Method for estimating maximum permissible load weight for Japanese native horses using accelerometer-based gait analysis

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ABSTRACT

The aim of this study was to establish a method for estimating loading capacity for Japanese native horses by gait analysis using an accelerometer. Six mares of Japanese native horses were used. The acceleration of each horse was recorded during walking and trotting along a straight course at a sampling frequency of 200 Hz. Each horse performed 12 tests: one test with a loaded weight of 80 kg (First 80 kg) followed by 10 tests with random loaded weights between 85 kg and 130 kg and a final test with a loaded weight of 80 kg again. The time series of acceleration was subjected to fast Fourier transformation, and the autocorrelation coefficient was calculated. The first two peaks of the autocorrelation were defined as symmetry and regularity of the gait. At trot, symmetries in the 100, 110, and 125 kg tests were significantly lower than that in First 80 kg ($P < 0.05$, by analysis of covariance and Sidak’s test). These results imply that the maximum permissible load weight is less than 100 kg, which is 29% of the body weight of Japanese native horses. Our method is a widely applicable and welfare-friendly method for estimating maximum permissible load weights of horses.

Key words: autocorrelation, gait analysis, horse, loading capacity, symmetry.

INTRODUCTION

Therapeutic horseback riding, such as hippotherapy and riding for the disabled, has received considerable attention in recent years. While favorable effects that a horse gives to the rider have been described (Masumura et al. 2004; Matsuura et al. 2011), there have been few studies on the stress of therapeutic riding for a horse from the viewpoints of behavior and exercise physiology (Matsuura et al. 2010). To ensure the rider’s safety in therapeutic riding, it is important to estimate the maximum permissible load weight of the horse. Under an excessive load, the horse would be subjected to both physical stress and mental stress, in addition to the risk for disabled riders and support staff.

Matsuura et al. (2008) investigated the influence of equine conformation on rider oscillation and relationships between these factors and evaluation of horses as therapeutic riding, and they showed that short and wide-backed horses such as Hokkaido native horses and Kiso native horses are suitable for therapeutic riding. However, Japanese native horses are relatively small and might suffer from an overload if the rider’s weight is too heavy. Although there is a short mention about the upper limit of a rider’s weight in the Official Manual of Riding for the Disabled Association (Riding for the Disabled Association: RDA 1990), the information is limited to English breeds and the information was obtained not scientifically but empirically. According to the RDA Japan, the optimum weight that a horse can be loaded with safely is 16% to 17% of the body weight of the horse, although the reason is not given. On the other hand, Hadrill (2002) suggested that a pack animal could safely carry a third to half of its own weight for several hours if the animal was in a reasonable condition. The Japanese Imperial Army had a rule of criterion of load for a packed horse, that is, one-third of the horses’ body weight. Hokkaido native horses used to carry on their backs up to 400 kg.
of timber and materials for construction of steel towers for high-voltage electrical power lines. In any case, the criteria have little scientific basis. Determination of the loading capacity of Japanese native horses is important not only for effective use of draught horses, including therapeutic riding horses, but also for animal welfare.

Since walking and trotting are both symmetrical gaits, the symmetry and regularity of the gait can be calculated by wave analysis using accelerometric data (Barrey et al. 1995). When the load given to the horse is gradually increased, the symmetry or regularity of the gait would be decreased at some point. Depending on this assumption, in the present study we estimated the maximum permissible load weight for a Japanese native horse by gait analysis using an accelerometer.

**MATERIALS AND METHODS**

**Horses and rider**

Six mares of Japanese native horses aged between 6 and 12 years (mean ± SD age: 10.0 ± 2.76 years) were used in the present study. A lot of Japanese native horses are natural pacers, while the horses in the present study showed typical trot in the experiment. The withers height, body length, girth circumference, and cannon circumference were measured. Body weight of each horse was estimated from the following formula according to Wagner and Tyler (2011).

\[
\text{Body weight (kg)} = \left(\frac{\text{girth circumference}}{\text{body length}}\right)^2 \times \frac{11880}{11}
\]

An able-bodied, experienced male rider (age: 24 years, body weight: 66 kg) rode all of the horses. This study received ethical approval from the ethics committee of Kitasato University School of Veterinary Medicine.

**Measurements and tools**

A set of riding equipment and a set of rider’s clothes were used in the same manner for every test. The total weight of the riding equipment, including a saddle, a saddlecloth, a saddlepad and a boa was 11 kg. The total weight of the rider’s clothes, including a helmet, a rider’s vest, a pair of boots and a pair of chaps was 3 kg. The saddlecloth (Fig. 1a) and the rider’s vest (Fig. 1b) were modified to adjust weights up to 20 kg and 30 kg, respectively, by the use of lead packs. Total weight, including the rider’s body weight was adjusted to 80, 85, 90, 95, 100, 105, 110, 115, 120, 125 or 130 kg by adding lead weights set in the saddlecloth and/or the rider’s vest.

Accelerometric data were obtained according to the modified method of Matsuura et al. (2005). An accelerometer (Crossbow, CXL10LP3) was fixed in the sagittal plane between the Pectoralis ascendens muscles of the horse, and a data logger (Crossbow, Ready DAQ AD2000) was attached at the withers of the horse by elastic belts. The accelerometer was selected to record the range of accelerations of ± 10 g. The measuring axes were approximately vertical, lateral and longitudinal for the standing horse.

Measurements were carried out for each horse in 12 tests for both walking and trotting. The total weight for the first test was 80 kg (First 80 kg). The weights for the next 10 tests (from 85 to 130 kg) were determined randomly (i.e. the measurement order of each test was decided by lot in advance.) The last test was carried out with 80 kg again (Last 80 kg) to evaluate the influence of the horse’s fatigue due to repetitive tests.

**Procedure**

The experiments were conducted in the riding grounds of Kitasato University and Towada Riding Club from July to December in 2010. Each horse walked and trotted along a straight course. The course is shown in Figure 2. Two assistants deployed at the start and goal point checked times. To keep the speed at 1.1 m/sec for walking and at 3.0 m/sec for trotting, the horse with the rider passed pylons set at even intervals following the time keeper’s calls. The acceleration of each horse was recorded from just before starting to immediately after stopping at the end of
the course at a sampling frequency of 200 Hz (intervals of 1/200 sec).

**Gait analysis**

Accelerometric data of the vertical axis for 5.12 sec (1024 points) during the horse passing near the center of the test course were used for gait analysis. The time series of acceleration was subjected to fast Fourier transformation (FFT), and the autocorrelation coefficient was calculated using numerical software (Kyplot 5.0 KyenceLab, Tokyo, Japan). The symmetry and regularity of each gait were calculated according to the procedure of Barrey *et al.* (1995). This mathematical procedure indicates how similar a periodic waveform is to itself in the course of time by calculating the correlations between the measurements of a time series. At normal walk and trot, a complete stride comprises two similar dorsoventral motions, so that one peak of correlation should occur at each point of time corresponding to each half-stride. The first two peaks of correlation provide two coefficients that quantify gait symmetry (left vs. right motion) and gait regularity (stride, vs. stride_{n+1}), respectively. Since Barrey *et al.* (1995) also used the sum of symmetry and regularity as an indicator of gait quality, we
termed it stability. The relations between these indices, waveform and gait are shown in Figure 3. Stride length was calculated by multiplying velocity by the time required for one stride.

Statistical analysis
Statistical significance was defined as $P < 0.05$. The average of two measurements was used as each sample for statistical analyses. One-way repeated measures analysis of variance (ANOVA) was used to compare the indicators among 12 weights, and Dunnett’s multiple comparison test was used to identify the differences between different weights and first 80 kg. Analysis of covariance (ANCOVA) was also performed, with measurement order as a covariate, and Sidak’s multiple comparison test was used to identify the differences between different weights to adjust the effect of fatigue due to repetitive measurements.
RESULTS

Body measurement and estimated weight of horses

Withers height (mean ± SD) was 140.3 ± 2.8 cm, body length was 142.9 ± 3.6 cm, girth circumference was 167.9 ± 7.9 cm, cannon circumference was 17.7 ± 0.4 cm and estimated body weight was 339.9 ± 37.5 kg.

Walk

Walking velocity (mean ± SD) was 1.11 ± 0.01 m/sec. The symmetries were between 0.28 and 0.37, and there were no significant differences between loaded weights. The regularities were between 0.17 and 0.23, and the stabilities were between 0.46 and 0.60. There were also no significant differences in regularity and stability between loaded weights. The stride lengths were between 1.24 m and 1.34 m, and there were no significant differences between weights.

Trot

Trotting velocity (mean ± SD) was 2.89 ± 0.17 m/sec. Figure 4 shows the effect of loaded weight on symmetry evaluated by repeated measures ANOVA and Dunnett’s multiple comparison test. Symmetries in the 90, 100, 110, 115, 125 and Last 80 kg tests were significantly lower than that in the First 80 kg (P < 0.05). The regularities were between 0.55 and 0.63, and there were no significant differences between loaded weights. Figure 5 shows the effect of loaded weight on stability evaluated by repeated measures ANOVA and Dunnett’s multiple comparison test. Stability in the 125 kg test was significantly lower than that in the First 80 kg (P < 0.05). The stride lengths were between 1.83 m and 1.89 m, and there were no significant differences between loaded weights.

Figure 6 shows the effect of loaded weight on symmetry evaluated by ANCOVA and Sidak’s multiple comparison test. Adjusted symmetries (mean ± SE) in the 100 kg test (0.67 ± 0.02), 110 kg test (0.68 ± 0.02) and 125 kg test (0.66 ± 0.02) were significantly lower (P < 0.05) than that in the First 80 kg (0.81 ± 0.03), and adjusted symmetry in the 125 kg test was significantly lower (P < 0.05) than that in the 85 kg test (0.77 ± 0.02). Figure 7 shows the effect of loaded weight on stability evaluated by ANCOVA and Sidak’s multiple comparison test. Adjusted stabilities...
Figure 7  Effects of loaded weight on stability at trot evaluated by analysis of covariance (ANCOVA) and Sidak’s multiple comparison test. Values are expressed as means ± SE (n = 6). For other definitions, see legend of Figure 4.

were between 1.22 and 1.47, and there were no significant differences in adjusted stability between loaded weights.

DISCUSSION

Frequency analysis is a powerful tool for studying a horse’s gait, since movement in spatial position or acceleration with gait is a periodic variation. Peham et al. (1996) showed a method to detect asymmetry of gait in lame horses using frequency analysis. Audigé et al. (2002) described a method to identify a lame limb for clinical application. Barrey et al. (1995) reported indices to evaluate symmetry and regularity of gait using autocorrelation coefficients. However, there has been no study in which loading capacity was estimated by applying these techniques. To our knowledge, this is the first study in which loading capacity was evaluated objectively using gait analysis.

As far as we evaluated using repeated measures ANOVA and Dunnett’s test, the symmetries of trotting horses in the 90, 100, 110, 115, 125 and Last 80 kg tests were significantly lower than that in the First 80 kg (P < 0.05, Fig. 4). In the present study, the horse had to repeat 10 tests between the First 80 kg and Last 80 kg, and fatigue of the horse might therefore have influenced the outcome. To adjust for the effect of fatigue, ANCOVA was conducted with measurement order as a covariate. The justification for this view is that the larger the numbers of measurement order, the worse the gait rhythm becomes due to increasing fatigue. ANCOVA and Sidak’s multiple comparison test revealed that symmetries of the trotting horse in the 100, 110, and 125 kg tests were significantly lower than that in the First 80 kg (P < 0.05, Fig. 6). ANCOVA also proved that there were no significant differences in adjusted stability at trot between loaded weights (Fig. 7), except stability in the 125 kg test, that was significantly lower than that in the First 80 kg (P < 0.05) as evaluated by ANOVA and Dunnett’s test (Fig. 5).

Although symmetry in 100 kg was significantly decreased than that in the First 80 kg (P < 0.05), those in 105, 115 and 130 kg were maintained in the present study (Fig. 6). To explain this phenomenon is difficult. If a similar experiment was conducted using a machine with a carrying capacity of 100 kg, the symmetry would have continued to decrease by the fundamental physical law when we gradually added loaded weights over 100 kg. Generally, a margin of error in biological response is larger than that in mechanical response. In pharmaceutical science, to determine optimum concentration where medicinal benefits are expected and at the same time the side effects are minimized, a cumulative continuous infusion was often adopted as an experimental design. In a cumulative continuous infusion, the blood level of the medical substance is raised incrementally, and comparing with the placebo group is the most important point to determine the optimum concentration. In the present study, we added loaded weight not gradually from light to heavy but randomly, and did not prepare a placebo group. To define maximum permissible load weight more clearly, a placebo group in which we repeatedly measured with 80 kg without adding weight might be necessary.

Since the first priority is safety both in the present study and pharmaceutical science, overestimation should be avoided. According to ANCOVA and Sidak’s multiple comparison test, adjusted symmetries in the 100, 110 and 125 kg were significantly lower (P < 0.05) than that in the First 80 kg (Fig. 6). These results suggest that maximum permissible load weight of trotting Japanese native horses is one of 100, 110 or 125 kg. However, if 125 kg is adopted as the maximum permissible load weight, there is a risk of overestimation of the loading capacity. In light of the safety of the rider and horse, we speculated that 100 kg, which is 29% of body weight is a more appropriate weight for the maximum permissible load weight.

According to Powell et al. (2008), heart rates, respiration rates and rectal temperatures of light riding horses trotting at 4.8 km followed by cantering at 1.6 km were higher when carrying 25% and 30% of their body weight than those with 15% and 20% weight carriage. Similarly, they reported that the horses tended to have greater changes in muscle soreness and muscle tightness when carrying 25% of their body weight, and significant changes in soreness and tightness scores were found in horses carrying 30% of their body weight (Powell et al. 2008). On the other hand, Sloet van Oldruitenborgh-Oosterbaan et al. (1995) showed that a load between 12.6% and 16.3% of the horse’s body weight influenced heart rate and blood lactate concentration compared with the horse...
working unloaded in the case of Dutch Warmblood horses at trot on a treadmill. They also reported significant differences in fetlock extension and maximal fetlock range of motion.

The estimation in the present study agrees with the results obtained by Powell et al. (2008) and the rule of the Japanese Imperial Army and is lower than results obtained by Hadrill (2002). Estimation by the RDA Japan, which is between 16% and 17%, is much lower than our estimation, probably because of the consideration for safety of both the disabled rider and the side-walker who helps the rider from both sides of the horse.

In order to determine the effect of each weight load, a 45-min measurement was necessary for the method of Powell et al. (2008) and 25-min measurement was necessary for the method of Sloet van Oldruitenborgh-Oosterbaan et al. (1995). In those studies, the horse had to continue trotting or cantering during the time-consuming measurements. Since we did not use physiological analyses but used gait analyses, the horse only had to walk or trot for a few minutes to evaluate each weight load in the present study. Although fatigue of the horse affected the outcome in the present study, this problem could be greatly improved with fewer trials. For example, modification of weight interval from 5 kg to 10 kg would greatly reduce the number of trials. Compared with other studies, the method used in the present study imposes little burden on the horse and is therefore more advantageous for animal welfare. Another advantage of our method is that a treadmill is not necessary and is therefore suitable for measurements of horses for therapeutic riding. Our method also enables analysis of not only accelerometric data but also spatial data obtained by motion analysis using a high-speed camera.

A limitation of the present study is that we failed to evaluate loading capacity at walking between 80 to 130 kg, where Japanese native horses can keep the same gait rhythm at walking. If the horse only walks, the maximum permissible load weight would be over 130 kg. Walking is the most common gait in therapeutic riding. Therefore, further studies are needed to clarify loading capacity at walking.

We showed a widely applicable and welfare-friendly method to evaluate loading capacity of horses by gait analysis using an autocorrelation coefficient. The findings in the present study lead to the preliminary conclusion that the maximum permissible load weight of trotting Japanese native horses is less than 100 kg, which is 29% of body weight.

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REFERENCES


