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Forelimb and hindlimb ground reaction forces of walking cats: Assessment and comparison with walking dogs

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ABSTRACT

The primary aim of this study was to assess the potential of force plate analysis for describing the stride cycle of the cat. The secondary aim was to define differences in feline and canine locomotion based on force plate characteristics. Ground reaction forces of 24 healthy cats were measured and compared with ground reaction forces of 24 healthy dogs.

Force-time waveforms in cats generated by force plate analysis were consistent, as reflected by intra-class correlation coefficients for peak vertical force, peak propulsive force and peak braking force (0.94–0.95, 0.85–0.89 and 0.89–0.90, respectively). Compared with dogs, cats had a higher peak vertical force during the propulsion phase (cat, 3.89 ± 0.19 N/kg; dog, 3.03 ± 0.16 N/kg), and a higher hindlimb propulsive force (cat, –1.08 ± 0.13 N/kg; dog, (–0.87 ± 0.13 N/kg) and hindlimb impulse (cat, –0.18 ± 0.03 N/kg; dog, –0.14 ± 0.02 N/kg).

Force plate analysis is a valuable tool for the assessment of locomotion in cats, because it can be applied in the clinical setting and provides a non-invasive and objective measurement of locomotion characteristics with high repeatability in cats, as well as information about kinetic characteristics. Differences in force-time waveforms between cats and dogs can be explained by the more crouched position of cats during stance and their more compliant gait compared with dogs. Feline waveforms of the medio-lateral ground reaction forces also differ between cats and dogs and this can be explained by differences in paw supination–pronation.

Introduction

Orthopaedic diseases in cats can cause lameness, but this is not a common clinical finding in osteoarthritis (OA), the most frequently diagnosed orthopaedic disease in the cat. Age is a risk factor for feline OA and prevalence of 22–72% have been reported in cats over 6 years of age (Hardie et al., 2002; Clarke et al., 2005; Godfrey, 2005); severity also increases with age (Lascelles, 2010; Slingerland et al., 2011). Abaxially, the elbows, hips, shoulders and tarsi are the most commonly affected joints (Slingerland et al., 2011). Axially, the 4th to 10th thoracic vertebrae are most frequently affected, but the lumbosacral vertebrae are the most severely affected (Kranenburg et al., 2012). Early diagnosis and treatment of OA are important, because of the detrimental effects of OA on quality of life (Bennett and Morton, 2009; Kranenburg et al., 2012; Corbee et al., 2013; Guillot et al., 2013).

The diagnosis of orthopaedic diseases can be challenging in cats, because they often do not tolerate a full orthopaedic examination (Hardie et al., 2002; Zamprogno et al., 2010; Kranenburg et al., 2012) and so less stressful methods are desirable. Additionally, the interpretation of orthopaedic examination findings in cats is semi-subjective and largely depends on the observer (Lascelles et al., 2012). Determining the severity of lameness by the number of osteophytes visible on radiographs is not reliable, since this does not correlate with lameness as assessed by force plate analysis (Suter et al., 1998), or with pain, crepitus, or reduced range of joint motion upon orthopaedic examination (Lascelles et al., 2012). More often, subjective assessments by cat owners using standardized questionnaires (client-specific outcome measures) are used to determine the presence of lameness or impairments during gait and other movements (Slingerland et al., 2011; Benito et al., 2012, 2013a, 2013b). However, cat owners find it difficult to score lameness and cannot recognize pain or lameness due to OA, because a stiff gait, unkempt hair coat, or reluctance to jump, are often considered to be normal aspects of feline aging (Kranenburg et al., 2012; Corbee et al., 2013). Thus, it is important for clinicians and researchers to monitor the effects of treatment using objective measures.

Several methods of gait analysis have been described for cats and dogs, including accelerometry (Lascelles et al., 2010; Guillot et al., 2012, 2013; Mazurek et al., 2012; Grand et al., 2013), imaging using

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high-speed cameras to record the movement of reflective patches attached to the skin (Gillette and Angle, 2008), pressure-sensitive walkways (Lascelles et al., 2007; Rialland et al., 2012), and force plate analysis (Suter et al., 1998). Scales and pressure-sensitive walkways only provide an assessment of the vertical ground reaction force (Fz). Using a three-dimensional force plate, the cranio-caudal force (Fy) and the medio-lateral ground reaction force (Fx) exerted during the stance phase can also be determined (Merkens, 1987).

Force plate analysis has been used in dogs and horses to evaluate lameness and/or the effects of treatment in a non-invasive, objective fashion (Theyse et al., 2000; Hazewinkel et al., 2003; Guedes et al., 2012; Kalis et al., 2012; Oomen et al., 2012; Smolders et al., 2012; Spaak et al., 2013; Van der Peijl et al., 2012). The first study to document force plate analysis for the evaluation of locomotion in dogs with hip dysplasia was published by Dueland et al. (1977). After the publication of a study by McLaughlin et al. (1991), force plate analysis became an objective standard in the evaluation of canine locomotion.

Most published studies using force plate analysis in cats are the result of comparative neurophysiology research and do not have application to veterinary clinical practice (Suter et al., 1998; Gregor et al., 2006; Prilutsky et al., 2011). Clinical studies documenting the use of force plate analysis in cats are generally limited to measurements of Fz (Grösslinger et al., 2006; Guillot et al., 2012; Moreau et al., 2013), but the analysis of force-time waveforms in all three directions could potentially improve insight into kinetic gait data (Al-Nadaf et al., 2012; Fransz et al., 2013). Because cats and dogs share similar orthopaedic diseases, a comparison of ground reaction forces during over-ground walking is likely to be a valuable first step in the assessment of force plate analysis as a diagnostic tool in cats.

The first aim of this study was to quantify three-dimensional ground reaction forces during over-ground walking in cats. Our secondary aim was to assess differences in ground reaction force patterns in cats and dogs.

Materials and methods

Animal care and training

This study was conducted with permission of an ethical and welfare committee, as is required under Dutch legislation (NL DEC 2011.III.01.008).

Twenty-four healthy domestic Shorthair cats (12 males, 12 females; mean age 7 years, range 2–14 years; mean body weight 3.8 kg, range 2.2–6.9 kg) from a university cat colony, were trained to walk on a leash. Some cats walked easily on the leash, but most cats needed to wear a cat harness and required time to acclimatize. All cats learned to walk on a leash without stopping and without accelerations in an average of five 30-min sessions within a 2-week training period. It was important for the cats to walk with an uninterrupted gait at a constant speed to avoid differences due to a different gait type or duration of the stance phase (Halbertsma, 1983). Average walking speed across trials and cats was 0.7 ± 0.1 m/s. Prior to each training session, cats were fasted and were allowed to adapt to the force plate room for 10 min. Kibbles and affection were used to encourage the cats to walk.

The data obtained in 24 healthy cats were compared with data of 24 healthy Labradors (8 males, 16 females; mean age 16 months, range 15–17 months; average body weight 26 kg, range 21–32 kg). All cats and dogs were considered healthy based on clinical and orthopaedic examination by a Board certified veterinary surgeon (HH) and normal urinalysis, complete blood count, and serum biochemistry. No abnormalities were observed on plain radiographs of the joints and vertebrae in any animals enrolled in the study.

Data collection

The body weight of each cat was determined on an electronic scale (DIWAC VS150) and recorded immediately before force plate measurement. A quartz piezoelectric force plate (Kistler type 9261) with Kistler 9865B charge amplifiers, mounted flush in a walkway (5 m for cats, 11 m for dogs) was used. The walkway was enclosed by a fence to guide the animal over the force plate. A force platform area of 40 cm long and 60 cm wide was used for dogs and was decreased to 25 cm long and 60 cm wide for cats using a firmly attached overlay plate (Fig. 1; Appendix: Supplementary material, Adaptation of the force plate for use in cats). Sampling rate was 100 Hz. Amplifiers were connected to a computer so that signals, which corresponded with ground reaction forces in the vertical (Fz), cranio-caudal (Fy), and medio-lateral (Fx) directions, could be recorded.

Before data collection, equilibration and calibration of the force plate were performed according to the manufacturer's specifications. Data from all four legs were collected in 10 trials in one session for each of 24 cats. This was repeated after 3 weeks to determine intra-session and intersession variability. The trial data collected in the first session were used for comparison with that obtained for dogs.

Forward velocity was measured using photoelectric switches and a microsecond timer (Hazewinkel et al., 2003). Measurement commencement and termination were automatically regulated as each cat passed switches incorporated in the fence. The same person guided all cats on a leash over the force plate during all recordings without acceleration. Each pass across the platform was also evaluated by a single observer, to confirm that the forelimb was followed by the ipsilateral hindlimb in the same run and that each foot contacted the force plate completely (Video 1). Trials were discarded for incorrect walking speed, distracting head motions, gait irregularities, partial loading of the plate, or more than one foot striking the plate simultaneously.

To obtain qualitative information about fore- and hindlimb movement patterns, we filmed three cats and three dogs walking in the walkway using a high-speed camera (Casio Exilim EX-F1 6 Megapixel 60fps Hi-speed) in both sagittal and frontal planes. Ten trials were filmed per dog ($n = 3$) and per cat ($n = 3$). Typical examples are presented in Appendix: Supplementary material, Video data (Video files 1–6).

Data analysis

All ground reaction force data were normalized to body weight. Impulses were calculated by NI Lab view 8.2 software and presented in Newtons × s/kg body weight (N/kg body weight). Ground reaction force data were time-normalized with respect to stance time for direct comparison of force-time waveforms within and between cats and dogs. The tangent of the peak angle of the initial force (Fz, Fy, Fx) was presented as a measure of the rate of increase of the force over time at the beginning of stance (tangent α, β, γ, respectively). All trials were averaged first within-animal (i.e. average of 10 trials per individual animal) and then averaged across animals. Data are presented as means ± standard deviation of averaged force data across animals.

Typical points identified in the complete force-time waveforms (Fzmax1, Fzdip, Fzmax 2, Fymax, Fymin, t Fy = 0, Fxmax1, Fxdip, and Fxmax2) are shown in Fig. 2, in addition to the angles α, β, and γ. The symmetry between left and right legs was calculated using the ratio according to Mueller et al. (2007) (Table 1).

Video data were synchronized to force plate data using switches in the fence that registered the placement of mass on the force plate coupled to a lamp (Appendix: Supplementary material, Video data, Video file 1). The video data were recorded with 60 frames/s (fps), but displayed at 25 fps to produce slow motion (2.4 times slower).

Statistical analysis

Statistical analyses were performed using commercially available software (R-statistics, R i386 3.0.1). Kolmogorov–Smirnov tests were performed to test for normal distribution; all force plate data were normally distributed. Paired *t* tests were used to make comparisons between different time points and the left and right legs. One-way ANOVA was used to test for differences in selected parameters between cats and dogs. All comparisons were based on average of 10 steps per animal. Statistical significance was set at $P < 0.05$. Intra-class correlation coefficient (ICC) was calculated to test the reproducibility of the data. ICC was considered high at >0.90 (Bénard et al., 2010).

Results

Force plate data

The left and right fore- and hindlimbs revealed symmetry in amplitude of 87–97% for Fzmax, Fymax, Fymin (Table 1). Data for subsequent measures of 10-step samples revealed within-day ICCs of 0.85–0.95 and between-day ICCs of 0.82–0.94 (Table 1). Force plate data for cats and dogs are presented in Tables 2 and 3, respectively. Feline and canine force-time waveforms are presented in Figs 3 and 4, respectively.

Cats – forelimbs

The peak vertical force of the right forelimb (Fzmax1 = 5.70 ± 0.38 N/kg) was reached at 32 ± 1% of the stance phase,