# Assessing repeatability and validity of a visual analogue scale questionnaire for use in assessing pain and lameness in dogs

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**Objective**—To develop a visual analogue scale (VAS) questionnaire that is repeatable and valid for use in assessing pain and lameness in dogs.

**Sample Population**—48 client-owned dogs with mild to moderate lameness.

**Procedure**—The dogs were from 3 studies conducted during a 3-year period. Of the 48 dogs, 19 were used in repeatability assessment, 48 were used in principal component analysis, and 44 were used in model selection procedures and validity testing. A test-retest measure of repeatability was conducted on dogs with a change of < 10% in vertical peak force. A force platform was used as the criterion-referenced standard for detecting lameness. Principal component analysis was used to describe dimensionality of the data. Repeatable questions were used as explanatory variables in multiple regression models to predict force plate measurements. Peak vertical, craniocaudal, and associated impulses were the forces used to quantify lameness. The regression models were used to test the criterion validity of the questionnaire.

**Results**—19 of 39 questions were found to be repeatable on the basis of a Spearman rank-correlation cut point of > 0.6. Model selection procedures resulted in 3 overlapping subsets of questions that were considered valid representations of the forces measured (vertical peak, vertical impulse, and propulsion peak). Each reduced model fit the data as well as the full model.

**Conclusions and Clinical Relevance**—The VAS questionnaire was repeatable and valid for use in assessing the degree of mild to moderate lameness in dogs. (*Am J Vet Res* 2004;65:1634–1643)

Pain has been referred to as the fifth vital sign in humans, and measuring it has been an evolving process.[1] In domestic animals, pain is difficult to determine and this can become an even greater task considering that patients cannot talk to clinicians. Pain in humans and domestic animals has been described as an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage.[2] Pain in nonhuman animals has also been defined as an aversive sensory experience that elicits protective motor actions, results in learned avoidance, and may modify species-specific traits of behavior, including social behavior.[2] When applied to locomotor movement, this learned avoidance is referred to as lameness. In the context of veterinary medicine, lameness has been most commonly described as a deviation in the normal gait of an animal.[3] Pain from stimulation of nociceptors in the abnormal limb results in lameness.[4] Most animals in which lameness is evident are believed to be experiencing pain. However, it is possible for an animal to have mechanical lameness not associated with painful sensations.

It is believed that the extent of lameness is associated with the amount of pain. Therefore, an accurate measurement of lameness may help when assessing the amount of pain. However, quantifying lameness may be difficult even for veterinary orthopedic surgeons experienced in gait assessment and gait abnormalities because lameness may not be evident in a clinical setting.[5] For example, working or hunting dogs will often only display their lameness when involved in activities.[3] In addition, the current methods of measuring lameness are not uniform among all members of the veterinary profession. For these reasons, clinical examination may be inaccurate for the diagnosis and detection of lameness. Thus, gaining detailed information from owners about the activity and behavior of their dogs may aid clinicians.

Lameness is clinically assessed by analysis of a dog's gait. The gait is a description of the motion of the limbs and has historically been subjectively evaluated. A more objective and quantitative method is kinetic gait analysis, which is accomplished by examining the forces a limb exerts on a force plate. Force plate analysis has had growing acceptance in quantifying the severity of lameness in dogs.[6-17] Force plate data have been used to verify a change in lameness and have also been used in conjunction with various lameness scales.[6-11] Force plate data collected for healthy animals correlate with morphometric measurements, as expected.[12] Forces from healthy dogs have been analyzed to determine the amount of variation inherent in the various forces that can be measured.[13] On the basis of these aforementioned studies, **vertical force (Fz)** and **craniocaudal force (Fy)** appear to be repeatable measures, whereas **mediolateral force (Fx)** appears to be less reliable.

In several studies,[14-17] investigators have surgically

Received December 19, 2003.
Accepted April 12, 2004.
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The authors thank Drs. Donald Hulse and William Burkholder for technical assistance.
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induced lameness in dogs to facilitate the evaluation of changes in gait. These studies revealed that when an animal is lame in 1 limb, there is redistribution of forces in the other limbs through increases in the forces placed on the contralateral limbs or the ipsilateral limb. Because differing proportions of forces are exerted on forelimbs, compared with forces exerted on hindlimbs, and there is a redistribution of forces on limbs when an animal is lame, a global outcome variable should account for the amount of redistribution.

The degree of anxiety exhibited by an animal can also be used to judge the amount of pain experienced by that animal. Owners may be the best persons to judge this degree of anxiety because they are most familiar with the typical behavior of their animals. In a preliminary study,[18] investigators documented that owners provide useful and valuable information pertaining to the behavior of their dog when considering chronic pain. In another study,[19] investigators also suggested the use of a questionnaire completed by someone familiar with the dog.

Useful questionnaires must be repeatable and valid. Repeatability or reliability (the extent to which a measurement can be repeated under identical conditions) of questionnaires can be measured by use of the test-retest method.[20,21] This method uses the same individual for 2 measurements and reduces the amount of variability that may be introduced by use of multiple individuals. The test-retest method of assessing reliability has also been used extensively in the measurement of human health.[22-25] Various studies[5,26-28] have been conducted in animals to determine the measurement that is the most reliable and most accurate in detecting and quantifying evidence of pain. A **visual analogue scale (VAS)** reportedly[5,26-28] is more likely to detect subtle changes than that detected by use of numeric rating scales.

The validity of a measurement is described as the degree to which an instrument measures that which it was intended to evaluate.[20,21] There are various forms of validity that may be used when describing a measurement. Criterion validity is used when describing the correlation between the measurement in question and another external measurement of the same phenomenon.[20,21] Criterion validity of a questionnaire has been documented by use of correlations with other validated questionnaires.[29-32]

The questionnaire in the study reported here was designed to be comprehensive and created on the basis of human pain scales modified to canine behavior. We hypothesized that it would capture information about the entire concept of pain as well as the lameness aspect of pain. In a preliminary study[a] of the test-retest assessment of the questionnaire, it had excellent agreement in more than half of the questions and poor agreement in < 15% of the questions.[a] The preferred method to validate a questionnaire by use of criterion validity is by comparison with a criterion-referenced standard (ie, the most accurate method, procedure, or measurement that is known to represent the true value of the factor being tested). In our study, force plate analysis was used as the criterion-referenced standard. The objectives of the study reported here were to test the questionnaire for a large number of dogs (ie, more than for the preliminary assessment) and further evaluate its reliability, test the criterion validity of the questionnaire by use of force plate measurements, and develop and evaluate the validity of a shortened questionnaire.

## Materials and Methods

**Selection of subjects**—For the study reported here, we used client-owned dogs that were examined at the Veterinary Medical Teaching Hospital of Texas A&M University. Dogs of any breed or sex were eligible to participate in the study provided they had clinical signs of lameness. Dogs generally weighed ≥ 13.6 kg, which facilitated recording of 2 separate limb strikes during force plate analysis.

Data for this study were collected as part of other research projects. The dogs were from 3 cohorts. The first cohort was used in a preliminary study of the reliability of the questionnaire, whereas the other 2 cohorts consisted of dogs enrolled in a clinical study of nutraceuticals or a study to examine the effects of weight loss on lameness. Dogs were recruited by one of the authors (LT) who obtained informed consent from the owner when a dog fit the inclusion criteria of one of the cohorts.

The first cohort of dogs was used in a preliminary study to test reliability of the questionnaire. This study was conducted between June and November 1997. These dogs were chosen because their lameness was believed to be relatively constant. Lameness was quantified by use of force plate analysis. When a dog had a change of < 10% in peak Fz between 2 visits to our facility, the lameness was considered to be the same. Dogs were included in this cohort when they had degenerative joint disease in any limb, as determined on the basis of radiographic and clinical documentation; dogs could be any age, breed, or sex and were included when 2 limb strikes could be recorded. Initial assessment of this cohort of dogs included an orthopedic examination, force plate evaluation, and analysis of the questionnaire completed by the owner. The owners of these dogs were instructed to return the dogs to our facility in 1 or 2 weeks to repeat the assessment. Fifteen dogs met the inclusion criteria and were used in the study reported here. Of those 15 dogs, 11 had a change of < 10% in their peak Fz and were used in the test-retest assessment of reliability.

The second cohort was from a study of nutraceuticals conducted between April 1999 and May 2001. Dogs of any breed or sex, between 2 and 10 years of age, and weighing between 23 and 41 kg were included when they met the criteria, which included a body condition score[b,c] between 2 and 4 (scale of 1 to 5); chronic, recurring lameness of l limb for more than 4 months as a result of degenerative joint disease secondary to hip dysplasia or repair of a unilateral cruciate-deficient stifle within the preceding 1 to 6 years; a lameness score between 2 and 4 (scale of 1 to 5); radiographic evidence of osteoarthritis in 1 or more joints of the affected limb; and ground reaction forces of the affected limb (obtained by use of the force plate) were less than those for the contralateral limb. An additional criterion was that owners of the dogs must have evaluated the dog at home and returned the dog to our facility for a scheduled reevaluation.

Dogs were excluded from the second cohort when they received any nonsteroidal anti-inflammatory drug within the preceding 14 days, an injection of a corticosteroid within the preceding 8 weeks, an orally administered corticosteroid within the preceding 8 weeks, any chondroprotective agent or nutraceutical product within the preceding 12 weeks, or any sulfonamide or tetracycline within the preceding 7 days.

Dogs were also excluded when they were pregnant or medically ill, as determined on the basis of results of clinical or laboratory evaluation; were lame or had gait abnormalities attributable to an immunologic, neurologic, infectious, or neoplastic condition; had undergone surgery (other than elective neutering) within the preceding 6 months; or had an initial lameness score of 1 or 5 (scale of 1 to 5).

Initial assessment of dogs in the second cohort included physical examination (including an orthopedic examination), a CBC count, serum biochemical analysis, urinalysis, radiographic evaluation, and force plate analysis; the owners also had to complete a questionnaire. The dogs were randomly prescribed a nutraceutical or control product. Owners were instructed to return the dogs to our facility 4 and 8 weeks after the original assessment; dogs were assessed in a similar manner during these reevaluations. Twelve dogs met all the inclusion criteria and were used for the study of the lameness questionnaire reported here. None of these dogs were used in the reliability evaluation because a treatment or control product was given between initial assessment and the subsequent assessment. Thus, similar conditions necessary for a test-retest evaluation were not available.

The third cohort of dogs was from a study of weight loss that took place between June 1998 and November 2000. Dogs were included on the basis of lameness attributable to hip osteoarthritis and being overweight. Dogs were classified as overweight when they were ≥ 15% above their optimal body weight, had a body condition score of ≥ 4 (scale of 1 to 5), and had estimated body fat of ≥ 25% as assessed by a board-certified veterinary nutritionist.[b,c] Hip osteoarthritis was diagnosed on the basis of results of an orthopedic examination and examination of radiographs. Dogs could be either sex and were required to be > 2 years old, between 18 and 55 kg, and obedient when on a leash. An orthopedist determined from the medical history that osteoarthritis in each dog was stable. Owners provided informed consent and agreed to comply with a weight-loss regimen that consisted of changes in diet and exercise. Dogs with osteoarthritis in any other joint, evidence of pain in another joint, or neurologic diseases were excluded from the third cohort.

Initial assessment of dogs in the third cohort included a complete physical examination (including an orthopedic examination), radiographic evaluation, and force plate analysis; owners were required to complete a questionnaire. Many dogs were reevaluated 2 weeks after the initial examination and before start of the weight-loss regimen so that they could be included in testing the reliability of the questionnaire before there were any known changes. Seventeen dogs met the inclusion criteria and were used in the study of the lameness questionnaire reported here. Of these 17 dogs, 9 were returned to our facility for a second evaluation prior to any dietary change; 8 of these 9 dogs also had a change of < 10% for Fz and were used in the test-retest assessment of reliability.

**Questionnaire for assessment of pain**—The questionnaire[d] consisted of 39 questions that adhered to the format of a 10-cm VAS. The questionnaire was administered at our facility by one of the authors (LT). Some of the questions were in the following format: How willing is your dog to play voluntarily? How difficult is it for your dog to lie down? There was a corresponding VAS line for each question with contrasting descriptors at each end (eg, not at all and very willingly or difficult and easy, respectively).

**Lameness assessment by use of the force plate**—Force plate data were collected in a laboratory.[e] The force plate[f] was installed centrally in an 11-m runway. The surface of the force plate was level with the surrounding floor. The area was covered with a thin carpet that served to camouflage the location of the force plate. Signals from the force plate and its integrated photoelectric cells proceeded through an amplifier[g] and into a designated computer.[h] Data from each foot strike were recorded at 2-millisecond intervals for 650 milliseconds. Forces were analyzed by use of commercially available software,[i] and peak forces (Fz, Fy, and Fx) with associated impulses were recorded.

All cohorts of dogs were allowed a few minutes to become familiar with the laboratory and walked across the runway several times before the trials were recorded. A valid trial consisted of a dog being led at a trot across the runway and the forelimb and ipsilateral hind limb sequentially contacting the surface of the force plate. The forces used for analysis were peak forces of Fz and Fy and their associated impulses. Maximum slope values of the Fz curve during the increase and decrease of the curve were also recorded for those dogs evaluated after we installed upgraded software.[i] Vertical forces were recorded as the peak (or maximum) force detected and the impulse, which is the force measured over time. Craniocaudal forces were recorded similarly. The Fy was divided into propulsion and braking forces for each limb. These forces were standardized by dividing the force by the weight of the dog. A minimum of 5 trials was recorded for both the left and right sides of a dog during each assessment, and the mean value of these trials was used to assess lameness. A constant velocity (1.6 to 2.1 m/s) and minimum acceleration ($0 \pm 0.5$ m/s$^2$) were required for all valid trials; velocity and acceleration were determined by use of photoelectric cells. The same handler led the dogs across the force plate throughout the study. All trials were videotaped to record the gait of each dog and for use in verifying acceptable limb strikes.

**Analysis of reliability**—The questionnaire was tested for reliability by use of a test-retest method. Each question represented a continuous variable with a corresponding score of 0 to 10. The questions were compared by use of the Spearman rank correlation[j] because the data were not normally distributed. A question was considered repeatable when it had a correlation of at least 0.6 and was significant ($P < 0.05$). Questions with < 18 responses (a total of 19 possible responses) were excluded.

**Analysis of validity**—Criterion validity of the questionnaire was tested by evaluating dogs from all cohorts that were lame, as determined on the basis of force plate analysis. Multiple linear regression models were used.[j] The first questionnaire from each dog was used to determine whether the VAS data could predict results of force plate analysis.

A global lameness score was calculated for each force measurement (eg, peak Fz or vertical impulse) by determining the absolute difference in the hind limb forces and adding it to the absolute difference in forelimb forces. This calculation was an estimate of the degree of lameness for each dog that quantified the redistribution of forces. For example, when the difference in peak Fz of the forelimbs was 2.66% and the difference in the peak Fz of the hind limbs was 10.70%, then a value of 13.36 would be used as the value for the dependent variable total peak vertical difference. This represented an absolute change in percentage of body weight on the basis of Fz.

Six linear models were developed by use of the global lameness score for each of the 6 forces (dependent variables) and each of 19 repeatable questions (independent variables). The assumptions of multiple linear regression were evaluated.[33,34] When needed, transformations by use of the Box-Cox method[34] were used to maintain those assumptions.

Validity of the 6 models was assessed by use of the **coefficient of determination ($R^2$)**, the adjusted $R^2$ value, and the $P$ value for the regression models. Models that used specific forces as dependent variables that were significant ($P < 0.05$) were considered valid full models. Three valid models were then used to further reduce the questionnaire.

**Reduction of questionnaire—**Questions were grouped into areas representing owner assessment, mobility, and behavior because there was not a sufficient number of dogs to assess all questions simultaneously. Each of these groups was analyzed by use of **principal component analysis (PCA)**.[j] Similar to the linear regression models, all first questionnaires of dogs were used for the PCA. Four more dogs that lacked force plate data were added for the PCA to provide a total of 48 dogs. Principal components extracted had an eigenvalue (which is proportional to the amount of variance) > 1. Factor loading of > 0.6 was considered to load strongly onto the corresponding component.

After determining the principal components, reduced linear regression models were built by including a representative question from each principal component. The $R^2$ value, adjusted $R^2$ value, and $P$ value for the regression model were used to determine fit of the model. Because this method did not achieve the desired model fit, other methods were used to determine the final reduced models. A backward-selection algorithm was used on the 3 full models for comparison with the reduced models on the basis of PCA. Spearman correlations were also determined for comparison of questions with each other. A priori knowledge of the areas that the questionnaire was designed to measure and trial-and-error techniques by use of model fit and coefficient changes were used in the reduction of variables.[35] It was determined that each principal component should be represented in the final models. It was found for each reduced model that 1 component needed to be represented by 2 questions to achieve the desired model fit.

The resulting reduced questionnaire was obtained by use of various dependent variables (ie, total peak vertical difference, total vertical impulse difference, and total peak propulsion difference) that were believed to be useful in the development of regression models for the questionnaire. Thus, 3 sets of independent variables (questions) were obtained. The 3 reduced models were then compared with each of their respective full models to determine whether the shortened questionnaires accurately predicted the degree of lameness in a dog.

Table 1—Identification of repeatable questions for use in a questionnaire to assess pain and lameness in dogs.

| Question | Spearman rank correlation coefficient | No. | $P$ | Group† |
|---|---|---|---|---|
| Overall owner assessment for preceding month* | 0.741 | 19 | < 0.001 | Owner |
| Overall owner assessment for preceding week* | 0.688 | 19 | 0.001 | Owner |
| Mood of dog during preceding month* | 0.688 | 19 | 0.001 | Behavior |
| Mood of dog during preceding week* | 0.681 | 19 | 0.001 | Behavior |
| Attitude of dog during preceding month* | 0.736 | 19 | < 0.001 | Behavior |
| Attitude of dog during preceding week* | 0.808 | 19 | < 0.001 | Behavior |
| Frequency of postures of a happy dog* | 0.742 | 18 | < 0.001 | Behavior |
| Frequency of owner frustration | 0.605 | 13 | 0.028 | — |
| Frequency of offering treats during preceding month | 0.361 | 17 | 0.154 | — |
| Frequency of massaging dog during preceding month | 0.893 | 12 | < 0.001 | — |
| Change in amount of interaction with family | 0.346 | 17 | 0.173 | — |
| Change in type of interaction with family | 0.213 | 18 | 0.397 | — |
| Change in frequency of daily activity | 0.495 | 19 | 0.031 | — |
| Change in amount of daily activity* | 0.687 | 19 | 0.001 | Behavior |
| Frequency of engaging in other activities | 0.398 | 19 | 0.092 | — |
| Willingness to play voluntarily* | 0.886 | 19 | < 0.001 | Behavior |
| Change in voluntary play during preceding month | 0.510 | 19 | 0.026 | — |
| Amount of voluntary exercise | 0.468 | 19 | 0.044 | — |
| Change in voluntary exercise (preceding month) | 0.086 | 18 | 0.734 | — |
| How often dog gets exercise* | 0.800 | 19 | < 0.001 | Mobility |
| Difficulty in jumping | 0.577 | 19 | 0.010 | — |
| Change in amount of assistance when jumping | 0.265 | 16 | 0.321 | — |
| Difficulty in lying down | 0.393 | 19 | 0.096 | — |
| Difficulty in sitting* | 0.716 | 19 | 0.001 | Owner |
| Difficulty in rising from lying position* | 0.903 | 19 | < 0.001 | Owner |
| Difficulty in rising from sitting position | 0.482 | 19 | 0.037 | — |
| Difficulty in squatting to urinate or defecate* | 0.689 | 19 | 0.001 | Owner |
| Difficulty in lifting hind limb to urinate | 0.939 | 10 | < 0.001 | — |
| Willingness to walk up stairs | 0.819 | 14 | < 0.001 | — |
| Previous willingness to walk up stairs | 0.632 | 13 | 0.021 | — |
| Willingness to walk down stairs | 0.758 | 14 | 0.002 | — |
| Previous willingness to walk down stairs | 0.650 | 13 | 0.016 | — |
| Vocally indicates pain when touched | 0.455 | 19 | 0.050 | — |
| Stiffness when arising for the day* | 0.782 | 19 | < 0.001 | Behavior |
| Stiffness at end of the day (after activities)* | 0.744 | 19 | < 0.001 | Behavior |
| Indicates lameness when walking* | 0.819 | 19 | < 0.001 | Mobility |
| Indicates lameness when trotting* | 0.799 | 19 | < 0.001 | Mobility |
| Indicates lameness when running* | 0.870 | 19 | < 0.001 | Mobility |
| Pain when turning suddenly while walking* | 0.706 | 19 | 0.001 | Mobility |

*Repeatable questions. Questions were considered repeatable when they had a correlation coefficient ≥ 0.600, significant $P$ value ($P < 0.05$), and a minimum of 18 responses (19 responses possible). †During reduction of the questionnaire, repeatable questions were grouped into 3 groups representing owner assessment, mobility, or behavior.

— = Not applicable.

A composite of the questions from the 3 final reduced models resulted in 11 questions. These questions were further analyzed by use of linear regression models with only 1 independent variable entered at a time to determine the relationship between each predictor variable and dependent variable without other predictor variables in the model. This data also allowed for analysis of issues of multicollinearity.

## Results

**Repeatability—**Twenty-four dogs (15 from the first cohort and 9 from the third cohort) were eligible for the test-retest assessment. However, only 19 of these dogs (11 from the first cohort and 8 from the third cohort) were verified as having a change in peak Fz of < 10% by use of force plate analysis.

Of the original 39 VAS questions in the questionnaire, 19 (49%) were found to be repeatable **(Table 1)**. These 19 questions had a Spearman rank correlation coefficient that ranged from 0.68 to 0.90 ($P \leq 0.001$). Six questions had a response from < 15 clients (pool of 19 clients) and were removed from consideration.

**Validity—**Responses from 1 client for 2 questions that referred to a dog's attitude during the preceding month and preceding week were omitted for all models. The responses to these 2 questions resulted in highly influential points that skewed the results. Review of records warranted omission.

Six multiple linear regression models (1 for each force measured) were used with all of the 19 repeatable questions as independent variables **(Table 2)**. Some transformations of the dependent variables were necessary to accommodate model assumptions. All assumptions associated with multiple linear regression were met for all models, except when total peak braking difference was the dependent variable. For this model, we could not determine a transformation that would result in validation of all assumptions, and the summary statistics for the fit of this model did not appear to warrant further investigation (the $R^2$ value was low, the adjusted $R^2$ value was extremely low, and the model did not yield significant results). Dependent variables that provided the best fit when the full model was used were total peak vertical difference, total vertical impulse difference, and total peak propulsion difference.

**Reduction of questionnaire—**The PCA resulted in subgroups of questions that helped identify relationships among the variables contained in each group **(Table 3)**. A formal test of the reduced models, compared with their full counterparts, did not reveal significant differences for the 3 reduced models (total peak vertical difference, total vertical impulse differ-

Table 2—Summary of results for 44 dogs of models for each of 6 dependent variables and 19 repeatable independent variables.

| Dependent variable* | $R^2$ | Adjusted $R^2$ | $P$ |
|---|---|---|---|
| Total peak vertical difference | 0.731 | 0.488 | 0.008 |
| Total vertical impulse difference† | 0.680 | 0.390 | 0.031 |
| Total peak propulsion difference‡ | 0.663 | 0.359 | 0.043 |
| Total propulsion impulse difference | 0.575 | 0.191 | 0.185 |
| Total peak braking difference | 0.516 | 0.079 | 0.354 |
| Total braking impulse difference | 0.427 | –0.092 | 0.664 |

*The dependent variables were global lameness scores calculated for each force measurement by adding the absolute difference in the hind limb forces to the absolute difference in forelimb forces. †Required transformation (square root of y) to achieve a normal distribution. ‡Required transformation (1 divided by the square root of y) to achieve a normal distribution.

Table 3—Principal component analysis for 3 groups of questions on pain and lameness in dogs.

| Variables | Factor loading for components | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| **Owner group** | | | | | | |
| Overall owner assessment for preceding month | 0.849* | — | — | — | — | — |
| Overall owner assessment for preceding week | 0.877* | — | — | — | — | — |
| Difficulty in sitting | 0.743* | — | — | — | — | — |
| Difficulty in rising from a lying position | 0.783* | — | — | — | — | — |
| Difficulty in squatting to urinate or defecate | 0.836* | — | — | — | — | — |
| **Behavior group** | | | | | | |
| Mood of dog for preceding month | — | 0.917* | 0.172 | 0.111 | — | — |
| Mood of dog for preceding week | — | 0.861* | 0.185 | 0.07 | — | — |
| Attitude of dog during preceding month | — | 0.915* | –0.056 | 0.195 | — | — |
| Attitude of dog during preceding week | — | 0.918* | –0.059 | 0.193 | — | — |
| Change in amount of daily activity | — | 0.134 | 0.614* | –0.097 | — | — |
| Stiffness when arising for the day | — | 0.029 | 0.864* | 0.099 | — | — |
| Stiffness at end of the day (after activities) | — | –0.022 | 0.847* | –0.067 | — | — |
| Frequency of postures of a happy dog | — | 0.185 | –0.074 | 0.857* | — | — |
| Willingness to play voluntarily | — | 0.156 | –0.068 | 0.859* | — | — |
| **Mobility group** | | | | | | |
| How often dog gets exercise | — | — | — | — | 0.017 | 0.971* |
| Indicates lameness when walking | — | — | — | — | 0.886* | –0.128 |
| Indicates lameness when trotting | — | — | — | — | 0.959* | 0.045 |
| Indicates lameness when running | — | — | — | — | 0.856* | 0.11 |
| Pain when turning suddenly while walking | — | — | — | — | 0.713* | 0.408 |

*Represents factor loading value > 0.600.
— = Not determined.
A, B, C, D, E, and F are the principal components.

ence, and total peak propulsion difference). The 3 reduced models resulted in several common predictor variables (**Table 4**).

Some coefficients of these models did not yield significant results (**Table 5**). Inclusion of these variables was deemed essential because we required that all principal components be represented.

Comparison of the 11 questions remaining from all 3 reduced models revealed the relationship between dependent variables and each question (**Table 6**). The relationship between those questions arising from the same principal component and their corresponding dependent variable aided in the assessment of problems with multicollinearity. Any multi-

Table 4—Variables that remained in the model after incorporating principal components by use of a backward-elimination procedure.

| Predictors for total peak vertical difference* | Predictors for total vertical impulse difference† | Predictors for total peak propulsion difference‡ |
|---|---|---|
| Overall owner assessment for preceding month (A) | Overall owner assessment for preceding month (A) | Overall owner assessement for preceding month (A) |
| Mood of dog during preceding month (B) | Mood of dog during preceding month (B) | Mood of dog during preceding month (B) |
| How often dog gets exercise (F) | How often dog gets exercise (F) | How often dog gets exercise (F) |
| Attitude of dog during preceding month (B) | Attitude of dog during preceding month (B) | Stiffness when arising for the day (C) |
| Change in amount of daily activity (C) | Stiffness at end of the day (after activities) (C) | Stiffness at end of the day (after activities) (C) |
| Frequency of postures of a happy dog (D) | Willingness to play voluntarily (D) | Frequency of postures of a happy dog (D) |
| Indicates lameness when (E) | Pain when turning suddenly | Pain when turning suddenly while walking |
| walking (E) | while walking (E) | |

Components that yielded each variable are indicated in parentheses. *Values for this model were as follows: $R^2$, 0.631; adjusted $R^2$, 0.555; and $P < 0.001$. †For this model, the dependent variable required transformation (square root of y) to achieve a normal distribution. Values for the model were as follows: $R^2$, 0.496; adjusted $R^2$, 0.396; and $P = 0.001$. ‡For this model, the dependent variable required transformation (1 divided by the square root of y) to achieve a normal distribution. Values for the model were as follows: $R^2$, 0.444; adjusted $R^2$, 0.332; and $P = 0.003$.

*See* Table 3 for remainder of key.

Table 5—Coefficients of the reduced model as determined on the basis of a backward-elimination procedure and principal component analysis by use of various force measurements as dependent variables.

| | | Total peak vertical difference* | | Total vertical impulse difference† | | Total peak propulsion difference‡ | |
|---|---|---|---|---|---|---|---|
| **Independent variable** | **Component** | β | ***P*** | β | ***P*** | β | ***P*** |
| Constant | NA | 5.064 | 0.344 | 1.563 | 0.001 | 1.140 | < 0.001 |
| Overall owner assessment for preceding month | A§ | 2.819 | < 0.001 | –0.117 | 0.021 | –0.030 | 0.165 |
| Mood of dog during preceding month | B‖ | 6.266 | < 0.001 | 0.295 | 0.003 | 0.011 | 0.640 |
| Attitude of dog during preceding month | B‖ | –4.773 | < 0.001 | –0.266 | 0.002 | — | — |
| Change in amount of daily activity | C¶ | 0.974 | 0.097 | — | — | — | — |
| Stiff when arising for the day | C¶ | — | — | — | — | –0.052 | 0.002 |
| Stiffness at end of the day (after activities) | C¶ | — | — | –0.035 | 0.258 | 0.032 | 0.033 |
| Frequency of postures of a happy dog | D# | 0.696 | 0.045 | — | — | 0.008 | 0.503 |
| Willingness to play voluntarily | D# | — | — | 0.024 | 0.356 | — | — |
| Indicates lameness when walking | E** | 0.722 | 0.285 | — | — | — | — |
| Pain when turning suddenly while walking | E** | — | — | 0.101 | 0.004 | –0.045 | 0.002 |
| How often dog gets exercise | F†† | –0.012 | 0.971 | –0.047 | 0.863 | –0.024 | 0.041 |

Coefficients were considered significant at values of $P \leq 0.05$.

§A is the only component extracted from the owner group of questions. ‖B is 1 of 3 components extracted from the behavior group of questions. ¶C is another 1 of 3 components extracted from the behavior group of questions. #D is another 1 of 3 components extracted from the behavior group of questions. **E is 1 of 2 components extracted from the mobility group of questions. ††F is the other of 2 components extracted from the mobility group of questions.

NA = Not applicable. — = Not determined.

*See* Table 4 for remainder of key.

Table 6—Results of linear regression models for 44 pairwise comparisons to determine bivariate relationships among the final 11 questions and several dependent variables.

| Independent variable | Total peak vertical difference | Total vertical impulse difference* | Total peak propulsion difference† |
|---|---|---|---|
| Overall owner assessment for preceding month | | | |
| β | –1.485 | –0.105 | 0.010 |
| *P* | 0.013 | 0.013 | 0.555 |
| Mood of dog during preceding month | | | |
| β | 0.323 | –0.030 | 0.009 |
| *P* | 0.688 | 0.595 | 0.701 |
| Attitude of dog during preceding month‡ | | | |
| β | –0.850 | –0.088 | 0.006 |
| *P* | 0.255 | 0.092 | 0.763 |
| Frequency of postures of a happy dog | | | |
| β | –0.014 | –0.050 | 0.009 |
| *P* | 0.975 | 0.102 | 0.472 |
| Change in amount of daily activity§ | | | |
| β | –0.254 | –0.063 | 0.011 |
| *P* | 0.727 | 0.218 | 0.590 |
| Willingness to play voluntarily | | | |
| β | 0.104 | –0.006 | –0.004 |
| *P* | 0.803 | 0.837 | 0.761 |
| How often dog gets exercise‡ | | | |
| β | –0.207 | –0.049 | –0.011 |
| *P* | 0.641 | 0.110 | 0.360 |
| Stiffness when arising for the day | | | |
| β | 1.342 | 0.077 | –0.038 |
| *P* | 0.004 | 0.020 | 0.003 |
| Stiffness at end of the day (after activities) | | | |
| β | 0.475 | 0.025 | –0.013 |
| *P* | 0.309 | 0.451 | 0.321 |
| Indicates lameness when walking | | | |
| β | 1.136 | 0.064 | –0.037 |
| *P* | 0.002 | 0.016 | < 0.001 |
| Pain when turning suddenly while walking | | | |
| β | 1.330 | 0.115 | –0.037 |
| *P* | 0.006 | 0.001 | 0.005 |

*Required transformation (square root of y) to achieve a normal distribution. †Required transformation (1 divided by the square root of y) to achieve a normal distribution. ‡Only 43 pairwise comparisons were possible. §Only 42 pairwise comparisons were possible.

collinearity that existed did not skew the models with influential points.

## Discussion

Quantifying the amount of pain for a nonhuman animal may be a difficult task. To our knowledge, the study reported here is the first conducted in domestic animals in which a questionnaire on lameness (as determined by use of force plate analysis) was reliable and valid. Scales to determine validity of pain typically use more subjective methods, such as a comparison with other validated pain scales.[36] This method of documenting validity of a construct (the extent to which a measurement corresponds to a theoretic concept or construct) has been used extensively and is widely accepted in human health.[29-32] However, with technologic improvements, it has become possible to validate surveys and questionnaires by use of more objective assessments.

The use of force plate measurements to quantify mechanical lameness is valid and repeatable,[6-17] and we used force plate measurements as the criterion-referenced standard in the study reported here. Although we measured the forces on all limbs (2 ipsilateral limbs at a time), the use of a larger force plate that would enable measurement of the forces on all limbs simultaneously could reduce the amount of variability; unfortunately, such a force plate was not available to the authors. We were not able to document any reports on the creation of a global outcome from force plate measurements. However, it was derived on the basis of knowledge of redistribution of forces. Calculations used to determine the amount of lameness depicted by the force plate could have been a source of error in our study. For example, a dog with a similar amount of bilateral lameness in the hind limbs or forelimbs may not have a noticeable amount of lameness by use of this calculation. Despite this, a method was needed to create a global outcome variable from the force plate data, and we believed this was the most appropriate option.

The questionnaire in our study was reduced from 39 questions to 19 repeatable questions by use of the Spearman rank correlation. There could have been a potential source of bias in the test-retest portion of this study. Three of the questions queried owners about lameness evident during the preceding month. Because the second assessment was performed 2 weeks after the first assessment, there was a possibility that changes 3 to 4 weeks prior to the first assessment would not be captured by the second assessment. Thus, there could be a discrepancy between the responses to a question for the 1-month time frame that would not be captured by differences in force plate data between the 2 assessments. However, these questions did have significant correlations in the test-retest assessment and therefore were retained in the models. The use of these questions for the

1-month time frame may have a more important clinical use when there is an expected delay between the date on which an appointment is made and the date on which a physical examination is performed by a veterinarian.

Lack of agreement in a test-retest assessment could have been influenced by factors other than lack of reliability.[20,21] The sample size may have affected the repeatability analysis of the questionnaire; some questions were excluded because there was not a sufficient number of owners who responded to a particular question. This problem developed because some questions were not relevant to all dogs (eg, lifting a hind limb to urinate is predominately a male behavior) and questions referring to stairs only applied to owners with multiple-story housing. Thus, a larger sample size in the test-retest assessment of repeatability may have permitted more questions to be evaluated for repeatability.

Values for 3 dependent variables (total peak vertical difference, total vertical impulse difference, and total peak propulsion difference) were predicted well by the questionnaire, as determined on the basis of the $R^2$ value, adjusted $R^2$ value, and significance of the regression model by use of all 19 questions. These 3 dependent variables were used for the reduction procedures.

The procedure we used to reduce the number of variables in the questionnaire included PCA, which decreases the number of variables by reducing the dimensionality of many variables that may be correlated with each other.[17,20,37] This procedure uses the entire set of independent variables, which are believed to be correlated, and creates a new set of principal components that are not correlated while retaining the variation that was explained by the original variables. Ideally, PCA is performed as an exploratory technique to describe themes in a data set. For each of these principal components, a loading factor corresponding to independent variables was calculated that represented the degree to which this principal component was represented by each independent variable. It is conceivable that each of the principal components could have been represented by variables that had high loading factors. The result would have been a reduced model that accounted for nearly as much of the variation as was in the original model.

Ideally, our PCA would have been conducted on the entire questionnaire to document construct validity between those predetermined categories of questions and the principal components extracted. However, this was not possible because of constraints attributable to sample size. Instead, a PCA was performed on each group of questions. This helped us to identify the multicollinearity that was expected to exist among the independent variables with 6 distinct components (1 from the group of questions on overall owner assessment, 3 from the group of questions on attitude or behavior, and 2 from the group of questions on mobility). An attempt was made to reduce the questionnaire by including only 1 question from each principal component. However, for each dependent model, 1 question from each component did not achieve the desired fit. Thus, there were 7 independent variables (1 from each of the 6 components plus an additional question from another component that appeared to aid in the fit of the model) for each dependent variable. Although there was some overlap in the independent variables that were obtained for each model, there were also definite differences.

Some coefficients in the 3 reduced models did not appear to be significant and had a negligible effect, but they were forced into the model to represent each of the principal components. Lack of significance of these coefficients could have been attributable to a number of reasons, including multicollinearity and a lack of power attributable to sample size. The questionnaire could also have been measuring another aspect of pain that the model, which was developed on the basis of force plate measurements, could not capture. Thus, models developed entirely on the basis of force plate data may have differed slightly from models obtained by use of a dependent variable that measured all aspects of pain.

For the dependent variables total peak vertical difference and total vertical impulse difference, there was 1 behavior component that was represented by 2 questions (ie, mood of the dog during the preceding month and attitude of the dog during the preceding month). Similarly, for the dependent variable total peak propulsion difference, there were 2 questions on another behavior component (ie, stiffness when arising for the day and stiffness at the end of the day [after activities]). These 2 sets of questions were significantly correlated with each other, and their relationship was analyzed to attempt to determine whether there were any outliers that were highly influencing the model and requiring that both sets of questions be included in the model, similar to the situation for the questions on attitude during the preceding week and preceding month. However, we did not detect this phenomenon for these 2 sets of questions on behavior components. Thus, both sets of questions were included in the reduced models, and it was believed that their necessary inclusion may have been attributable to interpretation of these questions by the owners. For example, 1 question asked the owner to assess the dog's mood during the preceding month, whereas the other question asked the owner to assess the dog's attitude during the preceding month. These 2 descriptors may be perceived as synonymous by many people; however, owners in the study reported here clearly interpreted them differently. Similarly, the 2 questions on stiffness of a dog were both included in the model when total peak propulsion difference was used as the dependent variable.

Because no single force can capture all aspects of lameness for development of regression models, there will never be a perfect model in which lameness can be completely quantified by a single force. In the study reported here, force plate analysis was used as the criterion-referenced standard to detect lameness because it could quantify lameness more objectively than would be possible with other lameness scores and assessments. Thus, to say that a question did not provide useful information for lameness, as determined on the basis of force plate analysis, could be inaccurate. This discrepancy could account for some of the variability between the questionnaire and force plate measurements.

Differences in the reduced models may have been attributable to the dependent variables that were measured. For example, the model that used total peak vertical difference as the dependent variable measured the amount of change in lameness on the basis of maximum and minimum amount of force exerted on a limb in the vertical direction. The model that used total vertical impulse difference as the dependent variable assessed the changes in force over time in the vertical direction and thus measured more of an average force exerted by the limb. Questions that appeared to be unique to the first model included whether a dog was lame during walking and whether a dog changed the amount of certain activities described by the owner. Thus, depending on how a dog redistributes forces when lame and the stage of a condition (acute or chronic), the forces exerted on a limb may differ dramatically. One question included in the model that used total vertical impulse difference as the dependent variable but that was not included in the other models was whether the dog seemed to play voluntarily. The model that used total peak propulsion difference as the dependent variable also had 1 unique question (ie, whether the dog appeared stiff when rising for the day). Thus, by measuring multiple forces, various aspects of lameness were recorded. Conversely, not all owner-perceived changes were recorded by use of a single force.

The major objective of the study reported here was to establish a practical questionnaire that could be used by practicing veterinarians. The questionnaire was given to clients who could attest to their dog's abilities in the home environment. Ground reaction forces obtained from a force plate were used as a criterion-referenced standard as a measurement of the amount of mechanical lameness for each dog. The questions from 3 models were found to be repeatable, as determined on the basis of the test-retest assessment. The resulting models also measured the criterion validity of the questionnaire. On the basis of analysis of $R^2$ values, adjusted $R^2$ values, scatterplots, significance of the regression models, and significance of the coefficients, the models were found to be valid.

A composite of the 11 questions from all 3 models should help veterinarians determine the degree of lameness when a force plate is not available. This questionnaire can help clinicians in practice situations by allowing clients to provide information by completing the questionnaire. With the information gained, clinicians can then conduct the examination in a more focused direction. Results from this questionnaire could also be used in research settings that require determination of the degree of pain and lameness for a dog. A more objective and standardized evaluation can aid veterinary orthopedic researchers and facilitate projects that involve multiple investigators.

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[b]Burkholder WJ, Taylor L. Weight loss to optimal body condition increases ground reactive forces in dogs with osteoarthritis (abstr), in *Proceedings*. Purina Nutr Forum 2000;5:3.

[c]Burkholder WJ, Taylor L. Morphometric dimensions to quantify body weight and monitor weight loss in dogs (abstr), in *Proceedings*. Purina Nutr Forum 2000;5:4.

[d]Questionnaire available upon request.

[e]Canine Lameness Assessment Laboratory, Department of Veterinary Anatomy & Public Health, College of Veterinary Medicine, Texas A&M University, College Station, Tex.

[f]OR-6-5 force plate, American Medical Technology Inc, Watertown, Mass.

[g]Vishay 2200 amplifier, Vishay Measurements Group, Don Mills, ON, Canada.

[h]486 computer, IBM compatible, assembled in College Station, Tex.

[i]Acquire, Sharon Software, Dewitt, Mich.

[j]SPSS for Windows, version 11.0.1, SPSS Inc, Chicago, Ill.

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