a study by D. Puurunen et al (2016) showed differences in tryptophan metabolites, among which lower plasma levels of IPA and IAA correlated with a clear severity of ADHD behavior in dogs. Because *Enterobacteriaceae* of the genus *Clostridium* produces these tryptophan metabolites, the authors suggest negative correlations between ADHD behavior and the representation of these bacteria in the gut microbiota if the diets of the animals studied were similar (Puurunen et al., 2016).

This is also supported by data on the possibility of correcting aggression in dogs by introducing tryptophan supplements into the diet (DeNapoli et al., 2000). In dogs suffering from idiopathic epilepsy, a significant decrease in the representation of several bacterial phylotypes producing GABA as well as short-chain fatty acids has been found (García-Belenguer et al., 2021). In addition, cognitive deterioration - namely short-term memory - in aging dogs has been shown to be related to changes in gut microflora (Kubinyi et al., 2020); good test performance was correlated with a low proportion of actinobacteria. However, a study by Muñana KR. et al. (2020) showed no significant differences in the relative or absolute abundance of *Lactobacillus* species, the main microorganisms associated with CNS protection against neurological disorders, in dogs with idiopathic epilepsy compared to healthy animals.

At the same time, since 3-indolepropionic acid can be produced from tryptophan in the mammalian gut by *Clostridium* bacteria, this allows its use as a marker of the gut-brain axis and allows extrapolation of animal data to works on the influence of gut microbiota on ADHD in humans (Puurunen et al., 2016). This correlation is built by a decrease in available tryptophan, which leads to an overall decrease in serotonin levels as well as the ratio of serotonin to dopamine concentration (Puurunen et al., 2016).

Conclusion

This review analyzed the most common behavior disorders in dogs, their possible causes, and the comorbidity of such disorders. Among the leading behavioral disorders in the analyzed literature, fear and aggression, ADHD behavior and impulsivity were indicated. These results were obtained mainly using owner questionnaires and assessment of behavioral patterns of the animals. Despite the safety and non-invasiveness of such approaches, their accuracy remains relatively low due to possible misinterpretation of information and high individual variability. In addition, the questionnaires and checklists have a high level of subjectivity, because they depend on the characteristics of the perception of the dog's behavior by the owner and the expert.

The introduction of biochemical research methods, in particular, analysis of the concentration of cortisol in wool, saliva and blood plasma, oxytocin, vasopressin and prolactin, will help to increase the accuracy of the study of the causes and mechanisms of problematic behavior of dogs.

It should be noted that the proportion of works related to the use of biochemical and physiological diagnostic methods was significantly lower. This is probably due to the higher cost of such studies, their invasiveness, as well as the need to observe special conditions of material sampling. However, their combined use with questionnaires and behavioral methods will allow to reveal objective reasons of behavioral disorders in dogs, and to predict further development of the situation.

A multifactorial approach to the study of behavior can contribute to a general understanding of the dog's condition; identify signs of distress – physiological, emotional, behavioral, social. Therefore, the optimal approach to identifying problematic dog behavior should take into account medical and life history, analysis of behavioral tests and questionnaires, physiological indicators of the condition, assessment of postures, movements and minor signs of increased anxiety.

There is a lack of similar studies in the population of domestic dogs residing in the Russian Federation. Screening questionnaires covering a wide range of Russian owners have not been found at present. Therefore, conducting such a comprehensive study would allow obtaining a comprehensive picture of the presence, prevalence and causes of behavioral disorders in Russian domestic dogs, taking into account the public and social realities of the country.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.