Agreement between two traditional lunging protocols for physical fitness training in untrained horses

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Abstract

Background: Lunging is a training method that is performed in a round pen or on a lunge line. However, there is no consensus on applying lunging techniques for physical fitness training. Objectives: To investigate the effort intensity, autonomic responses, and method agreement in applying different lunging protocols to untrained horses. Study design: A non-randomised control trial. Methods: Sixteen untrained horses (aged 13.6 ± 6.3 years and weighing 358 ± 47.4 kg) were studied. Each horse was lunged with a similar programme on a lunge line and, subsequently, in a round pen at a two-day interval. The heart rate variability (HRV) and effort intensity, indicated as a percentage of maximum heart rate (%HRmax), were determined pre-lunging, during lunging at distinct gaits, and at 30-minute intervals for 120 minutes post-lunging. The correlation and method agreement between the two lunging methods were analysed with Pearson’s correlation coefficient and Bland–Altman plots, respectively. Results: The horses ran faster and covered longer distances during exercise on a lunge line than in a round pen. The effort intensity during cantering reached moderate levels (75.1 ± 2.4% HRmax) with occasional high-intensity levels (88.1 ± 1.3% HRmax) via both lunging methods. The HRV reached a minimum during cantering and returned to the baseline 120 minutes post-lunging. The HRV parameters (SDNN, RMSSD, LF, HF, SD1, and SD2) were strongly correlated (r p [?] 0.97 and p < 0.001 for all) with a large correlation effect size (R² > 0.85) and excellent agreement (average differences were within mean + 1.96 SD) between the two lunging methods. Main limitations: The running speed and distance reported during lunging may not be entirely accurate due to the manual calculation required. Conclusions: Lunging can provoke optimal physiological responses in horses. The two tested lunging methods may be applied interchangeably for physical fitness training.
for 120 minutes post-lunging. The correlation and method agreement between the two lunging methods were analysed with Pearson’s correlation coefficient and Bland–Altman plots, respectively.

**Results:** The horses ran faster and covered longer distances during exercise on a lunge line than in a round pen. The effort intensity during cantering reached moderate levels (75.1 ± 2.4% HRmax) with occasional high-intensity levels (88.1 ± 1.3% HRmax) via both lunging methods. The HRV reached a minimum during cantering and returned to the baseline 120 minutes post-lunging. The HRV parameters (SDNN, RMSSD, LF, HF, SD1, and SD2) were strongly correlated ($r_p$ [?]) 0.97 and $p < 0.001$ for all) with a large correlation effect size ($R^2 > 0.85$) and excellent agreement (average differences were within mean ± 1.96 SD) between the two lunging methods.

**Main limitations:** The running speed and distance reported during lunging may not be entirely accurate due to the manual calculation required.

**Conclusions:** Lunging can provoke optimal physiological responses in horses. The two tested lunging methods may be applied interchangeably for physical fitness training.

**KEYWORDS:** Effort intensity; Exercise; Horse; Lunging; Method agreement; Stress responses

1. **INTRODUCTION**

Equestrian sports demand top-notch performance from horses, which is achieved through rigorous training that ensures their fitness to compete. The frequency, intensity, and duration of training can be adjusted to elicit specific adaptive responses depending on the horse’s sport. Cardiovascular parameters are commonly measured during training to gauge the horse’s physical fitness in terms of its aerobic and anaerobic capabilities, as well as to monitor its health and welfare. Heart rate (HR) is commonly used to measure the intensity of exercise in horses and is expressed as a percentage of maximal heart rate (%HRmax). Practical exercise training can decrease resting HR via physiological adaptation. Heart rate variability (HRV) is another important measure that is frequently used to indicate stress responses and predict sports performance during exercise. HRV refers to the variation in intervals between successive heartbeats in the cardiac cycle, which are affected by sympathetic and parasympathetic nerve impulses acting on the heart’s sinoatrial node. A decline in HRV variables, such as beat-to-beat (RR) intervals and root mean square of successive RR interval differences (RMSSD), can indicate a reduction in parasympathetic (vagal) action in horses. Similarly, a decrease in several HRV variables, including the standard deviation of normal-to-normal RR intervals (SDNN), RMSSD, very low-frequency band (VLF), low-frequency band (LF), high-frequency band (HF), and the standard deviation of the Poincare plot perpendicular to the line of identity (SD1) and along the line of identity (SD2) can reflect reduced vagal activity and sympathetic dominance during exercise in horses.

Lunging exercises are valuable training techniques that involve horses moving in circles at a specified distance around their handlers. Lunging is commonly utilised to train young horses, release excess energy after confinement, and as part of veterinary lameness examinations. This exercise can be performed on a lunge line or in a round pen; each approach offers advantages and disadvantages. For example, using a Pessoa training aid on a lunge line can improve posture, balance, and core muscle engagement, while round-pen lunging is suitable for training multiple horses simultaneously. However, these methods can threaten both the horse’s welfare and the handler’s safety if performed incorrectly.

In practical terms, trainers often choose the lunging method they use for physical fitness training based on their abilities, preferences, or subjective assessments. However, to address the lack of objective evidence regarding horses’ physiological responses to these methods, this study aims to achieve two goals: 1) To investigate and compare physiological responses in untrained horses performing exercise both in a round pen and on a lunge line to verify the physical benefits of these methods, and 2) to determine a practical application of the two lunging methods by observing the correlation between horses’ physiological responses to them and the agreement of application between both methods. It was hypothesised that horses exercise with similar effort intensity and produce equal physiological responses during lunging exercise in both methods.
2. MATERIALS AND METHODS

2.1 Animals

This study included 16 horses consisting of eight geldings, seven mares, and one stallion. Their average age was 13.6 years with a standard deviation of 6.3 years, and their average weight was 358 kg with a standard deviation of 47.4 kg. These horses had no prior experience with lunging as exercise. The horses were recruited from two locations. Eight healthy horses (three geldings and five mares) were recruited from the [masked for review] laboratory unit, which is part of the Faculty of Veterinary Medicine at [masked for review]. The other eight horses (five geldings, two mares, and one stallion) were selected from the Horse Lover’s Club in [masked for review]. Ten of the recruited horses had never been trained for sports, and the other six had not been trained for more than 5 years before the study. To be included, the horses had to pass a basic examination and show no signs of lameness or gait abnormality. They also could not have undergone medical or surgical intervention for at least 30 days before the study. The horses would have been excluded if they had displayed lameness or an irregular gait during or after lunging, but all 16 horses were sound and able to participate in the study. The Horse Lover’s Club horses were housed in separate 4x4 metre stalls and allowed to graze in the paddock for a few hours each day. The horses at the [masked for review] laboratory unit were allowed to graze freely in the paddock during the day and kept together in a non-partitioned barn at night. All horses were provided with commercial pellets and electrolyte supplements three times daily, as well as free access to water. This study was approved by the [masked for review] Institute of Animal Care and Use Committee (ACKU66-VET-090).

2.2 Experimental protocols

Before the study began, the horses received a thorough health examination and were found to be in good health with normal haematological parameters. During the study, they were lunged on a sand surface in a 10-meter radius circle. Initially, they were trained on a lunge line with a halter, but they were subsequently trained in a round pen according to the exercise programme outlined in Table 1. Two qualified handlers were recruited for the study. Each handler lunged the same horses in an anti-clockwise direction using the two tested lunging procedures. To avoid confounding factors, each handler lunged only four horses daily from 04.00 h–09.00 h to avoid unsuitable weather during the day. After exertion, the horses were cooled down with tap water for 5 minutes and left in their designated stables with free access to hay and water for at least 120 minutes.

2.3 Data collection and acquisition

2.3.1 RR recording

Before the lunging procedures, a heart rate monitoring (HRM) device (Polar Electro Oy, Kempele, Finland) was applied to the horses. This device has been proven to measure HR and HRV precisely in horses, and it was used for RR recording for 60 minutes. The procedure involved attaching the Polar equine belt to the trotter and heart rate sensor (Polar H10), soaking it in water, applying ultrasound gel to the belt’s skin-side surface to enhance signal transmission, fastening it around the horse’s chest, and placing the sensor on the left side of the middle chest. The Polar sports watch (Polar Vantage V2) was wirelessly connected to the sensor for RR recording. The data were recorded for 30 minutes before lunging, during the entire lunging period, and for 120 minutes after lunging.

2.3.2 RR data processing

The Polar FlowSync program (https://flow.polar.com/) was used to upload data on RR intervals, which were then processed into HRV variables with Kubios premium software (Kubios HRV Scientific; https://www.kubios.com/hrv-premium/). The resulting data were exported as MATLAB MAT files. Any artefacts in the RR interval time series were automatically corrected by the Kubios premium program, which also identified noise using automatic noise detection set at a medium level and based on the RR interval data. Smoothness priors were applied to remove nonstationarities in the RR intervals time series. The user guideline manual specified a cutoff frequency of 0.035 Hz (https://www.kubios.com/downloads/Kubios_HRV).
HRV variables were computed via three methods: time-domain (SDNN, RMSSD), frequency-domain (LF, HF), and non-linear (SD1, SD2). The HRV variables were determined 30 minutes before lunging, during the first, second, and third exercise periods, and at 30-minute intervals for 120 minutes after lunging.

2.3.3 Movement speed and distance covered

The average movement speed and distance covered during the lunging manoeuvres were calculated manually. To determine the circumference of each circuit, the formula $2\pi r$ was used, where $r$ is the radius of the circle (9.5 metres). Then, the circumference was multiplied by the number of rounds each horse completed to calculate the total distance covered in km. All horses completed lunging manoeuvres for 54 minutes under the same conditions. To calculate the individual movement speed, the formula $[(\text{covered distance in km} \times 60 \text{ minutes})/54 \text{ minutes}]$ was used and the results were expressed in km/h.

2.3.4 Effort intensity

The mean and maximum heart rates were recorded with the Polar sports watch and used to determine the intensity of effort during lunging. This was calculated as a percentage of the reference maximum heart rate ($\%HR_{\text{max}}$) using the formula $[(\text{measured HR} \times 100)/220]$, where 220 is the reference maximum heart rate (beats/min) for horses, as established in previous reports. The intensity was then classified as very low ($<50\% HR_{\text{max}}$), low (50–63% $HR_{\text{max}}$), moderate (64–76% $HR_{\text{max}}$), high (77–93% $HR_{\text{max}}$), or very high ($>94\% HR_{\text{max}}$), based on previous studies.

2.4 Data analysis

The analysis was conducted with GraphPad Prism version 10.2.2 (GraphPad Software Inc, San Diego, USA). To assess the effects of the lunging method and time on the horses’ HRV variables and effort intensity ($\%HR_{\text{max}}$), a repeated measures two-way ANOVA with Greenhouse–Geisser correction was employed to examine the interaction and independent effects. Then, Tukey’s post-hoc test was used to analyse the changes in HRV variables within and between groups at specific time points. The normal distribution of the data was verified with the Kolmogorov–Smirnov test, enabling the application of an unpaired $t$-test to determine the differences in movement speed and covered distance during exercise using both lunging methods. As the data were normally distributed, the Pearson correlation coefficient ($r_p$) method was utilised to calculate the correlation between the HRV variables derived from each lunging method and represented as weak (0.10 $\leq r_p < 0.40$), moderate (0.40 $\leq r_p < 0.70$), strong (0.70 $\leq r_p < 0.90$), or very strong ($r_p \geq 0.90$) correlations. The $R^2$ was used to determine the effect size of the unpaired $t$-test and correlation coefficient, which were categorised as small (0.04 $\leq R^2 < 0.25$), medium (0.25 $\leq R^2 < 0.64$), or large ($R^2 \geq 0.64$) effect sizes.

The method agreement between lunging in the round pen and lunging on the lunge line was assessed with a Bland–Altman plot. The results are presented as mean ± SD and statistical significance is set at $p < 0.05$.

3 RESULTS

3.1 Speed of movement and distances covered

The horses ran faster, leading to longer distances covered, when lunging on a lunge line than in a round pen ($p < 0.01$ for both). A medium effect size of comparisons was detected in both variables ($R^2$ $\geq 0.39$ for both) (Table 2).

3.2 Effort intensity and heart rate variability

Due to changes in the $\%HR_{\text{max}}$ (calculated from mean and peak recorded heart rate) and HRV variables (SDNN, RMSSD, LF band, HF band, SD1 and SD2) over time ($p < 0.0001$ for all), these parameters were analysed at specific times.

During Exercise 1, effort intensity increased from resting state to low intensity (18.9 +- 0.1% vs. 56.2 +- 0.3%; $p < 0.0001$) before reaching moderate intensity at exercise 2 (18.9 +- 0.1% vs. 75.1 +- 2.4%; $p < 0.0001$). It then decreased to low intensity during Exercise 3 (18.9 +- 0.1% vs. 56.4 +- 1.3%; $p< 0.0001$).
and gradually decreased 30–90 minutes post-lunging ($p < 0.01–0.0001$) before returning to baseline at 120 minutes post-lunging. Notably, effort intensity was higher in Exercise 2 than in Exercises 1 and 3 (75.1 ± 2.4% vs. 56.2 ± 0.3% and 56.4 ± 1.3%, respectively; $p < 0.0001$ for both comparisons). Additionally, exertion occasionally increased to high-intensity effort during Exercise 1 (40.0 ± 0.0% vs 78.9 ± 1.1%; $p < 0.0001$) and Exercise 2 (40.0 ± 0.0% vs 88.1 ± 1.1%; $p < 0.0001$) (Table 3).

During lunging, a significant decrease in HRV variables (SDNN, RMSSD, LF band, HF band, SD1 and SD2) was observed compared to pre-lunging, with the lowest values occurring during Exercise 2 ($p < 0.0001$ for all variables in Exercises 1–3). The LF and HF bands gradually increased to baseline levels at 60 and 90 minutes post-lunging, while the remaining variables returned to baseline at 120 minutes post-lunging (Figure 1).

### 3.2 Correlation coefficients and method agreement

The correlation coefficients and method agreement are presented in Table 4. The computed HRV variables indicate a strong correlation, corresponding to a large effect size, between the two lunging methods. For example, the SDNN has an $r_p$ of 0.9745 and an $R^2$ of 0.9496, while the RMSSD has an $r_p$ of 0.9723 and an $R^2$ of 0.9454. Similarly, the LF band has an $r_p$ of 0.9249 and an $R^2$ of 0.8554, and the HF band has an $r_p$ of 0.9372 and an $R^2$ of 0.8783. The SD1 has an $r_p$ of 0.9724 and an $R^2$ of 0.9455, and the SD2 has an $r_p$ of 0.9779 and an $R^2$ of 0.9563. Although the bias of the comparisons (average difference ± SD) between the two lunging methods varies among the HRV variables (SDNN, 0.4 ± 7.7; RMSSD, 2.3 ± 10.4; LF band, -60.0 ± 815.5; HF band, 19.8 ± 250.9; SD1, 1.6 ± 7.4; and SD2, -0.5 ± 7.9), they remain within the upper and lower limits of agreement, denoted by the mean difference ± 1.96 SD in Figure 2.

### 4. DISCUSSION

A recent study investigated the effects of lunging in a round pen and on a lunge line on various heart rate and heart rate variability factors in untrained horses. The findings showed that horses can perform intermittent high-intensity exercise through both lunging techniques, with no significant variations in exercise effort and autonomic responses by technique. Notably, the autonomic responses to lunging in a round pen displayed a strong correlation and excellent agreement with those of lunging on a lunge line. This study illuminates the physiological reactions and method agreement of conventional lunging methods in horses.

In general, lunging exercises can be performed with or without aids to develop specific skills in a horse. Research has shown that aids such as a chambon, rubber bands, and triangle side reins can affect how horses move and alter their muscle function during lunging. However, welfare risks are associated with excessive use of these aids. In this study, as the horses were not accustomed to lunging aids, using them could have risked injury and caused fear, anxiety, and discomfort, potentially altering their HRV during lunging exercises. Therefore, horses that performed the exercise without aids were more likely to produce accurate physiological responses. The horses also covered a longer distance on a lunged line than in a round pen, likely because they had more freedom and tended to accelerate to move away from the handlers. In contrast, the perimeter fence in the round pen prevented them from escaping, permitting them only to move forward.

The intensity of effort in horses is measured with $\text{VO}_{2\text{max}}$ and $\%\text{HR}_{\text{max}}$ while exercising or otherwise exerting themselves physically. In this study, $\%\text{HR}_{\text{max}}$ was utilised to indicate effort intensity because HR is simple to record during lunging exercises with an HRM device, which is both convenient and reliable for recording HR and RR intervals in horses for HRV analysis. The optimal range for horses’ maximal heart rate is 212–242 beats/min, depending on the breed. As this study was conducted on ponies, the $\%\text{HR}_{\text{max}}$ was calculated with a reference maximal heart rate of 220 beats/min for ponies. Although the HR recorded during the first trotting and cantering phases indicated low and moderate effort intensities, respectively, it occasionally reached high-intensity levels during lunging exercises with both methods, suggesting that these untrained horses performed intermittent high-intensity exercise during lunging manoeuvres. Not only did the effort intensity fluctuate, but lunging also caused a marked decrease in HRV during the exercise regimens with both lunging methods. This result aligns with previous reports of reduced HRV during field
and laboratory exercises, indicating a reduced vagal and a shift toward sympathetic dominance during exercise in lunged horses. Notably, despite differences in their running speed and distance covered, the modulation in effort intensity and HRV did not vary between horses lunged in a round pen or on a lunge line. This finding is supported by the lack of interaction between the lunging method and the time of HR and HRV modification, suggesting that untrained horses experienced equal training loads and stress responses during both lunging exercises.

The HRV modulation analysis revealed a strong correlation between the horses subjected to different lunging methods. The correlation coefficient for all variables was greater than 0.90, indicating a significant relationship. Moreover, a large correlation effect size ($R^2 > 0.64$ for all variables) was observed, demonstrating the practical significance of this finding. However, while the correlation coefficient can determine the relationship between two variables, it cannot assess their differences. Therefore, a Bland–Altman plot, a data plotting method used to evaluate the agreement between two clinical measurements, was utilised to determine the variance in variables between the two lunging methods. Despite some variation in the mean differences of variables measured from the two methods, the total variance was close to zero, within the mean difference ± 1.96 SD. This suggests that both lunging methods demonstrate excellent agreement and could be used interchangeably for physical fitness training. However, this study raises questions about whether the physiological responses observed in untrained horses are similar to those found in trained horses when subjected to different lunging methods. Further investigation is needed to assess the modulation of skeletal muscle properties in response to these methods as well.

One of the limitations of this study is that the Polar sports watch could not automatically measure the horses’ running speed and distance covered while lunging without riders, as it could not be attached to them. As a result, running speed and distance covered were calculated manually and may not be entirely accurate. Furthermore, incomplete circuits were occasionally created during training on a lunge line with untrained horses, which caused errors in speed and covered distance. This led to missing data from horses in the lunge line group, so the movement speed and distance covered reported in this study should be interpreted cautiously.

5. CONCLUSION

Lunging can induce notable physiological reactions in untrained horses. The intensity of effort involved in the manoeuvres can be quite high. However, despite differences in horses’ pace and distance covered, comparable training efforts and corresponding autonomic responses indicate that both lunging techniques are equally effective for physical conditioning. This outcome offers greater flexibility in selecting lunging protocols for horse training and accommodating factors such as facility availability and individual lunging ability.

Table 1 Exercise programme during lunging in a round pen and on the lunge line for 54 minutes

<table>
<thead>
<tr>
<th>Exercise sequences</th>
<th>Gaits</th>
<th>Periods (minutes)</th>
<th>Exercise regimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Walking</td>
<td>5</td>
<td>Exercise 1</td>
</tr>
<tr>
<td>2</td>
<td>Trotting-up</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Walking</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Trotting-up</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Walking</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cantering</td>
<td>5</td>
<td>Exercise 2</td>
</tr>
<tr>
<td>7</td>
<td>Walking</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Cantering</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Walking</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Trotting-up</td>
<td>10</td>
<td>Exercise 3</td>
</tr>
<tr>
<td>11</td>
<td>Walking</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 The average speed of movement and distance covered during 54 minutes of lunging in a round pen
and on the lunge line

<table>
<thead>
<tr>
<th>Variables</th>
<th>Lunge line (N = 10)</th>
<th>Round pen (N = 16)</th>
<th>Effect size (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement speed (km/h)</td>
<td>12.3 ± 0.9</td>
<td>10.0 ± 1.5**</td>
<td>0.3932</td>
</tr>
<tr>
<td>Covered distance (km)</td>
<td>11.1 ± 0.8</td>
<td>9.0 ± 1.4**</td>
<td>0.3937</td>
</tr>
</tbody>
</table>

** indicates a significant difference at \( p < 0.01 \) from the variables of lunge line lunging

Table 3 Effort intensity indicated by \%HRmax, computed from mean and peak recorded HR

<table>
<thead>
<tr>
<th>Periods</th>
<th>Effort intensity</th>
<th>Effort intensity</th>
<th>Effort intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lunge line (N = 16)</td>
<td>Round pen (N = 16)</td>
<td>Pooled analysis (N = 32)</td>
</tr>
<tr>
<td>Pre-lunging</td>
<td>%HRmax (mean recorded HR)</td>
<td>%HRmax (mean recorded HR)</td>
<td>%HRmax (peak recorded HR)</td>
</tr>
<tr>
<td>Exercise 1</td>
<td>19.0 ± 3.1</td>
<td>18.8 ± 4.0</td>
<td>18.9 ± 0.1</td>
</tr>
<tr>
<td>Exercise 2</td>
<td>56.0 ± 9.6</td>
<td>56.4 ± 6.5</td>
<td>56.2 ± 0.3*</td>
</tr>
<tr>
<td>Exercise 3</td>
<td>73.4 ± 11.6</td>
<td>76.8 ± 6.6</td>
<td>75.1 ± 2.4*</td>
</tr>
<tr>
<td>Post-lunging</td>
<td>55.5 ± 10.3</td>
<td>57.3 ± 7.8</td>
<td>56.4 ± 1.3*</td>
</tr>
<tr>
<td>30 min</td>
<td>29.0 ± 5.5</td>
<td>28.7 ± 5.0</td>
<td>28.8 ± 0.2*</td>
</tr>
<tr>
<td>60 min</td>
<td>23.8 ± 4.8</td>
<td>24.1 ± 5.4</td>
<td>24.0 ± 0.2*</td>
</tr>
<tr>
<td>90 min</td>
<td>21.3 ± 4.1</td>
<td>22.5 ± 3.9</td>
<td>21.9 ± 0.8*</td>
</tr>
<tr>
<td>120 min</td>
<td>20.4 ± 3.6</td>
<td>21.0 ± 2.7</td>
<td>20.7 ± 0.4</td>
</tr>
</tbody>
</table>

HR : heart rate, HRmax : reference maximal heart rate (220 beats/min). * indicates a significant difference from the pre-lunging value. # indicates a significant difference from Exercises 1 and 3.

Table 4 Correlation coefficient, correlation effect size, and method agreement on the differences in HRV variables between the two lunging methods

<table>
<thead>
<tr>
<th>HRV variables</th>
<th>Correlation coefficient</th>
<th>Correlation coefficient</th>
<th>Correlation coefficient</th>
<th>Mean difference ± SD</th>
<th>95% Limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson’s ( r )</td>
<td>95% CI</td>
<td>Correlation effect size (R²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDNN (ms)</td>
<td>0.9745</td>
<td>0.8612 to 0.9955</td>
<td>0.9496</td>
<td>0.4 ± 7.7</td>
<td>-14.7 ± 15.4</td>
</tr>
<tr>
<td>RMSSD (ms)</td>
<td>0.9723</td>
<td>0.8501 to 0.9951</td>
<td>0.9454</td>
<td>2.3 ± 10.4</td>
<td>-18.1 ± 22.7</td>
</tr>
<tr>
<td>LF (ms²)</td>
<td>0.9249</td>
<td>0.6323 to 0.9866</td>
<td>0.8554</td>
<td>-60.0 ± 815.5</td>
<td>-1658 ± 1538</td>
</tr>
<tr>
<td>HF (ms²)</td>
<td>0.9372</td>
<td>0.6846 to 0.9888</td>
<td>0.8783</td>
<td>19.8 ± 250.9</td>
<td>-472.1 ± 511.6</td>
</tr>
<tr>
<td>SD1 (ms)</td>
<td>0.9724</td>
<td>0.8505 to 0.9952</td>
<td>0.9455</td>
<td>1.6 ± 7.4</td>
<td>-12.8 ± 16.0</td>
</tr>
<tr>
<td>SD2 (ms)</td>
<td>0.9779</td>
<td>0.8788 to 0.9961</td>
<td>0.9563</td>
<td>-0.5 ± 7.9</td>
<td>-16.0 ± 15.00</td>
</tr>
</tbody>
</table>

RR : beat-to-beat intervals, SDNN : standard deviation of RR interval, RMSSD : root mean square of successive RR interval differences, LF : low-frequency band, HF : high-frequency band, SD1 : standard
deviation of the Poincaré plot perpendicular to the line of identity and \( SD2 \): standard deviation of the Poincaré plot along the line of identity.

**List of Figure legends**

**FIGURE 1** Modification of HRV variables (\( N = 32 \)) at given times, including mean beat-to-beat (RR) intervals, in (a) the standard deviation of RR interval (SDNN), (b) the root mean square of successive RR interval differences (RMSSD), (c) the low-frequency band (LF), (d) the high-frequency band (HF), and (e) the standard deviation of the Poincaré plot perpendicular to the line of identity (SD1) (f) and along the line of identity (SD2), after lunging on the lunge line (blue) and in a round pen (red) pre-lunging, during Exercise 1 (the first trot), Exercise 2 (cantering), Exercise 3 (the second trot), and at 30-minute intervals for 120 minutes post-lunging. [*] indicates a significant difference from pre-lunging values.
FIGURE 2 Bland–Altman plots indicate agreement between HRV variables for the two lunging methods, including the standard deviation of (a) normal-to-normal RR intervals (SDNN), (b) the root mean square of successive RR interval differences (RMSSD), (c) the low-frequency (LF) band, (d) the high-frequency (HF) band, and (e) the standard deviation of the Poincaré plot perpendicular to the line of identity (SD1) and along the line of identity (SD2). The upper and lower dotted lines of each graph depict 95% limits of agreement, within +1.96 SD and -1.96 SD, respectively. $y = 0$ indicates perfect average agreement.

REFERENCES


