The evaluation of limb symmetry indices using ground reaction forces collected with one or two force plates in healthy dogs

Nicola J. Volstad; Gabby Sandberg; Sarah Robb; Steven C. Budsberg

University of Georgia, College of Veterinary Medicine, Athens, GA, USA

Keywords
Symmetry indices, force plate, dog, ground reaction forces

Summary
Objective: To compare the variability of symmetry indices within and between days when using one and two force plates for data collection.

Animals: Seventeen healthy client-owned adult dogs.

Methods: Vertical ground reaction force data were collected in a crossover study design, with four collection sessions on two consecutive days, and then two weeks apart (days 1, 2, 15, and 16) using both 1-plate and 2-plate collection methods. Symmetry indices were calculated for limb pairs using two standard equations (SI1 and SI2). Repeated measures analysis was used to compare symmetry indices data between plate systems and days. Significance was set at p <0.05.

Results: There were no significant differences between plate systems for SI1 and SI2. There were no significant differences between data collected on different days and no significant interaction effects between variables. Symmetry indices were consistently larger for ground reaction forces calculated from non-consecutive footfalls.

Conclusions: The use of two force plate systems will minimize variance caused by trial repetition and paired limb variation. When comparing SI1 to SI2, results were not significantly different. However, there were consistently higher mean values for SI1 compared with SI2 and symmetry indices were consistently larger for 1-plate systems compared to 2-plate systems for both symmetry indices.

Correspondence to:
Nicola Volstad BVSc(Hons)
University of Georgia
College of Veterinary Medicine
220 College Station Road
Athens, GA 30602–000
United States
E-mail: nicola.volstad25@uga.edu

Introduction

Force platform gait analysis is a commonly used diagnostic tool in veterinary orthopaedic research. It is used to assess treatment outcomes as it provides a non-invasive quantitative assessment of gait (1, 2). Typically, the ground reaction forces obtained from each study object are compared before and after surgical or medical intervention. Several factors affect the variability of the data collected and these include dog breed and conformation, velocity, trial repetition, and day-to-day change (2, 3–8). The sources of variability make direct comparisons between studies challenging. Most studies focus on the use of a single force platform for collection of ground reaction forces. When a single platform is used, footfalls of paired limbs cannot be captured in one pass as the technique only allows for collection of ground reaction forces from one ipsilateral limb pair at a time. The use of multiple force platforms allows for simultaneous collection of ground reaction forces from paired limbs. A recent study showed that the use of multiple force platforms decreased trial repetition and collection time, and the ground reaction forces data had a similar coefficient of variation compared to the use of a single force platform (9).

The use of symmetry indices calculated from ground reaction forces collected by single force platforms has been evaluated in the veterinary literature (12–14). In a healthy dog it is assumed that the left and right feet of a limb pair carry equal weight during the gait cycle. It has been shown that partial asymmetry in ground reaction forces is normal in healthy dogs at a trot and is not the result of a pathological state (12, 13, 15). Symmetry indices can be used to detect lameness as limb symmetry is expected to change with the presence of lameness due to the force distribution pattern (16–18). Several methods of symmetry index calculation have been described, with each index posing its own limitations (12, 14, 19, 20). These methods of symmetry index calculation differ from each other inherently and should not be interchangeable. Most studies evaluating the use of symmetry indices have obtained ground reaction forces using a single force plate (8, 12–14, 19). It has been suggested that variance attributable to paired limb variation or non-consecutive footfalls, which is inherent to data collected from single force plates, might be the cause of ground reaction forces asymmetries seen in healthy dogs (12). The use of two force platforms evaluating consecutive footfalls could eliminate this variation.
The objective of this study was to compare the repeatability and consistency of two methods of symmetry index calculation when using one and two force platforms for data collection in healthy dogs, and to evaluate the symmetry indices within and between days. The first hypothesis tested was that a symmetry index calculation using mean limb measurements of ground reaction forces would provide consistent results across sampling methods. The second hypothesis tested was that a symmetry index calculation using the difference between higher and lower limb measurements of ground reaction forces would be consistent only when consecutive footfalls were evaluated.

Materials and methods

Animals

Seventeen healthy medium to large breed client-owned adult dogs (17.8–40.8 kg) were used. Each dog underwent complete physical examination as well as radiographic evaluation of the hip joints, bilaterally. All included dogs were assessed as being healthy and free of any orthopaedic abnormalities. The study protocol was approved by the College of Veterinary Medicine, Clinical Research Committee at the University of Georgia. All owners signed informed consent documents after a complete discussion of the collection protocol.

Study design

The gait data were collected in a crossover study design, with four sessions on two consecutive days, and then two weeks apart (days 1, 2, 15, and 16) using both 1-plate and 2-plate collection methods. The order of the collection method (1-plate or 2-plates) was randomized using a random number generator. Two force plates were mounted in series at the centre of a 13 m platform. Body weights were recorded before each session. The ground reaction forces data, including peak vertical force (PVF) and vertical impulse (VI), were collected and normalized to the individual body weight and expressed as percentage. Each dog was trotted across the platform by a single handler at a velocity between 1.7 and 2.1 m/s, and an acceleration of ~0.5 to 0.5 m/s². Velocity and acceleration were measured using five photoelectric cells mounted 50 centimetres apart. The vertical ground reaction forces data were collected for all four limbs with the aid of a dedicated computer and software program. When collecting single force plate data, a valid trial was defined as the ipsilateral fore and hind feet striking the force plate. When collecting with two force plates, a valid trial was defined as a forefoot strike on the first force plate, with the ipsilateral hind foot striking the same plate afterward and the contralateral feet striking the second force plate in the same manner. For both 1- and 2-plate collection methods, five valid trials from each left and right limb pairs were collected at each testing day for analysis.

Symmetry calculations

Symmetry indices were calculated for PVF and symmetry indices for the fore-limb and hindlimb pairs for each dog from each collection session. The first symmetry index (SI1) was an adaption from the symmetry indices described by Herzog and colleagues, and used the difference between the superior and inferior limb measurement between contralateral limb pairs, and then calculating the mean symmetry indices from these measurements (14, 19):

\[
SI1 = \frac{Xs - Xi}{1/2(Xs + Xi)} \times 100
\]

where:

- \(Xs\) = PVF of the limb measuring the superior or higher value of PVF between the two limbs of an ipsilateral limb pair
- \(Xi\) = PVF of the limb measuring the inferior or lower value of PVF between the two limbs of an ipsilateral limb pair

The second symmetry index (SI2) was an adaptation from the previously described symmetry indices, and used the mean limb measurements for five experimental trials of the left and right limbs (12, 19):

\[
SI2 = \frac{Xf - Xi}{1/2(Xf + Xi)} \times 100
\]

where:

- \(Xf\) = mean of a given gait variable for five experimental trials of the right limb
- \(Xi\) = mean of a given gait variable for five experimental trials of the left limb

The SI1 and SI2 were calculated for each dog for both 1-plate and 2-plate collections for each day (days 1, 2, 15 and 16). The symmetry indices evaluates weight bearing between two limbs and defines them as symmetrical (0) or asymmetrical (values above or below 0).

Statistical analysis

Plate system comparison

A two-way repeated measures analysis was used to compare symmetry index data between 1- and 2-plate systems and between days. The full mixed effects model included fixed factors of plate type, time and a plate by time interaction, and a random intercept for each dog. All hypothesis tests were two-sided and the significance level was set at \(\alpha = 0.05\). Absolute differences between symmetry indices in 1- and 2-plate systems for the same dog and the same time were calculated to obtain an estimation of variability between 1- and 2-plate systems for each symmetry index. In addition, absolute differences were calculated between symmetry indices measured on day 1 and 2 and between symmetry indices measured on day 15 and 16 for the same dog and the same plate system.

Symmetry index calculation method comparison

A two-way repeated measures analysis was used to compare absolute symmetry index...
Table 1  Symmetry index data for peak vertical force (PVF) and vertical impulse (VI) from all dogs compared between 1- and 2-plate systems and between time points (day 1, 2, 15 or 16).

<table>
<thead>
<tr>
<th>Limb</th>
<th>Plate system</th>
<th>Time point</th>
<th>Symmetry index 1 (mean ± SD)</th>
<th>Symmetry index 2 (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PVF</td>
<td>VI</td>
</tr>
<tr>
<td>Forelimb</td>
<td>1</td>
<td>1</td>
<td>5.06 ± 2.73</td>
<td>5.80 ± 2.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.31 ± 2.13</td>
<td>5.07 ± 3.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>5.04 ± 2.90</td>
<td>5.59 ± 2.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>4.82 ± 2.38</td>
<td>4.61 ± 1.95</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>4.25 ± 1.61</td>
<td>5.83 ± 2.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.70 ± 2.36</td>
<td>5.14 ± 2.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>3.94 ± 2.24</td>
<td>4.68 ± 1.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>4.36 ± 2.11</td>
<td>5.37 ± 2.92</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>3</td>
<td>1</td>
<td>6.08 ± 3.23</td>
<td>6.87 ± 2.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.63 ± 3.14</td>
<td>6.57 ± 3.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>6.64 ± 3.51</td>
<td>6.48 ± 2.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>5.14 ± 2.48</td>
<td>6.85 ± 3.88</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>5.54 ± 3.04</td>
<td>6.45 ± 3.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.67 ± 3.67</td>
<td>6.40 ± 2.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>5.52 ± 3.16</td>
<td>6.46 ± 4.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>5.85 ± 2.40</td>
<td>6.40 ± 4.00</td>
</tr>
</tbody>
</table>

Table 2  Pooled data for symmetry indexes collected with 1- and 2-plate systems for the same dog and the same time.

<table>
<thead>
<tr>
<th>Limb</th>
<th>Symmetry index 1 (mean ± SD)</th>
<th>Symmetry index 2 (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PVF</td>
<td>VI</td>
</tr>
<tr>
<td>Forelimb</td>
<td>1.85 ± 1.93</td>
<td>2.34 ± 2.16</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>2.15 ± 1.55</td>
<td>2.61 ± 2.12</td>
</tr>
</tbody>
</table>

Table 3  Pooled data for symmetry indexes collected at different time points (day 1 or 15, day 2 or 16) for the same dog and the same plate system.

<table>
<thead>
<tr>
<th>Limb</th>
<th>Symmetry index 1 (mean ± SD)</th>
<th>Symmetry index 2 (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PVF</td>
<td>VI</td>
</tr>
<tr>
<td>Forelimb</td>
<td>2.26 ± 2.04</td>
<td>2.65 ± 2.26</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>1.98 ± 1.55</td>
<td>2.25 ± 1.77</td>
</tr>
</tbody>
</table>

PVF = peak vertical force; VI = vertical impulse.

N. J. Volstad et al.: Symmetry indices with one or two force plates

© Schattauer 2017 Vet Comp Orthop Traumatol 1/2017

Results

When comparing data for all dogs, symmetry index data for both PVF and VI compared between 1- and 2-plate systems and between days (day 1, 2, 15 or 16) revealed no significant differences between the different symmetry indices. There were consistently higher mean values for SI1 compared with SI2 (Table 1). Pooled data for plate system (Table 2) or days (Table 3) for forelimbs and hindlimbs showed no differences between SI1 and SI2.

There were no statistical differences for data collected on different days. There were no significant interaction effects between variables including dog, plate system, time and plate by time.

Variance effects were similar for SI1 and SI2 for both PVF and VI (Table 4). The variance was consistently larger for data collected with the 1-plate system for both symmetry indices.

Discussion

The equation for SI1 was originally described by Robinson and colleagues in 1987 (22). The symmetry index was developed to be used as an outcome measure in human chiropractic research. The entire gait cycle of bipedal patients can be measured using a single force plate, thus the data collected is devoid of variation attributed to paired limb variance. The original symmetry index has been adapted several times since its original description and has been used to measure symmetry in the gait of quadrupeds (12, 14, 19).

The first hypothesis tested was rejected. The data showed no significant differences when comparing the first and second symmetry indices for PVF or VI. It is interesting that there was no difference when using paired limbs for calculations of data collected from non-consecutive footfalls compared to consecutive footfalls. However, it

Data variability

Variance for both symmetry indices were calculated for both PVF and VI and compared between 1- and 2-plate systems. All analyses were performed for forelimbs and hindlimbs separately. All analyses were performed using commercially available statistical software.

SAS V 9.4: SAS Institute, Inc., Cary, NC, USA

For personal or educational use only. No other uses without permission. All rights reserved.
should be noted that examination of data showed lower variance for symmetry indices when using consecutive footfalls in the 2-plate system. A previous study showed that less than three percent of variance was attributable to paired limb variation within the dataset when non-consecutive footfalls were evaluated (12). Two-force plate systems evaluate consecutive footfalls, and therefore this source of variance should be eliminated. Remaining variation within each dog is likely to be due to trial repetition, which is a major contributor to variance in force plate gait analysis (3, 7, 12). Recently, it has been shown that there is a significant difference in the time required to obtain a valid trial using a single force plate compared with two force plates. Furthermore, the number of trials needed to collect five valid trials was significantly greater with a single force plate as compared to collection with two force plates (9). Therefore, the use of two force plates will reduce the variance associated with trial repetition (9, 12).

The second hypothesis tested was rejected. When comparing results between 1- and 2-plate systems it was found that SI1 provided results similar to SI2.

In addition to the symmetry index calculations described in this study, two other symmetry index calculation methods have been described, but these have not been used frequently for force plate gait analysis in the veterinary literature (12, 20). The symmetry indices described in this study expressed data differently from the other symmetry index calculations described by Budsberg and colleagues in that it defined perfect symmetry as 0, with variations expressed as percentage of difference from 0 (12). The symmetry index calculations cannot be used interchangeably as each method calculates symmetry indices based on different measures. Symmetry indices are used in clinical studies to document variations between normal and pathological gaits and thereby assess changes in asymmetry due to improvement in a pathological state. Therefore, it is desirable that the symmetry index used provides precise data by minimizing the variance effect and maintaining a low standard deviation. Although a small amount of asymmetry is normal in healthy dogs, either naturally occurring or due to gait collection methods, asymmetry caused by pathology would be easier to detect when using a symmetry index calculation with less variance (12).

There are several limitations in this study. First, the current study did not investigate clinically affected dogs; thus, only speculations can be made about the use and repeatability of the described symmetry indices and plate systems in lame dogs. In addition, other less frequently used methods for symmetry index calculations reported in the veterinary literature were not evaluated. Therefore, conclusions regarding those methods cannot be made.

### Conclusion

The use of two force plate systems will minimize variance caused by trial repetition and paired limb variation. When comparing SI1 to SI2, results were not significantly different. However, there were consistently higher mean values for SI1 compared with SI2 and symmetry indices were consistently larger for 1-plate systems compared to 2-plate systems for both symmetry indices.

### Conflict of interest statement

The authors declare no conflict of interest. None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

### References