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Research Article

Quantitative Method to Assess Acute Stress Related Behavior in Dogs by Using Motion Capture Technology

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Abstract

Animal therapy is a form of healthcare intervention conducted with the aid of therapy animals, most commonly dogs. For a therapy dog to play an active role in animal therapy, an animal therapist must design a therapy program, which does not place the dog under stress. Generally, a dog's stress can be evaluated by observing its behavior. However, existing ethological evaluation indices of stress behavior are subjective and obscure, and discrimination between dogs' stress behaviors is difficult for observers with insufficient experience. Thus, we propose to quantitatively evaluate behaviors associated with acute stress in dogs. We quantified dog's behavior by using a motion capture system. Specifically, body and ear postures such as the "opening degree of left and right ears," "anteroposterior tilt of left and right ears," "height of the vertex above the floor," "height of the center of gravity above the floor," and "angle between the lateral axis of the body and the floor" were recorded using nine motion capture markers. During the experiments, a canine subject was acutely stressed using a tail clamp, and the dog's posture while under stress was quantitatively distinguished from non-stress postures via quadratic discrimination analysis (QDA). From the results, we distinguished the dog's body and ears postures while under acute stress from those under non-stressed conditions with 81% sensitivity and 93% specificity, and a quantitative evaluation of the dog's acute stress behavior was carried out.

Keywords: Animal therapy, dog's acute stress, motion capture, quantification

1. Introduction

1.1 Background and motivation

Animal therapy involves the use of animals to decrease patients' mental stress, and to enhance the effects of other treatments. Animal therapy includes animal assisted therapy (AAT) and animal assisted activity (AAA). The former is used to supplement a radical treatment, and is implemented by medical professionals [1-3]. The latter is intended to improve a patient's quality of life via contact with animals [4,5].

During AAT or AAA, a dog is often adopted as the therapy animal, because dogs are one of the animals most accessible to humans, and have sufficiently high level of intelligence to maintain a meaningful interaction. For a dog to play an active role in AAT or AAA, the therapy dog must be able to carry out the therapy program without experiencing physical or mental stress, as the dog's stress reduces the effectiveness of the treatment. Therefore, therapists must develop a therapy program that carefully takes the stress of the dog into account. This is also important from an animal protection perspective. To assess canine stress, the blood pressure (BP), electrocardiogram (ECG) or catecholamine concentration is often measured [6]. (In stress assessment for human, the electroencephalographic (EEG) signal is frequently used, but this is not suitable for dogs because a recording of EEG is interfered by a dog's body motion.) In many cases, dogs' stress is evaluated not only by biological signals such as the BP or ECG but also by their discriminative behavior. However it is difficult to assess subtle stress related behaviors.

Studies investigating stress behavior in dogs have been published previously. In one study [7], researchers noted ear posture as an index by which to determine stress levels, tracking ear postures such as "pinnae partly backward," "neutral ears," "pinnae partly high," and "pinnae maximally forward." In another study [8], dogs' body postures were described as follows: "lateral recumbency," "lowered body posture," and "standing, head hanging down."This allowed some stress behaviours to be detected. However, the identification of dogs' stress behaviors is difficult for an observer without high level of previous experience, because the above-described indices are subjective and obscure. For example, expressions such as "pinnae partly backward" do not truly provide concrete descriptions of ear postures. Thus, this study proposes the use of motion capture-based quantitative evaluation of dog's stress related behaviors, to allow for a more objective evaluation of stress in dogs.

1.2 Previous studies conducting quantitative evaluations of dog behavior

Several methods of quantifying dog behavior have been used previously. For example, gait analyses have been performed using an electromyogram or 2-D video recordings [9]. More recent studies have [10] utilized motion capture systems to examine X-linked myotubular myopathy (XLMTM) in dogs. This condition causes limb muscle weakness in young dogs, and dogs suffering from the disease are unable to walk normally. In one study [10], researchers fitted dogs' hind limbs with motion capture markers, and quantitatively diagnosed abnormal gaits. In another research project [11], caninegalloping locomotion, which cannot easily be observed because of spatial restrictions, was quantitatively evaluated using a motion capture system. In this study, researchers propose a measurement system based on a layout of motion capture markers.

1.3 Focus and purpose of this study

As described above, motion capture systems have primarily been used to quantify canine gait patterns. Therefore, the motion capture markers were attached to the subjects' limbs. However, the purpose of this study is to quantify behaviors related to stress; thus, ear and other body postures should be examined, as demonstrated by [7,8]. As a result, the motion capture markers should be positioned on the ears, head, and trunk, in order to quantify the indices described in previous studies of canine stress (e.g., "pinnae maximally forward" or "lowered body posture").

Of various types of stress related behaviors, those related to acute stress caused by pain will be the focus of this study, as stress associated with pain can be the cause of severe problems that inhibit the effectiveness of AAT and AAA programs. If the quantitative examination of acute canine stress behaviors is feasible, therapists will be able to design effective therapy programs, for which a standardized method of stress assessment for therapy dogs is required.

2.Marker placement for motion capture

2.1 Ethological stress related behaviours in dogs

In ethological examinations of canine stress, responses to stimuli such as a pain are defined as typical stress related behaviors. To evaluate canine stress, ethologists count the number of stress-related behaviors exhibited, and estimate the individual's stress level. Thus, ethologists perform subjective binary classifications in order to determine whether a certain behavior is stress-related. This study investigates the possibility of quantifying this ethological binary classification system using motion capture data.

In previous studies [7,8], researchers focused onthe following behaviors (or postures), and assessedthe dogs' stress levels by counting the number of behaviors observed.

a) Lateral recumbency
b) Sternal recumbency
c) Standing, head hanging down
d) Abnormal posture (prayer position)
e) Lowering of ear position

In Section 2.2, a pattern of marker placement designed to effectively quantify these stress behaviors is evaluated.

2.2 Marker placement and quantification of dog's postures

In this section, the information needed to measure canine body and ears postures is first considered, and then used to determine effective marker placements.

The quantification of body postures a), b), c), and d), requires the determination of whether the subject is in an upright or sitting position. This information can be obtained by measuring the height of the trunk above the floor. In practice, this study proposes to obtain this information by measuring the "height of the center of gravity above the floor."Similarly, to quantify postures c) and d), the position of head must be measured in addition to the "height of the center of gravity above the floor." This measurement is defined as the "height of the vertex above the floor."Body postures a) and b) are sitting postures, but they differ from each other with regard to the tilt of the lateral axis of the body. Therefore, body postures a) and b) are distinguished via the measurement of the "angle between the lateral axis of the body and the floor."The quantification of e) requires information relating to ear posture. Dogs' ears possess more muscles than human ears, and can execute complex movements. Thus, ear posture must be measured three dimensionally in order to be effectively quantified. In this study, information related to three dimensional ear posture is obtained by measuring the "opening degree of left and right ears," the "anteroposterior tilt of the left ear," and the "anteroposterior tilt of right ear."

Next, the quantification of the above ear and body postures using motion capture markers is described. Table 1, as well as Figures 1 and 2, show the positioning of the motion capture markers (M1 through M9). Using these nine markers, quantitative representations of canine posture are generated.

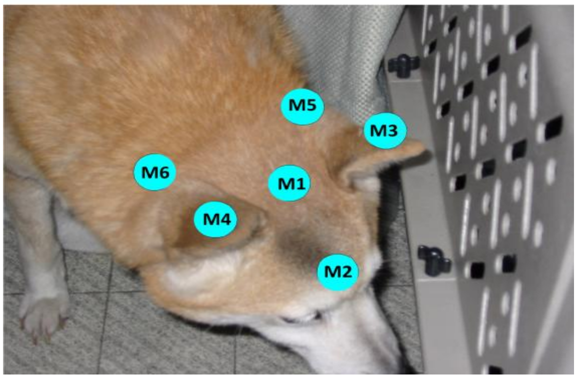

Fig.1 Positions of markers M1 through M6

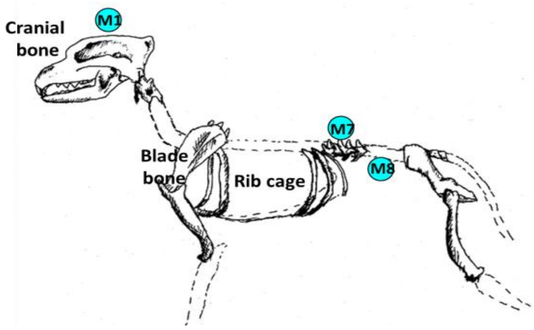

Fig.2 Positions of markers M1, M7, and M8

Table 1: Marker positions

Marker name	Marker position
M1	Vertex
M2	Front of cranium
M3	Back of right ear
M4	Back of left ear
M5	Below left ear of occipital area
M6	Below right ear of occipital area
M7	13th dorsal vertebra
M8	Left flank
M9	Right flank

- Height of the center of gravity above the floor

The dog's center of gravity is located at the 13th dorsal vertebra. Thus, the z-axis coordinate of the M7 marker, which is attached above 13th dorsal vertebra, is used to obtain position information for the center of gravity.

- Height of the vertex above the floor

The M1 marker is attached at the vertex. As with the "height of the center of gravity above the floor," the z-axis coordinate of the M1 marker is used to calculate the "height of the vertex above the floor."

- Angle between the lateral axis of the body and the floor

Markers M8 and M9 are symmetrically positioned on both flanks. When a dog stands erect with its feet together, the line connecting markers M8 and M9 is parallel with the floor. Therefore, the "height of the vertex above the floor" can be defined as the angle between the floor and the line connecting markers M8 and M9.

- Opening degree of left and right ears

Marker M1is in a fixed position, as it is fastened to the dog's head. The "opening degree of left and right ears" is calculated relative to marker M1. As shown in Figure 3, the "opening degree of left and right ears" is defined as the angle between the line segment connecting markers M3 and M1, and the line segment connecting markers M4 and M1 ($\theta 1$).

- Anteroposterior tilt of the left and right ears

Markers M5 and M6 are immobile and positioned on the dog's head. Therefore, the "anteroposterior tilt of the left ear" and "anteroposterior tilt of the right ear" are also calculated relative to each marker. The anteroposterior tilt of the right ear is defined as the angle between the line segment connecting markers M4 and M6, and the plane spanned by markers M2, M5, and M6 ($\theta 2$).The anteroposterior tilt of left ear is calculated in a like manner.

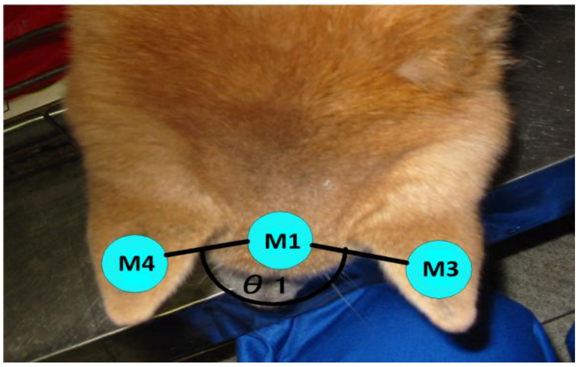

Fig.3 Opening degree of the left and right ears

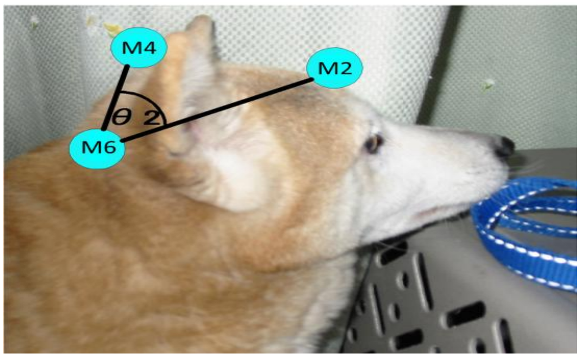

Fig.4 Anteroposterior tilt of right ear

3.Experiment

The experiments in this study were conducted under the guidance of a veterinarian. A tail clamp was used to induce acute stress in the subject. The tail clamp is a noninvasive means of inducing pain by pinching the dog's tail with forceps, a method which is often used to evaluate the effect of anesthetics.

In this experiment, one ShibaInu dog (female, 13-year-old) was used as the study subject. Each experiment was conducted four times. In one experiment, tail clamp trials were replicated eight times. Prior to the tail clamp trial, the dog was positioned in the posture shown in Figure5, in order to standardize the dog's initial posture. The duration of each tail clamp trial was 10 s, and 5 min breaks were taken between each trial, to allow the effects of the pain to dissipate. The dog's motion was tracked using the VICON motion capture system, the sampling rate of which was 120 Hz. In total, 120 Hz × 10 s resulted in the generation of1200 samples per tail clamp trial. In a subsequent evaluation, one in 1200 samples was used.

In addition to the tail clamp trials, joint activities between the dog and a human handler, such as walking on a leash, feeding, and petting were recorded using the motion capture system, in order to determine whether postures displayed during the tail clamp trial can be discriminated from those recorded during these joint activities.

This experiment was permitted by the former parent organization without requirement of an ethics application because of non-invasive way.

Fig. 5 Dog's posture prior to the tail clamp trial

4.Evaluation and results

4.1 Body and ear postures are difficult to distinguish from postures displayed during the tail clamp trials

Table 2 lists canine quantitative representations the study subject's postures. These were computed using the dog's posture immediately prior to the tail clamp trials, and the average values computed from the 32-pointdataset (eight trials over four days). Table 3 provides a quantitative representation of canine posture during the tail clamp trial. These tables show that the "opening degrees of the left and right ears" were wider and the "anteroposterior tilt of the right (and left) ear" was shallower during the tail clamp trial than immediately prior to the start of the trial. In addition, as shown in Table 3, the "height of the vertex above the floor," "height of the center of gravity above the floor," and "angle between lateral axis of the body and the floor" show that the dog lies with its side surface tap into floor. These ear and body postures correspond to body postures a) and e), described in Section 2. (Body postures b), c) and d) were not observed during this experiment.)

To evaluate whether the dog's postures during the tail clamp trials can quantitatively be distinguished from other postures exhibited under non-stress conditions, body and ears postures analogous to postures a) and e) were visually selected from the recordings of joint activities between the dog and its human handler. In this experiment, analogous body and ears postures were observed in the following situations:

S1) Being patted on the head
S2) Being approached by the handler
S3) Feeding
S4) Walking on a leash
S5) Lateral recumbency lowering both ears

Table 2: Quantitative representation of the shown in Figure5

Opening degree of left and right ears[rad]	Anteroposterior tilt of left ear [rad]	Anteroposterior tilt of right ear [rad]	Height of the vertex above the floor[mm]	Height of the center of gravity above the floor[mm]	Angle between the lateral axis of the body and the floor[rad]
1.961(0.100)	0.824(0.111)	0.845(0.196)	508.4(13.94)	236.0(10.05)	0.151(0.133)

Table 3: Quantitative representation of dog's posture during tail clamp

Opening degree of left and right ears[rad]	Anteroposterior tilt of left ear [rad]	Anteroposterior tilt of right ear [rad]	Height of the vertex above the floor[mm]	Height of the center of gravity above the floor[mm]	Angle between lateral axis of the body and the floor[rad]
2.452(0.1527)	0.591(0.330)	0.574(0.1131)	257.5(19.12)	127.3(23.11)	0.853(0.276)

Henceforth, postures of S1), S2), S3), S4), and S5) are designated as P1, P2, P3, P4, and P5, respectively. Postures P1 through P5were superficially similar to body and ear postures observed during the tail clamp trial. The potential for a quantitative assessment of canine stress behavior was evaluated by differentiating postures observed during the tail clamp from the five analogous postures described above. As with the dataset obtained during tail clamp trials, one sample was used as the representative value for each postureP1, P2, P3, P4, and P5.

4.2 Results of distinguishing between analogous postures

In this study, postures observed during the tail clamptrial (target group) and the analogous postures described in section 4.1 (non-target group) are differentiated using a quadratic discrimination analysis (QDA). To generate the QDA classifier, 16 of 32 samples taken during the tail clamp trials were randomly selected as learning data for the target group. The remaining 16 samples were used to evaluate the resulting model. Similarly, 16 samples of each posture P1, P2, P3, P4, and P5 were used as learning data for the non-target group, with the same number of samples used to evaluate the resulting model.

Classification accuracies were determined using the following equations:

$$Sensitivity = \frac{TP}{TP + FN}, \qquad (1)$$

$$Specificity = \frac{TN}{TN + FP}, \qquad (2)$$

Where TP represents the true positives (the number correctly classified as the target group), FN represents the false negatives, TN represents the true negatives (the number correctly classified as the non-target group), and FP represents the false positives.

The classification results are shown in Table 4. In addition, six quantitative representations of body and ears postures such as the "anteroposterior tilt of right ear," and "angle between the lateral axis of the body and the floor" were visualized using the principal component analysis (PCA).Two dimensional mapping the first and second principal components of quantified body and ear postures under acute stress and those under non-stress is shown in Figure 6.

Table 4: Classification accuracy

Sensitivity [%]	Specificity [%]
81	93

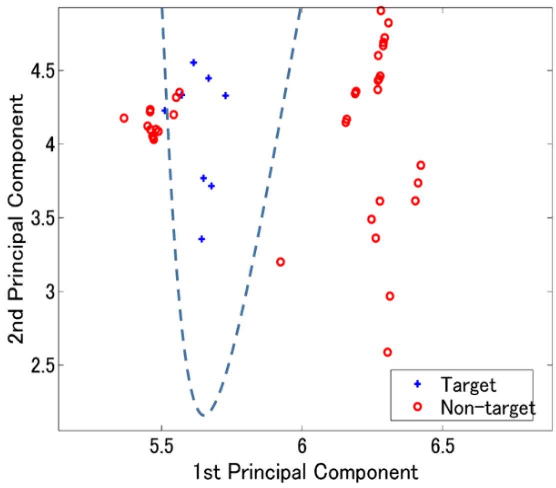

Fig. 6: Two-dimensional mapping of the first and second principle components of quantitative representations of the dog's postureunder acute stress (Target) and under non-stressconditions (Non-target).

5.Discussion

The goal of this study was to evaluate the possibility of quantifying acute stress-related behaviors in canines. A motion capture system was used to quantify the study dog's behavior, and parameters such as the height of the vertex above the floor, angle between lateral axis of the body and the floor, and three dimensional ear postures were calculated.

In this study, acute stress was induced using a tail clamp, and changes in posture were evaluated in order to determine whether the dog's behavior under acute stress could be quantitatively distinguished from analogous behaviors, using the QDA classifier. As shown in Table 4, behaviors associated with acute stress could be distinguished from analogous behaviors with 81% sensitivity and 93% specificity. Figure 6 also shows that behaviors related to acute stress can be distinguished from analogous behaviors if effective classifiers are adopted. These results indicate that behaviors related to acute stress can be evaluated quantitatively and automatically once classifiers are established by trained observers such as veterinarians, ethologists or trainers.

However, individual and breeds differences could not be evaluated, as this study was conducted using a single dog. In a narrow sense, behavioral responses related to acute stress can differ from one individual to the next, even when the same stimulus is applied. This is true among different breeds. However, in canine ethology, it is well-known that behaviors related to acute stress tend to be similar among individuals, even considering individual differences. Therefore, although the number of canine subjects included in this study was small, the study shows that a quantitative evaluation of behaviors related to acute stress is possible. To further confirm this result, differences in behavioral responses among individual dogs as well as different dog breeds will be examined in future studies using a larger number of canine subjects. Further, automatic analysis of a moving image-based quantitative evaluation of acute stress-related behavior will be attempted in the future.

6.Conclusion

The purpose of this research was to quantitatively evaluate a single dog's behavioral responses to acute stress. The dog's behavior was quantified using the VICON motion capture system. In particular, the dog's body and ears postures, such as the "anteroposterior tilt of the right ear," and the "angle between lateral axis of the body and the floor" were computed using nine motion capture markers. Atest dog was acutely stressed using a tail clamp, during which the dog's body and ear postures were recorded, then, using the QDA classifier, quantitatively distinguished from analogous postures observed under non-stress conditions. As a result, the dog's body and ears postures during acute stress could be discriminated from analogous postures observed under non-stress conditions, with 81% sensitivity and 93% specificity. In future studies, behavioral differences among individuals and breeds will be evaluated using a larger sample size of dogs.

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