Maximum permissible load weight of a Taishuh pony at a trot

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ABSTRACT: The aim of this study was to determine the loading capacity of a trotting Taishuh pony by gait analysis using a motion analysis system. Seven Taishuh Ponies (5 mares and 2 geldings) and their rider were fitted with a marker (70 mm in diameter placed on their chest) and recorded by 2 high-resolution digital DVD cameras (at a sampling frequency of 60 Hz) as they were trotting along a straight course. Each horse performed 7 tests: 1 test with a loaded weight of 70 kg, 5 tests with random loaded weights between 80 kg and 120 kg, and a final test with a loaded weight of 70 kg again. Three-dimensional movements of each marker were analyzed using motion capture system. The time series of the vertical displacements of the marker was subjected to spectrum analysis by the maximum entropy method, and the autocorrelation coefficient was calculated. The first 2 peaks of the autocorrelation were defined as symmetry and regularity of the gait, and the sum of symmetry and regularity was defined as stability. The cross-spectrum analysis (Blackman-Tukey method) also was performed to analyze the time lag and cross-correlation coefficient between the time series of both pony and rider. Among ponies, symmetry in the 120 kg test (0.54) was significantly lower than that in the first 70 kg test (0.75, $P < 0.05$) and stabilities in the 100 kg (1.17) and 120 kg (1.17) tests were significantly less than that in the first 70 kg (1.46, $P < 0.05$). Regarding the rider, there were no significant differences in symmetry, regularity, and stability between loaded weights. The time lag between the time series of horse and rider in the 120 kg test (47.6 ms) was significantly greater than that in the first 70 kg (14.3 ms, $P < 0.05$) test. These results suggest that the maximum permissible load weight of the Taishuh pony trotting at 3.0 m/s over a short distance was less than 100 kg, which is 43% of the BW.

Key words: autocorrelation, cross-correlation, gait analysis, horse, loading capacity, therapeutic riding

INTRODUCTION

There has been a recent surge in using horses to treat human mental health issues. Although favorable effects of therapeutic riding have been described (Kaiser et al., 2006b; Matsuura et al., 2011), the stress on these horses is still poorly understood (Kaiser et al., 2006a; Minero et al., 2006; Gehrke et al., 2011). Matsuura et al. (2008) found that short and wide horses are better suited for therapeutic riding, but the gait rhythms of such horses would be disrupted if the rider were too heavy. To ensure the welfare of horses, it is important to estimate their loading capacity.

The loading capacity was described to be 16 to 17% of the BW of the horse by the Riding for the Disabled Association (RDA) of Japan, and to be 33 to 50% of BW by Hadrill (2002). However, these criteria have little scientific basis. To our knowledge, there are 3 studies based on scientific evidence. According to Powell et al. (2008), heart rates, respiration rates and rectal temperatures were higher when horses carried loads that were 25 and 30% of their BW than those carrying loads of 15 and 20%. Sloet van Oldruitenborgh-Oosterbaan et al. (1995) showed that a load between 12.6 and 16.3% of BW influenced heart rate and blood lactate concentration compared with no load. According to gait analysis by Matsuura et al. (2013), the maximum permissible load weight of Japanese native horses was less than 100 kg, which was 29% of BW.

The Taishuh pony is 1 of 8 Japanese native horses, and is currently facing possible extinction. Because
Taishuh Ponies are short and wide, and have hard hooves, robust limbs, and calm temperament, they should be suitable for therapeutic riding, although they would be susceptible to the effect of the BW of the rider. It is important to determine their loading capacity for their effective use. We studied the maximum permissible load weight for Taishuh Ponies by gait analysis using a motion capture system.

**MATERIALS AND METHODS**

This study received ethical approval from the ethics committee of Kitasato University School of Veterinary Medicine.

**Horses and Rider**

Seven Taishuh Ponies (5 mares and 2 geldings) with ages between 4 and 13 yr (mean ± SD age: 9.6 ± 2.9 yr) were used. The ponies were routinely used as riding horses for visitor riders. They were in good condition, well trained, and did not exhibit signs of lameness. The BCS was determined by an experienced horse trainer. Some Taishuh Ponies are natural pacers, but the ponies in the present study showed typical trotting in the experiment. The withers height, body length, girth circumference, and cannon circumference were measured. The BW of each pony was estimated from this formula according to Wagner and Tyler (2011):

\[
\text{BW (kg)} = \left(\text{girth circumference}\right)^2 \left(\text{body length}\right)/11,880.
\]

An able-bodied, male rider with experience for more than 15 yr (age = 37 yr; BW = 53 kg) rode all of the ponies.

**Measurements and Tools**

A set of riding equipment and a set of riding 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 10 kg. The total weight of the riding clothes, including a helmet, a rider vest, a pair of boots, and a pair of chaps, was 3 kg. The rider wore a waist pouch including 4-kg lead packs at the waist. The saddlecloth and the riding vest were modified to adjust weights up to 20 and 30 kg, respectively, by the use of lead packs. Total weight including the BW of the rider was adjusted to 70, 80, 90, 100, 110, or 120 kg by adding lead weights into the saddlecloth and/or the riding vest.

Measurements were performed for each pony in 7 tests. The total weight for the first test was 70 kg. The weights for the next 5 tests (from 80 to 120 kg) were determined randomly (i.e., the measurement order of each test was decided by lot in advance). The last test was performed with 70 kg again to evaluate the influence of the fatigue of the horse due to repetitive tests.

**Procedure**

The experiments were conducted on the riding grounds of Asou Bey Park and the Meboro dam riding park in November 2011. Each pony trotted (sitting trot) along a straight course (Fig. 1). Two cameramen deployed near the goal point recorded moving images and an assistant deployed at the start point checked times. To keep the speed at 3.0 m/s, the horse with the rider passed pylons set at even intervals after the calls of the time keeper. The moving image of each test was recorded at a sampling frequency of 60 Hz using high-definition-type digital cameras.

**Gait Analysis**

A spherical marker 70 mm in diameter was fixed in the sagittal plane between the pectoralis descendens muscle of the pony, and another spherical marker was fixed in the front of the breast of the rider by elastic belts. Three-dimensional movement of each marker was calculated using a motion capture system (PV Studio 3D ver. 2.29, LAB, Miyazaki, Japan). The vertical movements at 400 points as the pony passed near the center of the test course were used for gait analysis. The time series of the data was subjected to spectrum analysis by maximum entropy method, and the autocorrelation coefficient was calculated using numerical software (Kyplot version 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 a normal trot, a complete stride consists of 2 similar dorsoventral motions, so that 1 peak of correlation should occur at each time point corresponding to each half-stride. The first 2 peaks of correlation provide 2 coefficients that quantify gait symmetry (left vs. right motion) and gait regularity (\textit{stride}_n vs. \textit{stride}_{n+1}), respectively. Because Barrey et al. (1995) also used the sum of symmetry and regularity as an indicator of gait quality, we defined that as stability. These methods for gait analysis have been described elsewhere (Matsuura et al., 2013). The relations between these indices, waveform and gait are shown in Fig. 2. The repeatability of analysis was estimated by CV of 5 consecutive measurements. The CV (\%) of symmetry, regularity, and stability were 9.27, 19.24, and 10.39, respectively. The error is calculated as the difference between the true marker size and the estimated marker size. The errors of the marker were 1.02 ± 0.59 cm. In the present study, the cross-spectrum analysis by the Blackman-Tukey method also was performed to analyze the time lag and cross-correlation coefficient between the time series of both pony and rider, using the numerical software (Kyplot version 5.0, KyenceLab Tokyo, Japan).

**Statistical Analysis**

Kwon et al. (2011) chose 1 of 3 trials to best represent the gait for each individual. In the present study, 1 of 2 instead of 3 measurements was used as each sample to minimize the effect of fatigue of the pony. Among the 2 measurements, the data from sound gait were chosen to avoid data with accidental stumbling. Statistical analyses were conducted using SPSS (SPSS Inc, Chicago, Illinois). One-way repeated measures ANOVA was used to compare the indicators among 7 weights and Dunnett’s multiple comparison test was used to identify the differences between different weights and the first 70 kg test. Differences were considered to be significant at \( P < 0.05 \) and considered to be a tendency at \( P < 0.10 \).

**RESULTS**

**Body Measurement, Estimated BW, BCS of Ponies, and Experimental Durations of Total Test**

Body measurement, estimated BW, BCS (1 to 9), and experimental durations of total test were shown in Table 1. Withers height (mean ± SD) was 123.9 ± 3.8 cm, body length was 133.6 ± 3.2 cm, girth circumference was 143.4 ± 4.1 cm, cannon circumference was 16.0 ± 0.8 cm, and estimated BW was 231.6 ± 16.8 kg. Body condition score (mean ± SD) was 4.6 ± 0.8. Experimental durations of total test (mean ± SD) was 46 ± 9.2 min.

**Autocorrelation Coefficient of the Pony**

Figure 3 shows the effect of loaded weight on the symmetry of the pony. The symmetries (mean ± S.E.) in the 120 kg test (0.54 ± 0.09) were significantly less (\( P < 0.05 \)) and that in the 110 kg test (0.56 ± 0.07) tended to be less (\( P = 0.070 \)) than that in the first 70 kg test (0.75 ± 0.02). The regularities of the pony were between 0.59 and 0.75 and there were no significant differences between loaded weights. Figure 4 shows the effect of loaded weight on the stability of the pony. Stabilities in the 100 kg test (1.17 ± 0.11) and the 120 kg test (1.17 ± 0.10) were significantly lower (\( P < 0.05 \)) and that in 110 kg test (1.25 ± 0.07) tended to be lower (\( P = 0.078 \)) than that in the first 70 kg test (1.46 ± 0.08). In all indices, there were no significant differences between the first 70 kg test and the last 70 kg test.

**Autocorrelation Coefficient of the Rider**

The symmetries of the rider were between 0.86 and 0.91 and there were no significant differences between loaded weights. The regularities of the rider were between 0.83 and 0.91 and there were no significant differences between loaded weights. The stabilities of the rider were between 1.70 and 1.82 and there were no significant differences between loaded weights.

**Cross-correlation Coefficient of the Pony and the Rider**

Figure 5a shows a typical example of the oscillation in the first 70 kg test. The time lag between the oscillation in the pony (solid line) and that in the rider (dotted line) was minimal. However, in the 120 kg test, the oscillation in the rider was delayed for a moment from that in the pony (Fig. 5b). Table 2 shows the time lags and cross-correlation coefficients between the pony and the rider. The time lag in the 120 kg test (0.048 ± 0.012 s) was significantly greater than that in the first 70 kg test (0.014 ± 0.007 s). The cross-correlation coefficients were between 0.89 and 0.97 and there were no significant differences between loaded weights. In all indices, there were no significant differences between the first 70 kg test and the last 70 kg test.

**DISCUSSION**

Horses trot in a regular rhythm. Moreover, the trot is a symmetrical gait. Therefore, the symmetry or regularity of the gait is relatively high in a reasonable condition. However, such a gait rhythm will be decreased at some point when the load given to the horse is gradually in-
Figure 2. Symmetry, regularity, and stability in gait analysis. At normal trot, 1 peak of correlation should occur at each point of time corresponding to each half-stride. When the original wave is delayed for a half-stride period, the autocorrelation coefficient between the original wave and the wave delayed as half stride shows the correlation between 2 adjacent half-strides. The correlation between 1 half-stride and the next half-stride means symmetry. Similarly, when the original wave is delayed for 2 half-stride periods (i.e., 1 stride), the autocorrelation coefficient between the original wave and the wave delayed as 1 stride shows the correlation between 2 adjacent strides. The correlation between 1 stride and the next stride means regularity. Stability was defined as the sum of symmetry and regularity.
increased. Possibly, the alteration in gait rhythm could be adaptation or adjustment for the horses. However, there is no doubt that the alteration in gait rhythm led to an increased risk for the rider. Depending on this assumption in the present study, we defined “overload” as a weight that disrupts the gait rhythm and we estimated the maximum permissible load weight for the trotting Taishuh pony.

The results of the present study showed that the symmetry of ponies started to decrease at 110 kg and the stability significantly decreased at 100 kg. Therefore, we determined that the maximum permissible load weight of a trotting Taishuh pony is less than 100 kg, which is 43% of the BW. In consideration of the weight of a saddle, the maximum BW of the rider for Taishuh pony should be 90 kg under trotting conditions. The estimation in the present study agrees with the suggestion by Hadrill et al. (2002) of between one-third and one-half of the BW of the horse. The estimation in the present study is greater than the results obtained by Powell et al. (2008) of between 25 and 30% of the BW and those obtained by Matsuura et al. (2013) of 29% of the BW. Moreover, the recommendation in the current study is much greater than those obtained by RDA Japan of between 16 and 17% of the BW and those obtained by Sloet van Oldruitenbourgh-Oosterbaan et al. (1995) of between 12.6 and 16.3% of BW. These variations could be due to differences in breed, gait, and course conditions.

We observed no significant differences in the symmetry of the rider between loaded weights, although the symmetry of the pony significantly decreased at the 120 kg test. A marked decrease in symmetry would be an indication that the rider was falling off the pony. Because the rider retained his balance, namely maintained a high symmetry, he did not fall off the pony. At the 120 kg test, the time lag of the oscillation between pony and rider was significantly increased compared with that in the first 70 kg test. The rider followed the apparently asymmetrical oscillation of the pony after a moment (47.6 s), which enabled him to maintain his own balance. On the other hand, there is another possibility that the time lag significantly increased in 120 kg from that in the first 70 kg test. In the present study, the rider was on the horse with a 30 kg vest in 120 kg test. There was no possibility that the lead weight moved independently from the rider because the lead weight was fastened to the rider. As proof of this, the rider kept his own symmetry, regularity and stability extremely high even if he put on the maximum 30 kg vest. This means that the rider could ride the pony as usual without the effect of the lead weight. However, a person whose BW is 53 kg has merely corresponding amount of muscle. If the rider whose BW was 83 kg rode the pony, he could have the potential to synchronize the oscillation of ponies, because of his corresponding amount of muscle. Accordingly, it remains possible that such a huge time lag between the oscillation of the pony and the rider would disappear if the rider whose BW was 83 kg rode the pony.

This is the first study in which loading capacity was evaluated by applying cross-spectrum analysis. Cross-spectrum analyses is a powerful tool for evaluating synchronization between a horse and its rider when they go around a curved course or start and stop, because in such a situation, symmetry, regularity, or stability cannot be used as an indicator of gait quality. More practical evaluation of the loading capacity would be possible through measurements in these various situations.

### Table 1. Body measurement, estimated BW, BCS, and experimental durations of total test

<table>
<thead>
<tr>
<th>Item</th>
<th>Pony #1</th>
<th>Pony #2</th>
<th>Pony #3</th>
<th>Pony #4</th>
<th>Pony #5</th>
<th>Pony #6</th>
<th>Pony #7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body measurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Withers height, cm</td>
<td>125.6</td>
<td>125.0</td>
<td>118.6</td>
<td>121.0</td>
<td>130.7</td>
<td>123.0</td>
<td>123.6</td>
</tr>
<tr>
<td>Body length, cm</td>
<td>137.1</td>
<td>134.5</td>
<td>130.9</td>
<td>132.9</td>
<td>138.5</td>
<td>130.9</td>
<td>130.6</td>
</tr>
<tr>
<td>Girth circumference, cm</td>
<td>140.5</td>
<td>140.5</td>
<td>140.2</td>
<td>145.1</td>
<td>151.0</td>
<td>145.8</td>
<td>140.8</td>
</tr>
<tr>
<td>Cannon circumference, cm</td>
<td>15.4</td>
<td>15.4</td>
<td>16.0</td>
<td>15.9</td>
<td>17.6</td>
<td>15.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Estimated BW, kg</td>
<td>227.8</td>
<td>223.5</td>
<td>216.6</td>
<td>235.5</td>
<td>265.8</td>
<td>234.2</td>
<td>217.9</td>
</tr>
<tr>
<td>BCS</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Experimental durations of total test, min</td>
<td>56</td>
<td>59</td>
<td>41</td>
<td>49</td>
<td>35</td>
<td>40</td>
<td>39</td>
</tr>
</tbody>
</table>

Figure 3. Effects of loaded weight on the symmetry of the pony. Values are expressed as means ± S.E. (n = 7). Filled circles represent values from the first 70 kg to 120 kg, and the unfilled circle represents the value of the last 70 kg. * P < 0.05 vs. the first 70 kg, † P < 0.1 vs. the first 70 kg.
In a previous report by Matsuura et al. (2013), the fatigue of a horse due to repetitive measurements affected gait quality because each horse had to repeat 10 tests between the first measurement and the last one, although the test course was same as the present study. As a result, great differences occurred in some indices between the first measurement and the last one, despite the horse being loaded with the same weight. Time taken to measure all weights was 87 ± 11.5 min/horse at that time. Therefore, analysis of covariance was conducted with measurement order as a covariate to adjust for the effect of fatigue. In the previous study, we measured both at walk and trot from 80 to 130 kg at intervals of 5 kg. In the present study, we measured at only trot from 70 to 120 kg at intervals of 10 kg. Time taken to measure all weights was 46 ± 9.2 min/pony in the present study. As a result, we observed no significant differences in all indices between the last 70 kg test and the first 70 kg test without adjustment. These results indicate that the problem is improved with fewer measurements.

The estimation of the maximum permissible load weight of pony would depend on the conditions that the experiment was done. There are many variables that could alter the maximum permissible load weight of pony. The 6 main factors include breed, test course, gait and speed, physical condition of the pony, rider, and training.

**Breed**

The loading capacity of larger breeds should be greater than that of smaller breeds. Especially in the smaller breeds, the effect of the BW of the rider would be serious. The degree to which the results in the present study may be generalized to the loading capacity of other breeds is unclear but warrants examination.

**Test Course**

The test course was straight and very short in the present study. The ponies carried the various weights over a straight 40 m course, which had taken less than 30 s to cover. Generally, a therapeutic riding horse might carry a rider for 10 to 30 min or more depending on the needs of the rider. If the ponies carried each load for 30 min and
were then tested, lighter weight loads might have altered gait rhythm due to effects of fatigue. To examine in longer duration, the use of a treadmill should be effective.

Also in the situation along a curved course, lighter weight loads should have altered gait rhythm because the symmetry would have decreased. Strictly speaking, horses do not exhibit symmetrical exercise when they trot along a curved course. Therefore, the symmetry could not be used as an index of gait quality. Instead, cross-spectrum analyses used in the present study will be a powerful tool for evaluating synchronization between a horse and rider in such a situation.

Gait and Speed

In our previous report (Matsuura et al., 2013), we observed that the gait rhythm of walking Japanese native horses (mean BW was 340 kg) did not change even if they were loaded with 130 kg. At walk, their loading capacity exceeds 130 kg, which means most people can ride them. Although walk is the most popular gait in usual therapeutic riding, there is no need to determine an upper limit of the BW of the rider when horses only walk along a flat straight course. During trotting, symmetry at 100 kg was significantly decreased than that at 80 kg (Matsuura et al., 2013). Trot is the second most popular gait in therapeutic riding. Trot is more often used than walk in therapeutic riding if the rider has sufficient athletic ability. Therefore, in the present study, we set a speed as 3.0 m/s, which corresponds to that of moderate trot.

Physical Condition of Pony

The physical state of the ponies would affect the outcome of the study. Very fit ponies might be able to carry more weight without overload than less fit ponies. A pony that weighs 250 kg but is very fat also may not have the same loading capacity as a 250 kg pony that is more heavily muscled and less fat. The ponies used in the present study were in good condition and regularly trained as riding horses. Their BCS was between 3 and 5 (mean ± SD: 4.6 ± 0.8). They were typical examples of the Taishuh pony.

Rider

In the present study, only 1 rider was used and that person had many years of riding experience. Consequently he had good balance, unlike many therapeutic riding patients who have poor balance. Poorly balanced weight affects gait differently than the same well-balanced weight. To examine the effect of poorly balanced weight, a treadmill will be a powerful tool. Heck et al. (1996) and McKeever et al. (2005) investigated the foreleg muscle characteristics and haemodynamics induced by resistance exercise, respectively. In their study, they used a combination of treadmill and a chain hoist, sling and weight apparatus. It would be useful to further investigate the effect of poorly balanced weight using their technique.

Training

Resistance training has been known to alter the weight carrying capacity of pony. Eight weeks of progressive resistance training increased the superficial digital flexor muscle cross-sectional diameter of forelimb (Heck et al., 1996) and ventricular pressure. The well trained pony could carry more weight without overload than the poorly trained pony. The Taishuh ponies used in the present study were under training regularly.

Although only 7 ponies were used in the present study, 7 ponies are about 20% of the population for the Taishuh pony. We cannot measure individuals without training, such as stallions, elderly ponies, those in poor condition, and foals. The 7 ponies measured in the present study were well-trained, healthy individuals. Thus, the sampling presents no serious problems. Taishuh ponies live on Tsushima Island, which is located midway between Kyushu Island and the Korean Peninsula (Nagasaki Prefecture, Japan, at latitude 34.2° N and longitude 129.3° E). Taishuh ponies were used as pack horses on precipitous mountain paths, particularly in Nagasaki Prefecture, because they have hard hooves and robust limbs. Women or children often take care of these ponies because of their calm temperament. The population of Taishuh ponies was 4000 in about 1900, but decreased to 170 in 1980 and is currently only 37.

Because these ponies are facing extinction, cutting-edge reproductive technologies are necessary for their preservation. However, it is also necessary to promote their effective use and to make efforts to expand the demand for them. Taishuh ponies should be used for the therapeutic riding because they have calm temperament, hard hooves, and robust limbs. Increasing the demand of Taishuh pony for therapeutic riding will lead to their

Table 2. Time lags and cross-correlation coefficients between pony and rider (n = 7)

<table>
<thead>
<tr>
<th>Weight load</th>
<th>Time lag, ms</th>
<th>Cross-correlation coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 70 kg</td>
<td>14.3 ± 6.7</td>
<td>0.97 ± 0.00</td>
</tr>
<tr>
<td>80 kg</td>
<td>9.5 ± 6.2</td>
<td>0.94 ± 0.02</td>
</tr>
<tr>
<td>90 kg</td>
<td>19.0 ± 6.7</td>
<td>0.91 ± 0.04</td>
</tr>
<tr>
<td>100 kg</td>
<td>21.4 ± 9.4</td>
<td>0.90 ± 0.04</td>
</tr>
<tr>
<td>110 kg</td>
<td>14.3 ± 6.7</td>
<td>0.89 ± 0.06</td>
</tr>
<tr>
<td>120 kg</td>
<td>47.6* ± 12.3</td>
<td>0.92 ± 0.02</td>
</tr>
<tr>
<td>Last 70 kg</td>
<td>19.0 ± 6.7</td>
<td>0.93 ± 0.02</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SE

*P < 0.05 vs. the first 70 kg.
preservation. Therefore, it is important to make more people aware of the Taishuh pony through riding. On the other hand, small horses are generally recognized as unable to carry heavy riders. Thus, it was important to determine the loading capacity of Taishuh ponies for their effective use. The results of the present study showed that a Taishuh pony can carry a rider whose BW is up to 90 kg. Accordingly, not only children but also larger adults can ride them. Therefore, a Taishuh pony can serve a more useful role for a broad range of clients in the field of therapeutic riding.

A limitation of the present study is the absence of any other physiological variables, such as heart rate. Further studies are needed to clarify the loading capacity during walking and cantering, and/or on a curved course, with poorly balanced riders.

In conclusion, the maximum permissible load weight of Taishuh pony trotting at 3.0 m/s over a short distance is less than 100 kg, which is 43% of the BW of the pony. This conclusion is limited by a condition that the experiment was done on a straight-short course with a well-balanced rider. However, the methodology shown in the present study will provide a better understanding of the loading capacity of horses.

**LITERATURE CITED**


