ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study

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Abstract

Introduction. Research on problem behavior in pet dogs is underrepresented in Russian zoopsychology, primarily due to the lack of measurable metrics for objective assessment of their behavior. Drawing on international studies, this work aims to identify objective markers of problem behavior in pet dogs. **Methods.** The pilot sample included 35 dogs—15 males and 20 females. The assessment consisted of the owner questionnaire CBARQ and behavioral tests: meet and greet, interaction with owner, and interaction with a stranger. Behavioral patterns were extracted from video recordings using the YOLO neural network. Movement speed was calculated using the Euclidean distance formula, and switching frequency was determined from behavioral pattern transitions. **Results.** Based on the median value of the "Fear and Anxiety" scale from CBARQ, dogs were divided into anxious and calm groups. Anxious dogs showed higher baseline values during the stranger interaction test and greater distance from the owner during all tests. From the anxious group, excitable dogs were additionally identified. Average speed was higher in excitable dogs and anxious dogs compared to calm dogs—most pronounced in anxious dogs. Switching frequency calculations showed differences in behavioral patterns depending on the dog's psychological profile. **Discussion.** The combination of various methods made it possible to analyze possible markers of behavioral disorders, taking into account the dog's chart, visual observation (distance between frames), data on motor

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ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

activity dynamics, and behavior patterns. As spart of the pilot study, test ethograms were obtained, allowing for the objective classification of a dog's behavior type. The possibility of adding movement speed and switching frequency to the dog ethogram, as well as the results of anxiety, aggression, and excitability analysis based on owner surveys, was demonstrated. It was found that contact with humans is a manifesting factor that allows the use of selected metrics to identify problematic dog behavior.

Keywords

Funding

For Citation

Introduction

Addressing the welfare of pet dogs opens a new chapter in modern zoopsychology (MacLean et al., 2021; Farhat et al., 2024). The diversity of behavioral patterns, adaptation and adjustment of pet dogs in society, and their ability to perform specific functions underscore the importance and relevance of research aimed at properly identifying functional and dysfunctional owner-pet dyads.

Despite extensive research on the ethological characteristics of dogs during socialization and contact with humans, pet dogs remain poorly studied in contemporary Russian science. Classical cynology and zoopsychology, based primarily on analyzing working qualities of dogs, have developed test batteries that allow analysis of dogs' psychoemotional characteristics from the perspective of their application to specific tasks. Pet dogs are not identical to working and laboratory dogs due to the formation of a special type of attachment to owners, similar to child-parent relationships (Konok et al., 2015; Dodman et al., 2018; Solomon et al., 2019; Riggio et al., 2020).

Therefore, the application of objective methods for analyzing pet dog's behavior is becoming increasingly relevant. Analysis of the articles (Gähwiler et al., 2020) and the

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

authors' own experience reveals difficulties owners face in identifying problem behaviors in dogs without guided questions. In the owner-pet dyad, this is a key factor, and dyad dysfunction is reflected in animal behavior. Identifying signs of behavioral disturbances in animals is necessary for assessing their welfare, communication with owners in the dyad, and creating opportunities for predicting future behavior (Gähwiler et al., 2020). The importance of considering dyadic interaction is evidenced by data obtained by Ren et al. (2024) showing correlation between frontal-parietal interactions in owners and dogs during eye contact and physical touch.

The need to apply objective computational methods to solve this task—identifying temperament type, anxiety, aggression, and fear—is related, among other things, to owner subjectivity when assessing animal welfare based on questionnaire tests (Zamansky et al., 2018, 2021; Rodriguez et al., 2023). Error rates when evaluating animal behavior based solely on questionnaire tests can reach up to 50% due to the variety of diagnostic methods and interpretation approaches (Rodriguez et al., 2023). Behavioral types and characteristics of dogs' psychoemotional states that owners evaluate as preferable may actually be causes or markers of animal suffering (Serpell, 2019). Deviations in dogs' behavior and their emotional interaction with owners can also be signs of declining health. Changes in subtle behavioral signs are generally difficult to identify without using specialized computational tools due to the complexity of pattern identification (Kim et al., 2024).

In Russian, research related to applying artificial intelligence systems for analyzing dog's behavior is not represented. In contrast, this direction is new and relatively well-developed in international articles. Computational animal behavior analysis (CABA) (Zamansky et al., 2021; Farhat et al., 2024), based on automated video analysis using convolutional neural networks, eliminates observer bias and lack of necessary information about behavioral patterns of biological species. The fact that dogs' psychoemotional state and overall welfare level are reflected in motor activity indicators is undisputed (Atif et al., 2023).

Research using artificial intelligence technology can be divided into two groups: those related to algorithm development (Barnard et al., 2016; Menaker et al., 2022; Amirhosseini et al., 2024; Farhat et al., 2024) and those related to its application for identifying and solving behavioral problems (Völter et al., 2023; Schork et al., 2024). In a study by Amirhosseini et al. (2024), cluster analysis methods in four machine learning models based on owner responses to CBARQ questionnaire identified five personality and temperament types in dogs with 99% accuracy. In Schork et al. (2024), convolutional neural networks analyzed dog sleep characteristics based on posture identification with 89% accuracy. In Völter et al. (2023), a machine learning system was used as a tool to determine whether dogs could distinguish behavioral patterns in situations where humans were unwilling or unable to pass food.

Farhat N. et al. (2024), based on a meta-analysis concluded that two-dimensional visualization dominates in video data analysis, with detection and tracking tasks being key. Barnard S. et al. (2016) developed 3D software for recording and analyzing dog behavior in kennel housing (as an unnatural environment that reduces welfare). Pose analysis and body part positioning relative to the main body axis (4 positions total) were used as markers. Subsequently, this enabled identification of behavioral patterns indicating reduced welfare (for example, prolonged rest and rare decrease in active movement time percentage when dogs were in cramped kennels or housed individually). In a similar study, artificial intelligence systems enabled determination of stress levels in shelter dogs based on head position.

Menaker et al. (2022) used a promising combined approach analyzing owner survey scores and clustering video recordings of dog behavior in response to strangers to create a system for objectively differentiating anxious and calm dogs. In a similar study (Martvel et al., 2025), applying artificial intelligence to analyze the spectrum of facial emotional expressions revealed reduced mobility and expressiveness of facial expressions in brachycephalic dogs, which could potentially complicate intraspecific communication.

The capabilities of artificial intelligence methods for assessing declining dog health were demonstrated by Kim S. C. and Kim S. (2024), who, based on numerical analysis of behavioral signs (sleep, licking, swallowing, and scratching) using a trained neural network with 87.5% accuracy, developed a scoring scale where high scores correspond to adequate health and welfare levels, while values dropping below 5 warrant immediate consultation with a veterinarian and animal psychologist.

Regardless of the chosen methodology and software, the advantage of the method lies in the simplicity and low cost of collecting behavioral data through video recording (Fomina et al., 2025; King et al., 2022). At the same time, the impossibility of identifying complex behavioral patterns using only observational methods and visual analysis of recordings justifies the use of resource-intensive convolutional neural network technologies for identifying behavioral patterns and analyzing quantitative behavioral characteristics such as movement speed, switching frequency, territory coverage, etc.

Another valid method for analyzing dog behavioral activity is the use of linear and angular acceleration analysis through accelerometry (Clarke, Fraser, 2016). This method allows analysis of animal activity using a portable recording device attached to a collar or harness. Applying AI to accelerometry data analysis enables identification of recurring behavioral patterns and frequency of switching between activity types. In a study by Marcato et al. (2023), based on analysis of linear and angular accelerations from accelerometers and gyroscopes fixed on dog harnesses or collar, a pose assessment system was developed. Data patterns corresponding to static poses (standing, sitting, lying) and motor activity in dogs were identified. The method enabled classification of resting state with 0.86 accuracy and distinguishing poses with raised or lowered head with 0.9 accuracy (Ladha & Hoffman, 2023), as well as estimating and annotating dog step count and distance traveled (Ladha et al., 2018).

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Video surveillance methods allow continuous recording of animal behavior in natural conditions but require resource-intensive video data coding. On the other hand, owner questionnaires are a quick and convenient way to obtain behavioral information but have high subjectivity. An integrative approach combining subjective and objective data is becoming increasingly relevant. An example of such an approach is qualitative behavior assessment (QBA), which demonstrates high reproducibility in interpreting affective states of animals (King et al., 2022).

The aim of this pilot study was to identify and test objective markers of problem behavior in pet dogs based on analysis of owner survey data and motor activity.

Methods

The target group for the study consisted of pet dogs. Animals (weight from 4 to 35 kg; age from 1 to 10 years), non-neutered, not participating in professional training or dog sports were admitted to participate. The pilot sample included 35 dogs of both sexes (15 males and 20 females) of different ages and breed affiliations.

Before the examination, owners were familiarized with the purpose and protocol of the study, testing procedures, and signed informed written consent for participation and possible use of the obtained data in research and educational activities. Participation was anonymous for humans; dogs were registered according to the name provided by the owner. The examination protocol and consent form were approved by the Local Independent Ethics Committee of Don state technical university (Protocol No. 1 dated February 5, 2024).

Dogs without recent history of illness, surgery, trauma, or acute stress episodes were selected for the study. Basic description of the methodology was previously presented in Fomina et al. (2025). The testing protocol included the following behavioral tests in chronological order:

1. "Introduction"—free dog's behavior in a new territory (at least 10 minutes), aimed at reducing the novelty effect. This test showed the greatest variability in the sample and was not used for further calculations.

2. "Owner"—typical interaction of the animal with the owner without provoking stress or aggressive reactions.

3. "Unknown"—contact of the dog with an unfamiliar person in the absence of the owner. Two faculty assistants previously unfamiliar to the animals acted as unknown.

4. "Being Alone"—dog's stay on the testing ground alone.

The experiment was conducted on a specially prepared testing ground equipped in an enclosed space of 20 m². The room was equipped with a hygrometer and thermometer; temperature was maintained at 19–21 °C, humidity at 25–30%. The floor of the testing ground was marked with squares with 60 cm sides, providing the possibility of spatial assessment of movements.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Before testing, owners completed a paper version of the CBARQ (Canine Behavioral Assessment & Research Questionnaire) adapted for Russian-speaking audiences. The original version of the test was presented by the authors in an open publication (Duffy & Serpell, 2012). The test included seven scales: "Training," "Obedience," "Aggression," "Fear and Anxiety," "Separation," "Excitability," "Attachment." The test translation was pre-checked to exclude linguistic distortions. Responses were digitized in table format (R7 Office Excel); for each dog, the percentage of points scored from the maximum possible value for each scale was calculated. This approach was chosen due to possible omission of individual questions if corresponding situations had not been previously observed by the owner.

For quantitative analysis of dog motor activity, the accelerometry method was used with an autonomous sensor device based on the MPU6050 module, which includes a three-axis accelerometer and three-axis gyroscope. The 50-gram device was fixed to the animal's individual collar or harness and allowed registration of linear accelerations and angular velocities along the X, Y, and Z axes throughout the entire experiment. This approach ensured continuous recording of movements with high sensitivity without disrupting the animal's natural behavior.

Figure 1

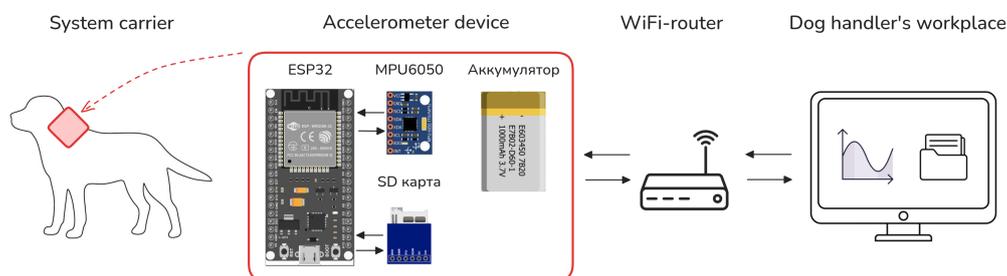*Schematic diagram of the accelerometry system components*

Figure 1 presents a schematic diagram of the accelerometry system components developed for monitoring dog motor activity during behavioral testing. The system includes a hardware module placed on the animal's body and remote access tools for device interaction and data retrieval. The device, fixed in the neck area, consists of an ESP32 microcontroller, MPU6050 sensor, memory card, and autonomous power source. The ESP32 microcontroller ensures data collection from the MPU6050 module, which integrates a three-axis accelerometer and gyroscope, and records this data to a microSD card in CSV format. Simultaneously, the ESP32 deploys a built-in web server that enables connection to the device from a computer via local Wi-Fi network. The web interface provides file viewing, selection, and download capabilities without requiring physical access to the device. This approach ensures autonomous and continuous collection of objective motor activity metrics with remote monitoring capability while minimizing interference with the dog's behavior during examination.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Before analysis, data preprocessing was performed, consisting of stages of correcting time stamps of records, removing duplicates and sorting data along the time axis, assessing the stability of temporal intervals based on statistical measures, signal interpolation, and setting the sampling frequency equal to 1000 Hz.

To extract hidden patterns of dog motor activity based on accelerometry data, an autoencoder was applied—a neural network algorithm trained without supervision. The model was used for automatic processing of segmented time windows of 1024 ms length, each of which included normalized values of accelerations and angular velocities. The autoencoder architecture included an encoder and decoder, trained using the mean squared error (MSE) loss function and Adam optimizer. After 80 training epochs, the loss function stabilized at a satisfactory level, indicating sufficient model convergence.

Based on the trained autoencoder model, each time segment of accelerometric data was passed through the encoder, resulting in formation of a compact vector representation of motor activity. Subsequently, transitions between different activity types were determined by analyzing differences between successive feature vectors. Thus, the autoencoder allowed transformation of raw, high-frequency data into stable behavioral features without the need for manual annotation.

Also for motor activity analysis, a video recording system was developed and implemented based on a Hikvision DS-2CD2043G2 IP camera, providing recording at 1920x1080 pixel resolution and 25 frames per second. The camera was connected to the local network and configured for continuous recording with subsequent storage of video data on external media. The device was placed stationary at a height of 10 cm from the ceiling, with an angle of inclination of approximately 60°, which allowed covering the entire area of the experimental testing ground and ensuring stable visual observation of the animal throughout the entire duration of the tests. To comply with research ethics principles, the face area of each person in the frames was subjected to blurring; the dog image was preserved in accordance with owner permissions.

The obtained video recordings were subjected to post-processing using computer vision software tools and a convolutional neural network trained on an annotated set of frames. To ensure quality behavioral analysis, recordings lasting at least 5 minutes were selected, in which the dog was present in the frame in the foreground for at least 90% of the time.

For analyzing interaction with a human in the "Owner" test, a "Contact" metric was also introduced, representing the visually assessed distance between the dog and owner in fixed frames. Frames were selected at equal time intervals (n = 10) and analyzed manually using the testing ground markings as the initial coordinate system and measurement scale. Distance was classified into the following categories: being held in arms, physical contact ("close," up to 10 cm), distance up to 50 cm, 50 to 100 cm, and 100 to 150 cm. Play behavior and active movements were excluded from assessment to increase analysis objectivity. Figure 2 shows the interface of the original software for measuring distance between owner and animal.

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Figure 2

Sample frame for assessing distance between owner and dog accounting for camera perspective distortions
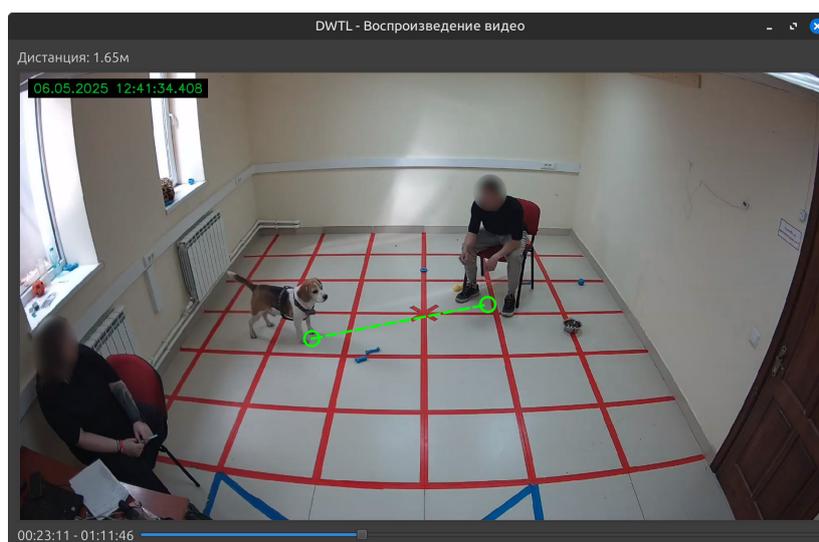
The system automatically outlined the dog's body, constructed movement trajectories, and calculated distances traveled. We extracted coordinates and trajectory data for each test and dog, enabling quantitative comparison of motor activity patterns across different experimental conditions.

We also generated heat maps visualizing zones of greatest activity and dog location frequency throughout the testing area. This approach allowed spatial analysis of behavior and identification of preferred and avoided zones under different test conditions.

We performed statistical data processing using R7 Office Excel, open online statistical calculators, and Python. Since the distribution of calculated data for CBARQ questionnaire scales, accelerometry metrics, and video recordings did not conform to normal distribution according to the Kolmogorov-Smirnov test ($p < 0.05$), we used nonparametric statistical methods for analysis. Intergroup differences were assessed using the Mann-Whitney U-test in pairwise comparisons. To analyze relationships between variables, we applied Spearman's correlation coefficient (two-tailed correlations). Differences were considered statistically significant at $p \leq 0.05$.

Results

The study included 35 pet dogs, including 15 males and 20 females; this ensured a balanced sex distribution. The mean age of the dogs was 4.8 ± 0.74 years, with the age range varying from 1 to 10 years. Breed distribution included representatives of small, medium, and large breeds weighing from 4 to 25 kg.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Analysis of CBARQ questionnaires demonstrated the ability to obtain valid data on individual behavioral characteristics of dogs in daily life. We calculated test scales for each dog and identified key behavioral features. CBARQ scale validity was assessed using Cronbach's alpha coefficient (values of at least 0.889 for each scale).

Preliminary analysis showed no significant sex differences on this scale. For males, the mean "Fear and Anxiety" scale score was 28.05 $\pm$ 3.35%, for females 25.23 $\pm$ 2.77% (p = 0.541). For the "Aggression" scale, mean values were 18.03 $\pm$ 3.39% and 17.44 $\pm$ 2.15% respectively (p = 0.87). The absence of significant differences allowed further research without accounting for animal sex.

To identify dog groups, we assessed CBARQ test scale scores for 35 dogs as percentages of maximum possible scores. Dogs were sorted relative to the calculated median value on the "Fear and Anxiety" scale (29.3%). Dogs scoring below the median were classified as "Calm dogs" (n = 16); those above the median as "Anxious dogs" (n = 19). The validity and appropriateness of this division were confirmed using discriminant analysis (Wilks' Lambda = 0.063, Chi-square = 38.623, p = 0.003).

Based on statistical data from the CBARQ test, significant differences between "Calm dogs" and "Anxious dogs" groups were found for the following scales: "Aggression" (7.68% and 34.13%, p < 0.001, U = 2.000, p < 0.001), "Fear and Anxiety" (11.81% and 42.32%, p < 0.001, U = 15.00, p < 0.001), "Excitability" (53.82% and 71.88%, p = 0.01, U = 29.00, p = 0.0487).

No significant differences were found for the remaining test scales ("Training": 67.88% and 60.94%; "Obedience": 53.65% and 53.52%; "Separation": 34.04% and 40.58%; "Attachment": 62.5% and 61.98%). Figures 3 and 4 and Tables 1 and 2 below present CBARQ testing results.

Figure 3

Mean CBARQ test scores (%) for "Calm dogs" and "Anxious dogs" groups (before subgroup division) (N = 35)
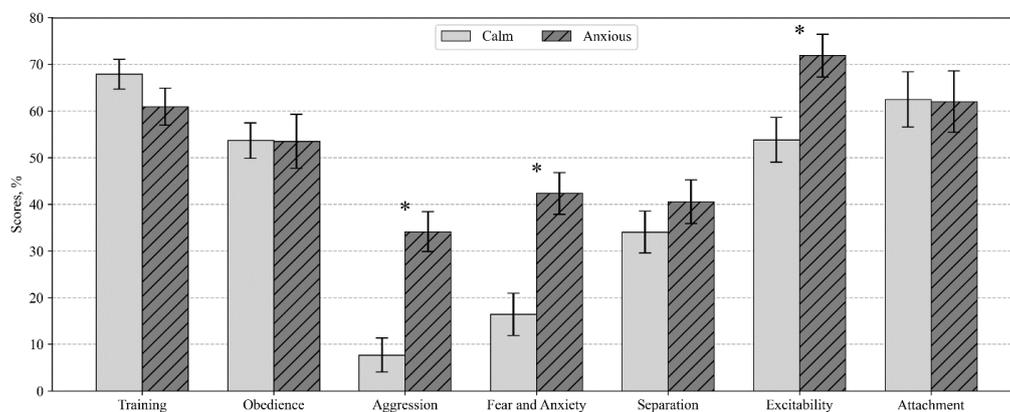
Note. The x-axis shows test scales; the y-axis shows scores as % of maximum.

Table 1

Statistical analysis results of CBARQ test scores in dog groups, as % of maximum per scale

Scale	Dog groups	
	Calm (n=18)	Anxious (n=16)
Training	67.88±3.19	60.94±3.97
Obedience	53.65±38	53.5±5.78
Aggression	7.68±3.63	34.13±4.3 U=2.0, p<0.001*
Fear and Anxiety	16.41±4.53	42.32±4.49 U=15.00, p<0.001*
Separation	34.04±4.5	40.58±4.69
Excitability	53.82±4.8	71.88±4.6 U=29.00, p=0.0487*
Attachment	62.5±5.9	61.98±6.57

*Note. *when comparing score values with those for the "Calm dogs" group.*

When conducting correlation analysis using the Pearson criterion for the "Calm dogs" group, no correlations of aggressive and anxious behavior features were found; a negative correlation was shown between the "Fear and Anxiety" and "Attachment" scale indicators (r = -0.643, p = 0.018). For the "Anxious dogs" group, a positive correlation was shown between the "Aggression" and "Fear and Anxiety" scale indicators (r = 0.571, p < 0.001), "Fear and Anxiety" and "Attachment" (r = 0.60, p < 0.001), and a negative correlation between the "Training" and "Obedience" scale indicators (r = -0.727, p < 0.001).

Based on the conducted analysis, the "Aggression," "Anxiety," and "Excitability" subscales were selected as most informative for determining the probability of behavioral disorders in dogs; results of the remaining subscales were not used in the study.

According to the results of visual assessment of distance between owner and dog, in the "Calm dogs" group 86.6% (11 dogs) were classified into the "Up to 50 cm" class. 6.6% of dogs sat next to the owner maintaining physical contact ("Nearby" class), 2.6% belonged to the "50 to 100 cm" class, and 4.6% to the "100 to 150 cm" class. Being held in arms by the owner was not recorded.
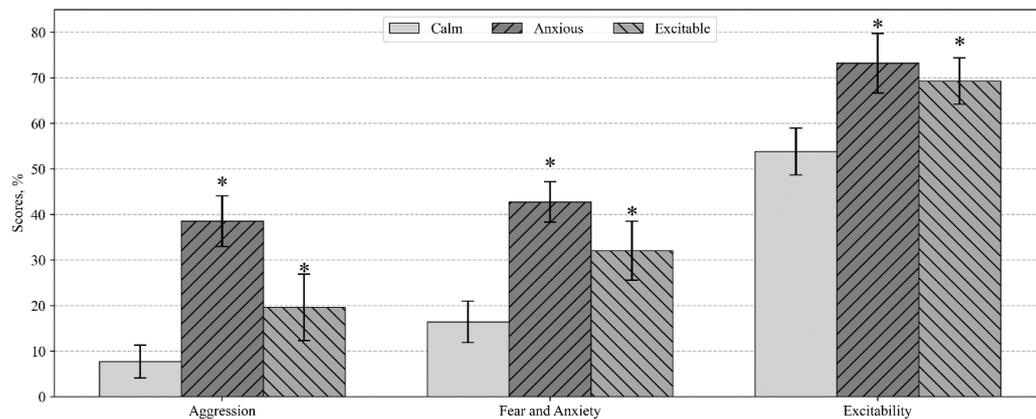
ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

In the "Anxious dogs" group, dogs were divided into two subgroups: 47.05% of dogs were classified into the " Nearby" class, 41.17% into the "50 to 100 cm" class. 11.7% were classified into the "Up to 50 cm" class. Being held in arms was recorded in less than 1% of frames.

In connection with the identified differences in the "Contact" metric, additional analysis of the three CBARQ test scale scores in the "Anxious dogs" group also showed their heterogeneity.

For dogs whose dominant class was " Nearby," high values were shown for the "Aggression" (38.5 $\pm$ 5.57%) and "Fear and Anxiety" (42.75 $\pm$ 4.42%) scales. For dogs whose dominant class was "50 to 100 cm," significantly lower values were shown for the "Aggression" (19.64 $\pm$ 4.3%, U = 11.5, p = 0.001) and "Fear and Anxiety" (32.04 $\pm$ 6.5, U = 2, p = 0.05) scales. The high value of standard deviation is due to the small sample of dogs. It should be noted that values of the "Excitability" scale indicator did not differ between groups of anxious dogs (73.22 $\pm$ 6.6% and 69.3 $\pm$ 5.1%), but were significantly higher compared to the "Calm dogs" group (53.82 $\pm$ 5.1%, U = 20.0, p = 0.02 and U = 31.0, p = 0.035 respectively).

Figure 4

Mean scores of three CBARQ test scales for groups "Calm dogs" (n = 18), "Anxious dogs" (n = 8), "Excitable dogs" (n = 7), identified based on comparison of test scores and "Contact" metric values

Note. The x-axis shows test scales; the y-axis shows scores as % of maximum.

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Table 2

Statistical analysis results of CBARQ test scores in groups "Calm dogs," "Anxious dogs," "Excitable dogs"

Scale	Dog groups		
	"Calm dogs" (n=18)	"Anxious dogs" (n=8)	"Excitable dogs" (n=7)
Aggression	7.68+3.63	38.53+5.56 U=14.0, p=0.006*	19.64+7.29
Fear and Anxiety	16.41+ 4.538	42.75+4.42 U=7.00, p=0.001*	32.041+6.49 U=32.0, p<0.044*
Excitability	53.82+5.16	73.22+6.57 U=20.00, p=0.02*	69.334+5.09 U=31.00, p=0.035*

*Note. *when comparing score values with those obtained for the "Calm dogs" group*

In connection with this, further analysis of indicators proceeded according to three groups:

1.   Combined "Calm dogs" group — 13 dogs (subdivision into subgroups was not performed).
2.   "Anxious dogs" group — 8 dogs.
3.   "Excitable dogs" group — 7 dogs.

Motor activity assessment based on accelerometry methods

Unprocessed data from the accelerometer were subjected to normalization in the range [0;1] and segmented into time windows of 1024 ms length. Each window was represented as a one-dimensional array of 3072 values (1024 values per axis). An autoencoder model consisting of an encoder and decoder was applied for automatic extraction of motor activity patterns. Training was conducted using the mean squared error (MSE) loss function and Adam optimizer (initial learning rate — 0.0001). The mean value of the loss function on the test sample was 0.0023, which confirms acceptable signal reconstruction accuracy and relevance of using the model for behavioral analysis.

As a result of motor activity data collection, they can be represented in the form of a graph of acceleration magnitudes and angular velocities. Figure 5 shows an example of accelerometry data with determination of dog activity type.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Figure 5

Example of accelerometry data with determination of dog activity type "standing on hind legs" (top), "jumping on owner, standing on hind legs" (bottom)
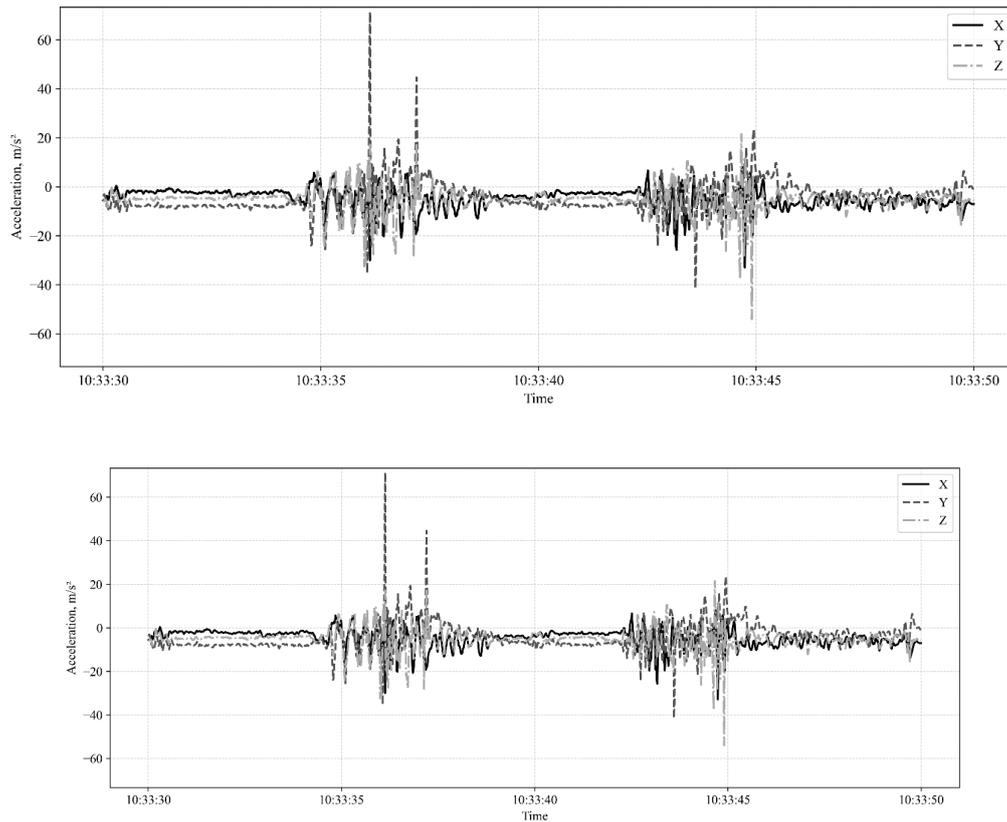
Based on the obtained time series, an integral metric was developed — the frequency of switching between activity types (act/min). The indicator reflects the number of motor pattern changes per unit of time and is a sensitive marker of excitation, anxiety, or stability of behavioral pattern in the dog.

For detailed analysis of mean speed and switching frequency indicators between four tests — "Introduction," "Owner," "Unknown," "Being Alone" in three dog groups, it was shown that for the "Switching frequency" metric in calm and excitable dog groups, no differences were revealed either between groups or between the first three tests. During transition to the " Being Alone" test, a significant decrease in switching frequency was shown in excitable dogs.

Maximum values of this metric were recorded in dogs of the "Anxious dogs" group (4.14 $\pm$ 0.08 act/min), which significantly differed from the "Calm dogs" groups (3.88 $\pm$ 0.09 act/min, U = 12.5, p = 0.048) and "Excitable dogs" (3.80 $\pm$ 0.12 act/min, U = 10.5, p = 0.043).

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Additional analysis within individual tests ("Owner," "Unknown," "Being Alone") showed that in the "Anxious dogs" group, the metric reached peak values in interaction with owner and stranger, decreasing during transition to the "Being Alone" test. In excitable dogs, a significant decrease in switching frequency was observed exclusively in the "Being Alone" test, while calm dogs demonstrated stable values regardless of the situation (Table 8).

Figure 6 shows a graph of activity switching frequency for different stages of the experiment.

Figure 6

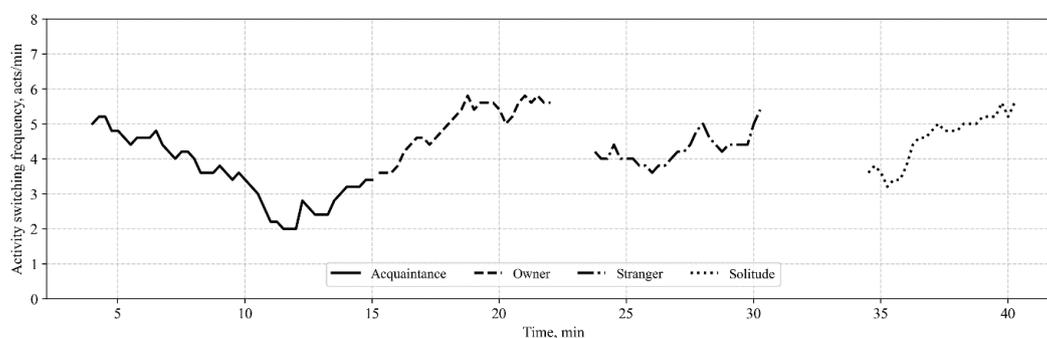*Activity switching frequency during the study*

Figure 7 shows the frequency characteristics of switching between activity types for different dog groups. The table presents values of key metrics depending on the test.

Figure 7

Switching frequency values between activity types in groups "Calm dogs," "Anxious dogs," "Excitable dogs," averaged over the entire examination time
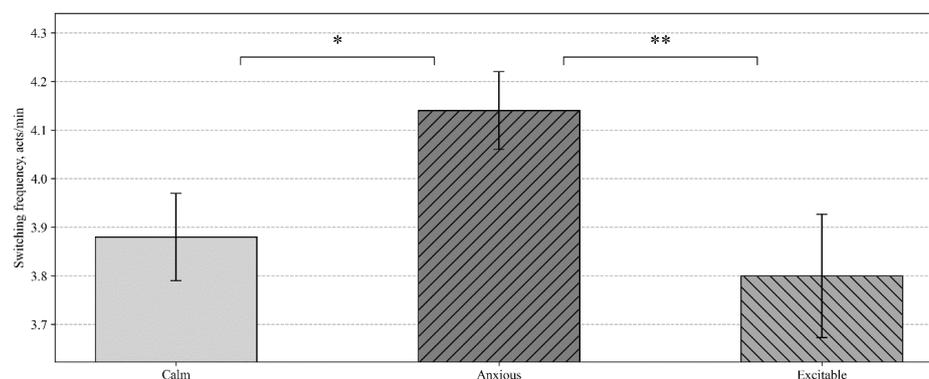
Note. The x-axis shows dog groups; the y-axis shows switching frequency, act/min. Signs * and ** indicate significant differences in metric values between groups.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

When analyzing video recordings, the mean accuracy of the trained model on the test dataset was 92.3% at a confidence threshold of 0.5. The precision indicator reached a value of 89.7%, and recall was 91.2%. Validation set control showed loss function stabilization at a level of 0.041 by the 80th epoch, indicating that the model achieved a state of optimal training without signs of overfitting.

Figures 8 and 9 show motor activity metric values in different dog groups. Table 3 presents statistical characteristics of motor activity metrics. As a result of video recording processing and neural network training, the following metrics were introduced for analyzing dog motor activity:

1. Mean movement speed. When analyzing mean movement speed of dogs, maximum values of this metric were in the "Excitable dogs" group (0.38 ± 0.03 m/s) and "Anxious dogs" (0.315 ± 0.04 m/s); in the "Calm dogs" group, values were lowest (0.30 ± 0.02 m/s).

2. Distance between points as an indicator of testing ground coverage. When analyzing distance between point concentrations, maximum metric values were in the "Excitable dogs" group (2.01 ± 0.13 m/s), and minimum in the "Anxious dogs" group (1.37 ± 0.28 m/s); in the "Calm dogs" group, values were intermediate (1.94 ± 0.12 m/s). This is consistent with the "Contact" metric indicators.

Figure 8

Distance values between point concentrations in groups "Calm dogs" (n = 18), "Anxious dogs" (n = 8), "Excitable dogs" (n = 7), averaged over the entire examination time
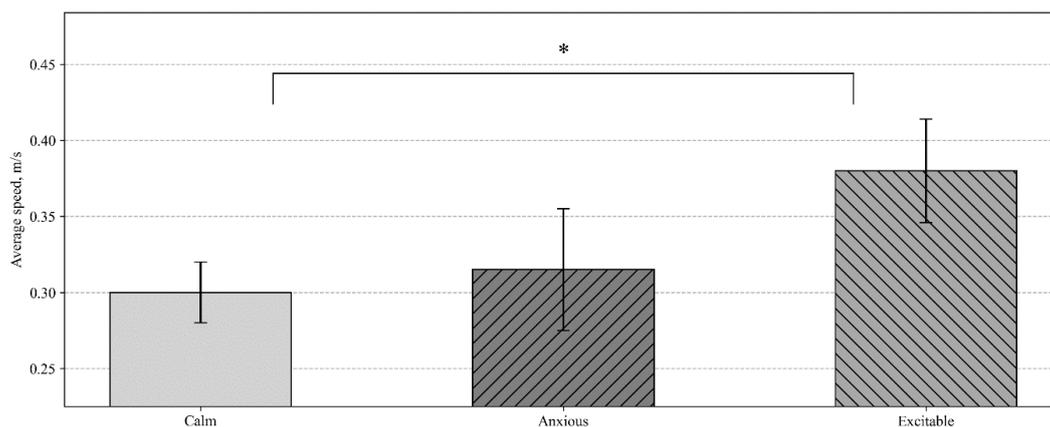
*Note. The x-axis shows dog groups; the y-axis shows distance, m. Signs * and ** indicate significant differences in metric values between groups.*

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Figure 9

Mean speed values in groups "Calm dogs" (n = 18), "Anxious dogs" (n = 8), "Excitable dogs" (n = 7), averaged over the entire examination time.
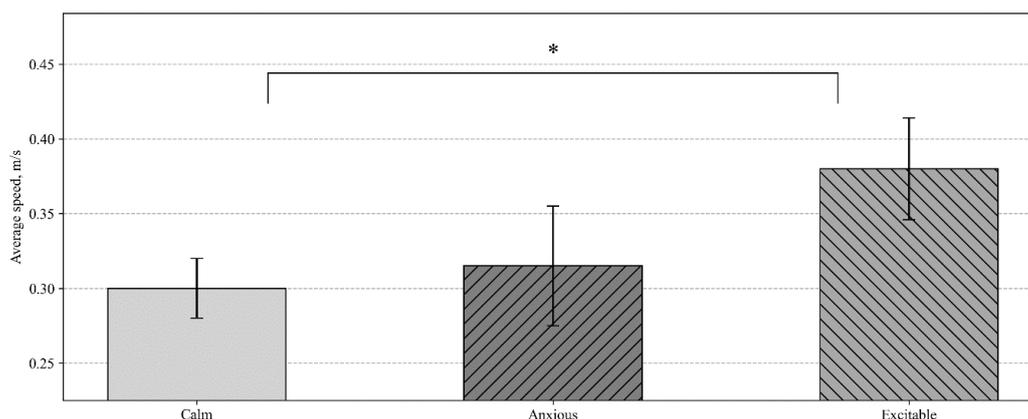
*Note. The x-axis shows dog groups; the y-axis shows mean speed, m/s. The * sign indicates significant differences in metric values between groups.*

Table 7

Results of statistical analysis of motor activity metrics in dog groups for the entire recording time

Metric	Dog groups		
	"Calm dogs" (n=18)	"Anxious dogs" (n=8)	"Excitable dogs" (n=7)
Switching frequency, act/min	3.88 $\pm$ 0.09	4.14 $\pm$ 0.08 U=12.5, p=0.048*	3.80 $\pm$0.127 U=10.5, p=0.043**
Distance between point concentrations, m	1.94$\pm$0.12	1.37 $\pm$ 0.28 U=19.5, p=0.013*	2.01 $\pm$0.13 U=12, p=0.021**
Mean speed, m/s	0.30 $\pm$0.02	0.315 $\pm$ 0.04	0.38 $\pm$ 0.034 U=29.5, p=0.034*

*Note. * when comparing values with those obtained for the "Calm dogs" group. ** when comparing values in the "Anxious dogs" and "Excitable dogs" groups.*

When analyzing values of the two metrics calculated separately for trials, we found that differences detected for the overall recording time were preserved (Table 8). We found no differences in the "Calm dogs" group between trials. For the "Anxious dogs" group,

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

we found maximum values of switching frequency in the "Owner" and "Unknown" trials. For the "Owner" and "Unknown" trials, no significant differences were found between the "Calm dogs" and "Excitable dogs" groups for both analyzed indicators. In contrast, in the "Anxious dogs" group, switching frequency and mean movement speed were higher in the "Owner" trial. In the "Unknown" trial, the situation changed: while high switching frequency was maintained, mean movement speed was significantly lower compared to both calm and excitable dogs. The "Being Alone" trial requires separate consideration, where maximum switching frequency was maintained in anxious dogs but sharply decreased, along with increased movement speed, in the "Excitable dogs" group. Based on this, this trial can be used to differentiate dogs.

Table 8

Results of statistical analysis of motor activity metrics in dog groups for three trials

Metric	Dog groups		
	"Calm dogs" (n=18)	"Anxious dogs" (n=8)	"Excitable dogs" (n=7)
Owner			
Switching frequency, act/min	3.69±0.37	4.42±0.27 U=16, p=0.05	3.66±0.34
Mean speed, m/s	0.47±0.04	0.52±0.09	0.48±0.04
Unknown			
Switching frequency, act/min	3.65±0.34	4.38±0.32	3.86±0.29
Mean speed, m/s	0.32±0.04	0.24±0.03 U=15, p=0.46	0.35±0.04
Being Alone			
Switching frequency, act/min	3.00±0.51	3.48±0.37	2.74±0.35
Mean speed, m/s	0.17±0.03	0.17±0.03	0.29±0.01 U=23, p=0.02

## Motor activity assessment based on video recording and movement tracking methods

The detailed visualization and digitization of dog movement allowed us to analyze behavior in different parts of the testing ground for individual animals. Visualization was

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

calculated based on coordinates of the dog's position, its speed, and distance traveled. Speed characteristics were divided into quartiles and visualized on the testing ground space. We identified slow, medium, and fast movements. The proportion of medium movements is associated with exploratory behavior, the proportion of slow movements with reduced activity, and the proportion of fast movements with excitability level. Differences in speed and occupancy density can indicate different behavioral patterns. Calculation of numerical values showed that significantly higher values of the proportion of fast movements were found in the "Excitable dogs" group (26.08 +/- 1%; U = 14.0, p = 0.02) compared to the "Anxious dogs" and "Calm dogs" groups (24.22 +/- 1.1% and 22.93 +/- 1.2%).

Additionally, for data visualization, we calculated "heat maps" where line brightness corresponded to movement speed, and the number of color spots ("hot spots") corresponded to zones of maximum time spent. Visual analysis of the obtained patterns showed that the "Calm dogs" group is characterized by pattern stability and a large number of "hot spots," regardless of size, sex, and breed, whereas the "Anxious dogs" group is characterized by a small number of "hot spots" and their lability. This is consistent with the results of analyzing the "Contact" and "Distance between points" indicators. Figures 10 and 11 show the results of the tracking system based on the neural network detector.

Figure 10

Visual representation of tracking and speed assessment of dog movement on the testing ground
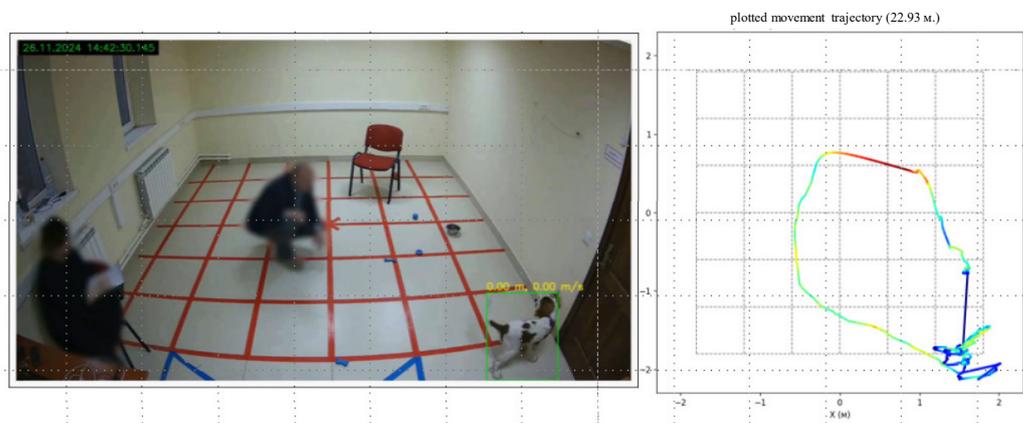

Note. *On the left is an image from the video recording camera; on the right is a schematic representation of the testing ground with the plotted movement trajectory (Spaniel, male, two years old).*

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Figure 11

Visual representation of tracking the movement of small breed dogs. Color shows the speed of the controlled object's movement

A - calm dog   B - anxious dog   C - excitable dog
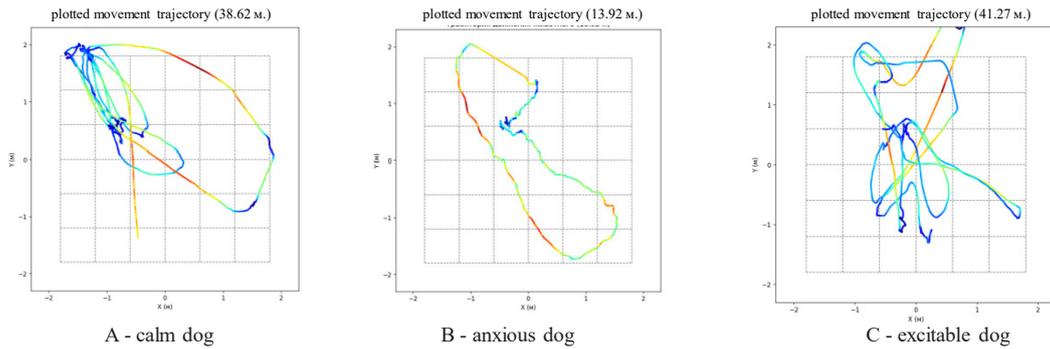
Application of the approach based on a convolutional detector of dogs of different breeds in video allows us to build occupancy maps and determine density. Figure 12 shows contour plots of dog occupancy in the context of slow, medium, and fast movements.

Figure 12

Contour representation of dog occupancy density for slow, medium, and fast movements

Figure 13 shows a heat map of animal occupancy throughout the entire experiment. "Warmer" colors show areas with higher occupancy density. Special markers show areas with the highest concentration of occupancy.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

Figure 13

Heat map of dog occupancy on the testing ground throughout the entire study
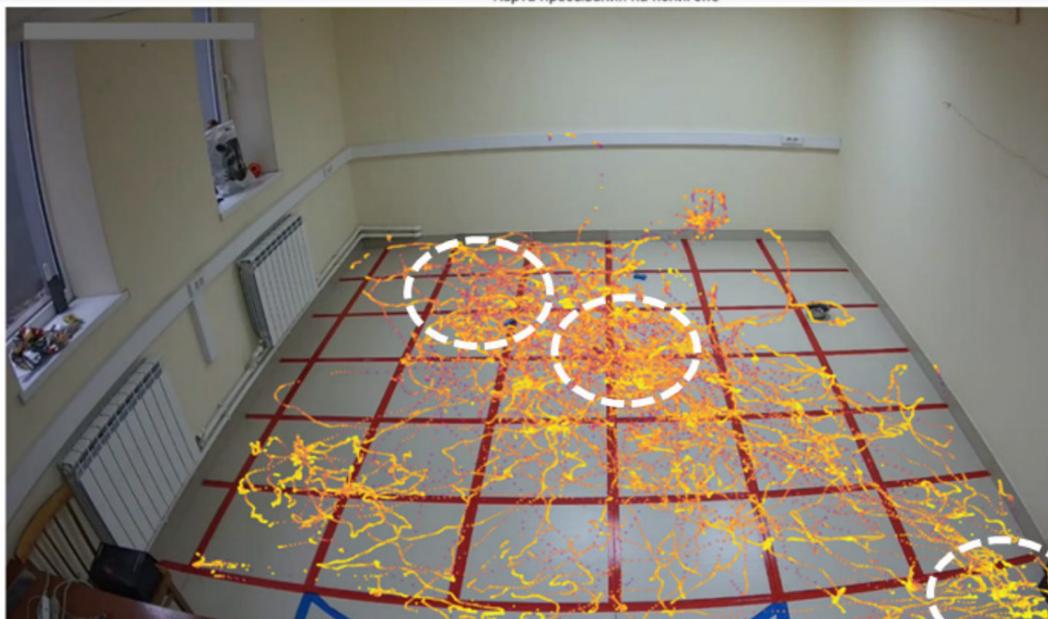
In the "Anxious dogs" group, we found a positive correlation between mean speed and percentage of slow movements (r = 0.868, p = 0.005) and a negative correlation with medium movements (r = -0.718, p = 0.045). In the "Calm dogs" group, in contrast, we found a negative correlation between mean speed and percentage of medium movements (r = -0.753, p = 0.002) and a positive correlation with fast movements (r = 0.740, p = 0.002) and switching frequency (r = 0.668, p = 0.009). "Calm dogs" and "Excitable dogs" are characterized by pattern stability and a large number of "hot spots," while "Anxious dogs" are characterized by a small number of "hot spots" and their lability. This is consistent with the "Contact" metric and confirms the possibility of identifying a specific motor pattern for differentiating dogs.

Discussion

Application of comprehensive methods for analyzing animal behavior includes a number of techniques that allow analysis of both physiological and behavioral indicators (Karl et al., 2020). In ethological science, the key method of analysis remains observation and analysis of behavioral aspects, including using video recordings. At the same time, visual analysis does not allow identification of certain activity patterns or calculation of movement speed and other characteristics. However, it is precisely calculation methods

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

that can create the possibility of objective behavior analysis and dog differentiation based on measurable metrics. This approach allows us to objectively obtain information, reduce the role of expert personal experience, and minimize the likelihood of anthropomorphism when interpreting behavioral aspects. Moreover, implementation of neural network technologies reduces the labor intensity of visual analysis when conducting such studies (Barnard et al., 2016). The importance of using objectively measurable markers is also related to the fact that due to the diversity of applicable methods in zoopsychological studies and differences in the studied populations, reproducibility of such results is no more than 50% (Rodriguez et al., 2021).

A valid marker is rapid assessment of the distance between owner and dog. Identification, already at the visual analysis stage, of differences in distance between owner and dog - primarily associated with distance shortening with increasing anxiety level and its lengthening with excitability - creates the possibility of using this metric for rapid analysis of relationships in the dyad. The chosen method of selecting frames in which precisely the dog, not the owner, determines the analyzed distance also allows using this metric to analyze the possibility of using the owner as a safe haven. This concept finds confirmation in the literature (Gacsi et al., 2013; Karl et al., 2020).

Based on CBARQ test analysis for the pilot sample, the most valid were high scores on the "Aggression," "Anxiety," and "Excitability" scales, which in combination with the "Contact" metric allowed objective identification of three dog groups. Considering the CBARQ test indicator analysis, we can assume that in the "Anxious dogs" group, the main factors of problem behavior may be aggression, anxiety, and excitability, while in the "Excitable dogs" group, excitability and to a lesser extent anxiety.

In our study, the small weight of the accelerometer and use of the dog's own collar reduces such a disadvantage of accelerometry as invasiveness due to the need to wear the device. Testing and database collection confirmed the possibility of its use, including in small breed dogs. Visual observation showed adaptation time to the device from one to three minutes depending on dog size. The totality of data obtained through video recording provided comprehensive characterization of behavioral patterns, including both quantitative indicators of motor activity and parameters of social interaction with humans. Based on motor activity analysis results, we selected markers for dog differentiation, key among which were distance between human and dog, mean movement speed, switching frequency, distance between concentration points, and percentage of fast movements. We used these metrics subsequently for classifying dogs by behavior type and analyzing differences between experimental groups.

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

The obtained data indicate that accelerometry allows differentiation of behavioral reaction types in animals with different behavioral profiles. Switching frequency between activities can serve as an additional objective marker of anxiety and excitability under near-natural conditions. Particularly important is that using a neural network model (autoencoder) allows processing large arrays of native data without the need for manual labeling. Visual analysis of accelerometry signals also allowed identification of specific activity patterns: standing on hind legs, jumping, and interaction with the owner. These episodes are consistent with video recording observations and confirm the accuracy of spatiotemporal positioning.

Based on digitization of three video analysis metrics, we showed that dogs for which increased excitability is assumed as a predictor of behavioral problems are characterized by the highest movement speed and maximum coverage of the testing ground area. Anxious dogs are characterized by high switching frequency between activity types, high movement speed, and small coverage of testing ground area. Intergroup comparisons showed the possibility of using the "Owner" and "Being Alone" trials for differentiating anxious and excitable dogs, since anxious dogs had higher switching frequency values. In a healthy dyad, owner presence could increase exploratory activity, which also finds confirmation in studies (Volter et al., 2022; 2023).

Hence, we can assert that based on analysis of switching frequency and decreased values in the "Being Alone" trial compared to interaction with humans, we can separate excitable dogs from calm ones, and values in the "Owner" trial can separate anxious dogs from calm and excitable ones.

Based on this, we can assume that contact with humans itself is a revealing situation for identifying problem behavior in dogs, the marker of which in this case can be considered the expression of exploratory behavior. The highest indicators of both metrics compared to those for human absence also indicate the revealing role of contact with humans. At the same time, for calm dogs as the most stable group, absolute differences between metric values were minimal.

The combination of high activity, switching frequency, and short distance from humans corresponds to decreased exploratory behavior in the anxious dogs group. This is confirmed by decreased movement speed during contact with an unfamiliar person, where exploratory behavior probably decreased even more. In contrast, for excitable dogs, human presence, due to similar values of studied indicators with the "Calm dogs" group, is a stabilizing factor. This is evidenced by excessive excitability manifesting in the "Excitable dogs" group only in the "Being Alone" trial. It should be noted that the two groups

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

of dogs with potentially problem behavior reacted differently to the absence of human contact. Despite decreased absolute values in this trial, anxious dogs still demonstrated maximum switching frequency, while excitable dogs demonstrated movement speed.

Moreover, these metrics can be interpreted from the perspective of the behavioral synchronization concept based on interspecific motor resonance and involvement of the mirror neuron system (Duranton et al., 2016; Lamontagne & Gaunet, 2024). In this regard, optimal is the use of trials related to contact with humans as revealing when determining the type of behavioral disturbances in dogs. Decreased motor activity and high switching frequency in the "Anxious dogs" group can be explained from the perspective of the deprivation syndrome concept. According to this concept, increased anxiety is accompanied by decreased exploratory behavior and motor activity in general, as well as activation of voluntary attention and increased vigilance (Zamansky et al., 2018). Based on our data, this concept also finds confirmation in increased switching frequency (as a reflection of voluntary attention), short distance between owner and dog, and a small proportion of fast movements around the testing ground (decreased exploratory behavior).

Thus, the combination of various methods allowed us to obtain a picture considering history (CBARQ), visual observation (distance by frames), data on motor activity dynamics using a wearable accelerometer, and data on behavior patterns using a stationary video camera. In total, already within the pilot study, we obtained test ethograms that allow objective classification of dog behavior type.

Common indicators for anxious and excitable dogs were high switching frequency and mean movement speed, and high scores on the "Excitability" scales. For anxious dogs, we determined high scores on the "Anxiety" and "Aggression" scales, short distance between dog and owner as well as activity concentration points, and high switching frequency in the "Owner" trial. For excitable dogs, we determined high movement speed and switching frequency, high percentage of fast movements, and large distance between activity concentration points and between dog and human.

Since it is behavior that is a reflection of the level of well-being and adaptability of dogs, behavioral parameters can and should underlie the methodology for assessing the level of anxious and aggressive behavior (Barnard et al., 2016).

Measurable indicators such as movement speed and switching frequency can be used as markers for analyzing probable disturbances in the adaptation process and predicting behavioral disturbances. This approach eliminates such an obvious disadvantage of measurable methods using biochemical indicators as invasiveness and the need to use expensive reagents (Miller et al., 2022) while allowing reproducible results.

Conclusion

This article presents a pilot study aimed at comparing data obtained from owners using the validated CBARQ questionnaire with objective parameters of motor activity in pet dogs. We used accelerometry and automated video recording analysis with convolutional neural networks as objective recording tools. The use of inexpensive video surveillance equipment and wearable sensors makes the proposed approach technologically accessible and promising for wide practical application and research in human and veterinary medicine. At the same time, it is necessary to consider that this study is a pilot and is based on a relatively small sample size.

Combining video tracking, accelerometry, and owner surveys can become the basis for a comprehensive system for assessing the psychoemotional state of animals. At the same time, questionnaire data can be used as an additional verification tool, compensating for possible AI errors associated with insufficient model training. This is especially relevant in the context of ongoing dataset formation in this field.

The advantage of such an approach is the simplicity of data labeling, their comprehensibility for interpretation, and the possibility of using short video fragments, which is consistent with approaches adopted in the literature for applying artificial intelligence, including for analyzing animal behavior (Martvel et al., 2025).

An ethogram as a set of behavioral activities of animals in certain situations can and should be used to analyze the level of animal welfare. The classical ethological method of observing animals in natural and controlled conditions allows, with certain competencies, identification of behavior patterns and their correlation with changes in dog adaptability level. At the same time, the method has quite high error rates due to possible observer bias, diversity of behavioral patterns, and influence of factors such as sex, age, and breed characteristics. Also, the visual observation method and ethogram construction, due to obvious limitations, is possible only over relatively short time periods.

Moreover, since the dog is a universal experimental animal maximally close to humans (compared to other small animals), competent behavior analysis based on motor activity can become an important aspect of conducting laboratory and clinical studies.

Application of artificial intelligence systems allows significant improvement of metric reliability and validity of applicable methods in general (Stubsjoem et al., 2022) by reducing bias and enabling calculation of indicator values. At the same time, despite obvious advantages, artificial intelligence methods can also be biased, since compilation of training datasets and subsequent interpretation of obtained data requires expert human participation (Menaker et al., 2022). Therefore, it is necessary to consider that

Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

ZOOPSYCHOLOGY AND PSYCHOPHYSIOLOGY

neural networks are primarily a tool for analyzing large volumes of empirical data, and expert opinion remains decisive.

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Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

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Anna S. Fomina, Pavel V. Vasiliev, Anastasia A. Krikunova, Pavel N. Ermakov, Valentina N. Burkova, Alexey M. Ermakov
Analysis of Problem Behavior in Pet Dogs Using Artificial Intelligence Technology: A Pilot Study
Russian Psychological Journal, 22(4), 2025

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Anna S. Fomina — literature data collection, conducting experimental research, analysis and generalization of obtained data, manuscript writing.

Pavel V. Vasiliev — preparation of material and technical research base, conducting experimental research, manuscript writing.

Anastasia A. Krikunova — conducting experimental research.

Pavel N. Ermakov — critical revision of manuscript text, manuscript editing.

Valentina N. Burkova — analysis and generalization of obtained data, manuscript editing.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.