Effect of head and neck position on intrathoracic pressure and arterial blood gas values in Dutch Warmblood riding horses during moderate exercise

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Objective—To evaluate the effect of various head and neck positions on intrathoracic pressure and arterial oxygenation during exercise in horses.

Animals—7 healthy Dutch Warmblood riding horses.

Procedures—The horses were evaluated with the head and neck in the following predefined positions: position 1, free and unrestrained; position 2, neck raised with the bridge of the nose aligned vertically; position 4, neck lowered and extremely flexed with the nose pointing toward the pectoral muscles; position 5, neck raised and extended with the bridge of the nose in front of a vertical line perpendicular to the ground surface; and position 7, neck lowered and flexed with the nose pointing towards the carpus. The standard exercise protocol consisted of trotting for 10 minutes, cantering for 4 minutes, trotting again for 5 minutes, and walking for 5 minutes. An esophageal balloon catheter was used to indirectly measure intrathoracic pressure. Arterial blood samples were obtained for measurement of Pao_2, $Paco_2$, and arterial oxygen saturation.

Results—Compared with when horses were in the unrestrained position, inspiratory intrathoracic pressure became more negative during the first trot (all positions), canter and second trot (position 4), and walk (positions 4 and 5). Compared with when horses were in position 1, intrathoracic pressure difference increased in positions 4, 2, 7, and 5; Pao_2 increased in position 5; and arterial oxygen saturation increased in positions 4 and 7.

Conclusions and Clinical Relevance—Position 4 was particularly influential on intrathoracic pressure during exercise in horses. The effects detected may have been caused by a dynamic upper airway obstruction and may be more profound in horses with upper airway disease. (*Am J Vet Res* 2012;73:522–528)

The overall training goal in dressage is athletic development that will enable horses to achieve a desirable gait and posture and hence performance during competition. Among equestrians, it is generally believed that altering the position of a horse's head and neck is important to achieve goal.[1] Studies[1–4] have demonstrated that a change in head and neck position influences back kinematics and the loading pattern of the locomotor apparatus in unridden and ridden high-level dressage horses. Although a flexed head and neck position induces an increase in range of motion of the thoracic and lumbar dorsum in unridden horses and a more equally divided weight load between forelimbs and hind limbs,[2] this effect is not reproducible in ridden horses.[3] However, an extremely elevated neck reportedly causes an increase in extension of the thoracic and lumbar dorsum in unridden as well as ridden horses.[2,3] This position also affects function of the locomotor apparatus much more than an extremely low neck, as evidenced by an increase in peak vertical forces in the forelimbs, which is a potential risk factor for injury.[1,4]

Abbreviations

HR	Heart rate
IP	Intrathoracic pressure
IPΔ	Intrathoracic pressure difference
Sao_2	Arterial oxygen saturation

Concern among those involved in international dressage about the head and neck positions of horses mainly relates to training with an extremely flexed head and neck position[5] (position 4 as defined in other studies[1–4]). This position has been referred to as Rollkur[6]; low, deep, and round[7]; or hyperflexion.[8]

Biomechanical studies[1–4] have yielded no evidence to suggest any deleterious effect of this position. However, there are reasons to believe that training horses in a flexed head and neck position could have an adverse effect on upper airway function because dynamic

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obstructions of the upper respiratory tract (ie, those that mainly influence airflow during inhalation, such as dynamic laryngeal collapse or axial deviation of the aryepiglottic folds) are a common cause of poor performance or abnormal respiratory noise in sport horses.[9] Other studies[10,11] have demonstrated that forced poll flexion not only contributes to the development of dynamic airway obstruction[9] but can also cause dynamic upper airway tract obstruction in healthy horses during strenuous exercise. Head and neck flexion could be associated with a more compliant upper airway allowing tissues to bulge into the airway and cause obstruction.[10] Such a hypothesis is supported by findings of a study[12] that show that head flexion decreases the pharyngeal diameter, which would increase upper airway resistance.

To detect dynamic obstruction of the respiratory tract during head and neck flexion, esophageal pressure can be measured by use of a balloon catheter, which is a noninvasive and accurate alternative to direct IP measurement by pleural puncture.[13–15] A dynamic obstruction during inhalation or exhalation causes an increase in peak-to-peak amplitude (IPΔ) during a respiration cycle, a more negative IP with inspiratory resistive breathing, and more positive expiratory pressure with expiratory resistive breathing.[16,17]

Another potential concern is that healthy horses develop arterial hypoxemia during exercise with a decrease in arterial oxygen pressure of approximately 10 to 18 mm Hg during exercise compared to rest, which is mainly attributable to diffusion limitations.[18–20] A further decrease in arterial oxygenation could be caused by obstructions in the upper airway tract or bronchoalveolar disease.[21–25] Therefore, measurement of arterial blood gas values is considered useful in determining the effect of airway abnormalities on exercise ability. The purpose of the study reported here was to evaluate the effect of various head and neck positions on IP and arterial oxygenation during exercise in horses. We hypothesized that head and neck flexion would cause an inspiratory obstruction, resulting in an increase in IPΔ, a more negative inspiratory IP, and a corresponding decrease in arterial oxygenation, in healthy Dutch Warmblood riding horses during moderate exercise.

Materials and Methods

Horses—Seven healthy base level–trained Dutch Warmblood riding horses (5 mares and 2 geldings) were used in the study. Mean ± SD age was 10.3 ± 3.6 years, height at the ridge between the scapulae (withers) was 161.2 ± 1.4 cm, and body weight was 531 ± 47.3 kg. None of the horses had a history of respiratory disease, cardiovascular disease, or neuromuscular disorders. Radiographic and ultrasonographic examination of the cervical portion of the spinal column revealed no abnormalities in any horse.

Horses were individually housed in box stalls and had free access to grass silage supplemented with concentrate feed. To accustom the horses to the experimental setup, each was trained for at least 3 weeks in various head and neck positions while being lunged. The study protocol was approved by the Committee on Animal Welfare of Utrecht University.

Experimental design—Each horse underwent a standardized exercise test while being lunged, consisting of a warmup (1-minute walk, 3-minute trot, and 1-minute canter, unrestrained) followed by a 10-minute trot (trot 1), 4-minute canter, 5-minute trot (trot 2), 5-minute walk, and cooldown (5-minute walk, unrestrained). After the warmup, the horses were guided into predetermined head and neck positions as defined in previous studies[1–4] by use of side reins. The postures achieved were positions 1, 2, 4, and 5 and a new position described for the present study, 7 (**Figure 1**). Positions 3 (elevated neck, bridge of the nose behind vertical) and 6 (forward-downward extension of the head and neck) as defined in previous studies[1–4] were omitted.

Correct positioning was determined on the basis of a preliminary study[26] and quantification of 4 angles: angle between a line connecting the spinous process of T6 with the wing of the atlas and horizontal (angle 1), angle between a line connecting the spinous process of T6 with the wing of the atlas and a line connecting the wing of the atlas with the lower part of the facial crest (angle 2), angle between a line connecting the wing of the atlas with the lower part of the facial crest and a vertical line perpendicular to the ground (angle 3), and angle between the bridge of the nose and a vertical line perpendicular to the ground (angle 4) and 2 distances (horizontal distance between the vertical lines passing through the lower part of the facial crest and the supraglenoid tubercle of the scapula [distance H] and vertical distance between the horizontal lines passing through the lower part of the facial crest and the lateral styloid process of the radius [distance V]). Angle 2 describes most accurately the amount of flexion in the laryngeal region.[10]

The horses completed the exercise test during a period of 2 days. The first day started with the head and neck in position 1 and in 2 other random positions, defined by a Latin square study design. The remaining 2 positions were evaluated on the second day. Between each exercise test, the horse rested for 2 hours.[27]

IP—Intrathoracic pressure was indirectly measured by use of an esophageal balloon catheter technique. The esophageal balloon (length, 7 cm; width, 3 cm) was made of a middle finger of a medical glove[a] sealed over the open end of a catheter[b] (inner diameter, 2.80 mm; outer diameter, 4.10 mm; length, 380 cm). Prior to each exercise test, the catheter was introduced via a lubricated stomach tube into the esophagus. After placement of the balloon at a distance from the nostrils corresponding to the height at the withers, the tube was pulled back and the catheter was tightened to the halter with adhesive tape. The catheter was then connected to a pressure transducer,[c] which was connected to a small portable computer.[d]

The pressure transducer was calibrated by use of a water manometer with 23 points ranging from 0 to 20 cm H_2O. The recordings were within the range of the system capacity. The pressure transducer and computer were both part of the harness.

After each horse completed the warmup, the balloon was inflated with 6 mL of air. The air tightness

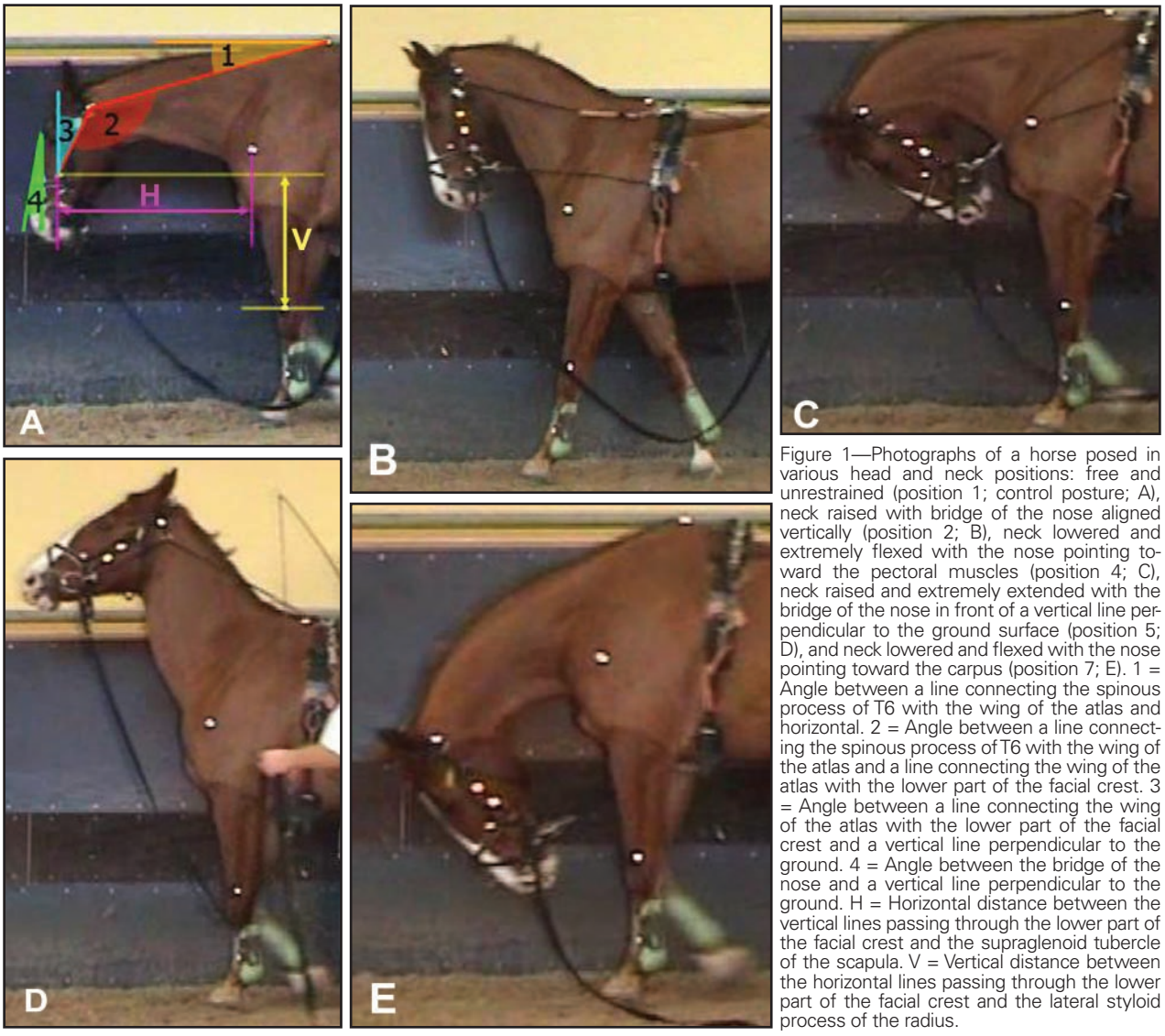

Figure 1—Photographs of a horse posed in various head and neck positions: free and unrestrained (position 1; control posture; A), neck raised with bridge of the nose aligned vertically (position 2; B), neck lowered and extremely flexed with the nose pointing toward the pectoral muscles (position 4; C), neck raised and extremely extended with the bridge of the nose in front of a vertical line perpendicular to the ground surface (position 5; D), and neck lowered and flexed with the nose pointing toward the carpus (position 7; E). 1 = Angle between a line connecting the spinous process of T6 with the wing of the atlas and horizontal. 2 = Angle between a line connecting the spinous process of T6 with the wing of the atlas and a line connecting the wing of the atlas with the lower part of the facial crest. 3 = Angle between a line connecting the wing of the atlas with the lower part of the facial crest and a vertical line perpendicular to the ground. 4 = Angle between the bridge of the nose and a vertical line perpendicular to the ground. H = Horizontal distance between the vertical lines passing through the lower part of the facial crest and the supraglenoid tubercle of the scapula. V = Vertical distance between the horizontal lines passing through the lower part of the facial crest and the lateral styloid process of the radius.

of the balloon was evaluated before and at the end of each exercise test. Data, including negative and positive peak pressures, IPΔs, and breathing frequencies, were analyzed by use of a custom-built software program, which calculated the mean values over each minute after correction for artifacts (eg, those produced by swallowing or blowing). To ensure measurement of a steady state, the first and last minute of the exercise phase were excluded.

Core body (esophageal) temperature—Core body temperature was measured by use of a thermoprobe[e] attached to the end of the esophageal catheter with adhesive tape. A small conducting cord connected the probe with the display, and the display was attached to the halter.

Blood gas analysis—One transverse facial artery of each horse was catheterized,[f] and arterial blood samples were collected in heparinized 3-mL syringes at the beginning of the exercise test and immediately at the end of each exercise phase. The syringes were then capped and stored on crushed ice for blood gas analysis[g] within 15 minutes after collection.[24] The Pa_{O_2} and Pa_{CO_2} values were corrected for core body temperature by use of the following equations[28]:

$$Pa_{CO_2} \text{ (corrected for T)} = (Pa_{CO_2} \text{ at } 37°C) \times 10^{0.019 \bullet (T - 37)}$$

$$Pa_{O_2} \text{ (corrected for T)} = (Pa_{O_2} \text{ at } 37°C) \times 10^{A \bullet (T - 37)}$$

$$A = (5.49 \times 10^{-11} \times [Pa_{O_2} \text{ at } 37°C]^{3.88} + 0.071)/(9.72 \times 10^{-9} \times [Pa_{O_2} \text{ at } 37°C]^{3.88} + 2.30)$$

in which T is core body temperature and A is a variable that is calculated for each time point.

HR—Electrocardiography was continuously performed during the exercise test by use of a telemetric device[h] to use HR as an indicator of workload and to monitor for pathological arrhythmias that were potentially caused by induced hypoxemia.

Statistical analysis—Statistical analysis was performed with the aid of statistical software.[i] Data, including peak pressures, peak-to-peak amplitudes, breathing frequencies, HRs, and arterial blood gas values were considered continuously dependent. Normality of data distribution was tested by plotting

the residuals in a P-P plot. Differences were tested by use of a linear mixed model with a random intercept to account for the repeated measurements, horse as the experimental unit, and head and neck position, gait, and the interaction between the 2 as fixed factors. Models were tested by comparing the maximum of likelihoods. Values of $P < 0.05$ after post hoc Bonferroni correction were considered significant. Data are presented as mean ± SD.

Results

Animals—The 7 horses achieved the following mean ± SD HRs during exercise testing: 10-minute trot (trot 1), 101 ± 8 beats/min; 4-minute canter, 128 ± 11 beats/min; 5-minute trot (trot 2), 104 ± 8 beats/min; and 5-minute walk, 73 ± 8 beats/min.

Angles—Preliminary testing revealed that compared with position 1, flexion of the laryngeal region

Table 1—Mean ± SD angles and distances defining specific head and neck positions in 7 Dutch Warmblood riding horses.

	Angle				Distance	
Position	1 (°)	2 (°)	3 (°)	4 (°)	H (cm)	V (cm)
1	–16.2 ± 5.6	131.9 ± 5.0	25.7 ± 4.5	11.9 ± 3.4	73.5 ± 9.0	60.2 ± 13.0
2	3.6 ± 5.0	87.2 ± 5.0	0.9 ± 6.6	–12.8 ± 6.6	43.9 ± 4.5	89.8 ± 8.0
4	–33.3 ± 3.2	84.4 ± 3.4	–38.9 ± 2.9	–51.7 ± 4.8	34.5 ± 3.4	46.7 ± 5.6
5	34.8 ± 8.0	119.2 ± 10.1	63.9 ± 9.5	47.2 ± 9.3	45.5 ± 5.6	144.8 ± 10.3
7	–41.5 ± 4.5	103.6 ± 6.9	–27.8 ± 4.0	–41.0 ± 5.8	37.2 ± 4.5	18.6 ± 8.7

Positions were defined as follows: position 1, free and unrestrained (control posture); position 2, neck raised with bridge of the nose aligned vertically; position 4, neck lowered and extremely flexed with the nose pointing toward the pectoral muscles; position 5, neck raised and extremely extended with the bridge of the nose in front of a vertical line perpendicular to the ground surface; and position 7, neck lowered and flexed with the nose pointing toward the carpus.

1 = Angle between a line connecting the dorsal spinous process of T6 with the wing of the atlas and horizontal. 2 = Angle between a line connecting the dorsal spinous process of T6 with the wing of the atlas and a line connecting the wing of the atlas with the lower part of the facial crest. 3 = Angle between a line connecting the wing of the atlas with the lower part of the facial crest and a vertical line perpendicular to the ground. 4 = Angle between the bridge of the nose and a vertical line perpendicular to the ground. H = Horizontal distance between the vertical lines passing through the lower part of the facial crest and the supraglenoid tubercle of the scapula. V = Vertical distance between the horizontal lines passing through the lower part of the facial crest and the lateral styloid process of the radius.

Table 2—Mean ± SD intrathoracic (esophageal) pressure, HR, and breathing frequency in the 7 horses in Table 1 in various predefined head and neck positions during 4 gaits: a 10-minute trot (trot 1), 4-minute canter, 5-minute trot (trot 2), and 5-minute walk.

	Position				
Variable	1	2	4	5	7
Trot 1					
Pes Max (cm H_2O)	18.4 ± 2.1	15.3 ± 4.0	10.3 ± 4.2	15.2 ± 2.7	13.0 ± 2.7
Pes Min (cm H_2O)	4.1 ± 1.6	–2.8 ± 2.7*	–7.7 ± 4.0*	–0.9 ± 3.4†	–6.1 ± 4.2*
Pes Δ (cm H_2O)	10.0 ± 1.9	13.7 ± 2.1	13.7 ± 1.9	11.7 ± 1.6	14.9 ± 3.4
Respiratory rate (breaths/min)	121 ± 16	125 ± 21	122 ± 24	121 ± 19	132 ± 13*
HR (beats/min)	102 ± 8	100 ± 8	103 ± 8	102 ± 11	99 ± 8†
Canter					
Pes Max (cm H_2O)	20.5 ± 2.1	17.4 ± 4.0	15.4 ± 4.2	18.8 ± 3.2	18.2 ± 3.7
Pes Min (cm H_2O)	–1.2 ± 2.9	–6.0 ± 4.2	–11.0 ± 5.6*	–5.7 ± 4.8	–6.6 ± 6.1
Pes Δ (cm H_2O)	17.7 ± 2.9	18.9 ± 1.9	22.1 ± 2.1	20.2 ± 3.4	20.6 ± 3.2
Respiratory rate (breaths/min)	100 ± 7	96 ± 7	98 ± 7	99 ± 7	97 ± 7
HR (beats/min)	130 ± 13	127 ± 8	129 ± 8	127 ± 13	129 ± 11
Trot 2					
Pes Max (cm H_2O)	10.3 ± 2.7	12.5 ± 5.6	7.2 ± 4.8	8.3 ± 2.4	10.9 ± 3.2
Pes Min (cm H_2O)	–8.6 ± 2.9	–9.0 ± 3.2	–15.2 ± 4.2†	–11.9 ± 4.8	–9.2 ± 6.0
Pes Δ (cm H_2O)	14.6 ± 3.2	17.0 ± 3.4	18.1 ± 2.9	15.7 ± 3.7	15.9 ± 4.5
Respiratory rate (breaths/min)	135 ± 16	138 ± 16	127 ± 24†	129 ± 16	132 ± 13
HR (beats/min)	105 ± 8	107 ± 5	103 ± 8	106 ± 8	100 ± 5†
Walk					
Pes Max (cm H_2O)	2.7 ± 2.4	5.5 ± 4.5	0.3 ± 3.2	0.1 ± 2.1	3.2 ± 4.5
Pes Min (cm H_2O)	–5.1 ± 2.7	–6.0 ± 4.2	–11.5 ± 3.2†	–10.9 ± 2.9†	–6.2 ± 6.1
Pes Δ (cm H_2O)	3.4 ± 1.1	7.1 ± 1.6	6.9 ± 1.9	6.4 ± 1.9	5.2 ± 2.4
Respiratory rate (breaths/min)	95 ± 8	103 ± 13*	96 ± 16	100 ± 8	96 ± 11
HR (beats/min)	72 ± 8	76 ± 11†	75 ± 8	76 ± 5	68 ± 5

*Value is significantly ($P < 0.001$) different than the respective position 1 value with post hoc Bonferroni correction. †Value is significantly ($P < 0.05$) different than the respective position 1 value with post hoc Bonferroni correction.

Pes Δ = Peak to peak amplitude esophageal pressure. Pes Max = Maximum esophageal pressure. Pes Min = Minimum esophageal pressure.

See Table 1 for remainder of key.

Table 3—Mean ± SD blood gas values corrected for core body temperature in the 7 horses in Table 1 in various predefined head and neck positions at 6 measurement points: start of exercise and end of warmup (1-minute walk, 3-minute trot, and 1-minute canter, unrestrained), trot 1, canter, trot 2, walk, and cooldown (5-minute walk, unrestrained).

	Position				
Variable	**1**	**2**	**4**	**5**	**7**
Start of exercise					
Pao_2 (mm Hg)	109.7 ± 22.8	103.6 ± 6.9	107.0 ± 13.3	102.3 ± 9.0	105.9 ± 9.3
$Paco_2$ (mm Hg)	44.8 ± 3.4	44.0 ± 1.9	42.9 ± 3.7	44.2 ± 3.7	43.2 ± 2.1
Sao_2 (%)	97.8 ± 0.5	97.7 ± 0.3	97.7 ± 0.8	97.5 ± 0.3	97.8 ± 0.5
Temperature (°C)	37.3 ± 0.8	37.2 ± 0.5	37.5 ± 0.8	37.7 ± 1.1	37.4 ± 0.5
Warmup					
Pao_2 (mm Hg)	76.1 ± 9.5	68.4 ± 6.4	77.3 ± 12.5	73.5 ± 8.7	75.5 ± 5.3
$Paco_2$ (mm Hg)	46.0 ± 2.9	44.6 ± 2.4	45.5 ± 4.2	46.2 ± 4.5	46.3 ± 2.9
Sao_2 (%)	95.2 ± 1.6	93.6 ± 2.1	94.8 ± 2.1	93.9 ± 1.3	95.0 ± 0.8
Temperature (°C)	37.0 ± 0.8	37.1 ± 0.8	37.6 ± 0.8	37.7 ± 1.1	37.6 ± 0.3
Trot 1					
Pao_2 (mm Hg)	70.3 ± 8.5	76.3 ± 6.9	76.8 ± 3.7	80.7 ± 6.9	75.9 ± 6.4
$Paco_2$ (mm Hg)	49.1 ± 4.5	49.1 ± 2.9	47.9 ± 2.9	49.9 ± 3.2	48.1 ± 2.9
Sao_2 (%)	93.1 ± 2.1	94.4 ± 1.3	94.0 ± 0.5	94.9 ± 1.1	94.7 ± 1.6
Temperature (°C)	37.8 ± 1.1	37.8 ± 0.5	37.7 ± 0.8	38.3 ± 0.5	37.5 ± 0.5
Canter					
Pao_2 (mm Hg)	65.6 ± 8.5	70.8 ± 4.5	74.9 ± 7.4	70.4 ± 6.9	71.1 ± 5.6
$Paco_2$ (mm Hg)	45.9 ± 4.5	46.8 ± 3.2	47.7 ± 4.5	49.3 ± 4.5	46.7 ± 3.4
Sao_2 (%)	92.1 ± 2.4	93.6 ± 1.1	94.3 ± 0.8	92.4 ± 1.9	93.7 ± 1.3
Temperature (°C)	37.8 ± 1.1	37.9 ± 0.5	38.2 ± 1.1	38.4 ± 0.8	37.9 ± 0.5
Trot 2					
Pao_2 (mm Hg)	70.9 ± 6.4	80.6 ± 17.0	80.4 ± 9.3	84.3 ± 11.1	78.7 ± 9.0
$Paco_2$ (mm Hg)	47.2 ± 2.7	45.8 ± 3.7	46.6 ± 4.8	45.7 ± 4.5	47.4 ± 3.4
Sao_2 (%)	93.6 ± 1.1	94.8 ± 2.4	95.1 ± 1.6	95.5 ± 1.9	94.8 ± 1.3
Temperature (°C)	37.9 ± 0.8	37.9 ± 0.5	38.0 ± 0.8	38.3 ± 0.5	38.1 ± 0.8
Walk					
Pao_2 (mm Hg)	88.0 ± 7.2	90.8 ± 6.6	89.4 ± 13.5	96.1 ± 12.2	92.6 ± 11.1
$Paco_2$ (mm Hg)	46.2 ± 2.7	45.6 ± 4.0	45.3 ± 2.7	44.7 ± 3.4	46.6 ± 4.0
Sao_2 (%)	96.3 ± 1.3	96.7 ± 0.8	96.6 ± 1.1	96.8 ± 1.3	96.7 ± 0.8
Temperature (°C)	38.1 ± 0.8	37.8 ± 0.8	37.5 ± 0.8	38.2 ± 0.5	37.7 ± 0.5
Cooldown					
Pao_2 (mm Hg)	89.9 ± 7.4	90.7 ± 6.6	88.8 ± 9.5	91.4 ± 8.0	93.0 ± 8.0
$Paco_2$ (mm Hg)	45.0 ± 6.4	45.7 ± 2.4	44.1 ± 3.7	46.2 ± 3.4	44.2 ± 2.9
Sao_2 (%)	96.4 ± 1.6	96.7 ± 0.5	96.7 ± 0.8	96.7 ± 0.8	96.9 ± 0.8
Temperature (°C)	38.1 ± 1.1	37.6 ± 0.5	37.5 ± 0.8	38.0 ± 0.5	37.8 ± 0.5

See Table 1 for key.

was greatest when the horses' heads and necks were in position 4, followed by positions 2, 7, and 5 (**Table 1**).

IP—Peak-to-peak amplitude and expiratory IP increased during the canter, compared with the trot 1 value ($P < 0.001$), and decreased in trot 2, compared with the canter value ($P < 0.001$), and walk, compared with the trot 2 value ($P < 0.001$). Compared with values measured during trot 1, expiratory IP and peak-to-peak amplitude were increased during trot 2 ($P < 0.001$). Minimum IP became more negative during canter, compared with the trot 1 value ($P < 0.001$), and during trot 2, compared with the canter value ($P < 0.001$), and became more positive during the walk, compared with the trot 2 value ($P = 0.008$). Compared with the value during trot 1, inspiratory IP became more negative during trot 2 ($P < 0.001$).

The interaction between head and neck position and exercise phase was significant for IP during inspiration but not during expiration or for peak-to-peak amplitude (**Table 2**). With position 1 as the reference position, inspiratory IP became more negative in position 4 followed by positions 7 and 2 (all $P < 0.001$) and position 5 ($P = 0.008$) during trot 1. Inspiratory IP became more negative in position 4 during the canter ($P < 0.001$) and trot 2 ($P = 0.008$), compared with the same exercise phases in position 1. During the walk, inspiratory IP became more negative in positions 4 ($P = 0.012$) and 5 ($P = 0.024$), compared with the walk in position 1. With position 1 as the reference position, IP during expiration decreased in positions 4 ($P < 0.001$), 5 ($P = 0.016$), and 7 ($P = 0.048$). Again, with position 1 as the reference position, peak-to-peak amplitude increased most in position 4, followed by positions 2, 7, and 5 (all $P < 0.001$). Furthermore, the horses produced an inspiratory snoring noise when exercised in position 4.

Breathing frequency—Breathing frequency decreased during the canter versus trot 1 ($P < 0.001$) and during the walk versus trot 2 ($P < 0.001$) and increased during trot 2 versus the canter ($P < 0.001$). Compared with trot 1, breathing frequency was increased during trot 2 ($P < 0.001$).

A significant interaction was detected between head and neck position and exercise phase. With position 1 as the reference position, breathing frequency increased

in position 7 during trot 1 ($P < 0.001$), decreased in position 4 during trot 2 ($P = 0.044$), and increased in position 2 during the walk ($P = 0.032$; Table 2).

HR—Heart rate increased during the canter, compared with values during trot 1 ($P < 0.001$), and decreased during trot 2, compared with values during the canter ($P < 0.001$), and during the walk, compared with values during trot 2 ($P < 0.001$). Compared with trot 1, trot 2 yielded a higher HR ($P < 0.001$).

A significant interaction was detected between head and neck position and exercise phase. With position 1 used as the reference position, HR decreased during trot 1 ($P = 0.020$) and trot 2 ($P = 0.008$) when horses were in position 7 and increased during the walk when horses were in position 2 ($P = 0.036$; Table 2).

Blood gas analysis—No significant difference between arterial blood gas values, corrected for core body temperature, was evident at the beginning of each exercise test. Independent of head and neck position, Pa_{O_2} and Sa_{O_2} decreased during the warmup, compared with the resting values ($P < 0.001$ for both values) and during the canter, compared with the trot 1 values ($P = 0.024$ and $P < 0.001$, respectively), and increased again in trot 2, compared with the canter values ($P < 0.001$ for both), and during the walk, compared with trot 2 values ($P < 0.001$ for both). The Pa_{CO_2} increased during the warmup, compared with the resting value ($P = 0.016$), and during trot 1, compared with the warmup value ($P < 0.001$).

No significant interaction between head and neck positions and exercise phase was evident for the blood gas variables. Independent of exercise phase with position 1 as the reference position, Sa_{O_2} increased from 94% to 95% in positions 4 ($P = 0.012$) and 7 ($P = 0.028$) and Pa_{O_2} increased from 77 to 83 mm Hg in position 5 ($P = 0.004$). The Pa_{CO_2} did not change significantly (**Table 3**).

Discussion

The present study was designed to investigate the hypothesis that head and neck flexion would cause a dynamic inspiratory obstruction resulting in an increase in IPΔ, a more negative inspiratory IP, and a corresponding decrease in arterial oxygenation in healthy base level–trained Dutch Warmblood riding horses during moderate exercise. Whereas the effects on IP were demonstrated in various positions, with the greatest effect seen in position 4, the expected concomitant decrease in arterial oxygenation was not observed.

The head and neck positions used in the present study were identical to those used in an earlier experiment,[1–4] with the exception of position 7. Position 7 was introduced here because in our experience, equestrians have 2 interpretations (positions 4 and 7) of the hyperflexed head and neck position used in certain training methods. The exercise test used was comparable to observed training methods used in the warmup arena for base level– as well as high level–trained dressage horses. Compared with the degree of flexion in position 1, flexion of the laryngeal region was most prominent in position 4, followed by flexion in positions 2, 7, and 5.

Exercise phase had an effect on IP in the present study. These findings are consistent with those of earlier studies[13–19] conducted to measure the effect of exercise with a neutral head and neck position on IP. It is remarkable to observe that in the present study, IP during inspiration did not become more positive until the walk phase. Our findings suggested that this preserved low inspiratory IP during trot 2 restored the relative arterial hypoxemia developed during the canter phase.

An increase in peak-to-peak amplitude from that in position 1 was detected for every other position evaluated, with the greatest effect noticed for position 4. The results for inspiratory IP were significant for position 4 in each exercise phase. Because each horse was used as its own control, the measured effects on IP are not likely to have been caused by a change in lung compliance or in viscoelasticity of lung tissue. Therefore, we believe that the increase in IP and the more negative inspiratory IP in all exercise phases when horses had their heads and necks in position 4 were most probably caused by the development of an inspiratory dynamic obstruction of the respiratory tract. Such a phenomenon would explain the abnormal inspiratory respiratory sounds noticed when this position was assumed. These findings are consistent with those of other studies.[10–12] The amount of flexion in the laryngeal region was much less in the alternative interpretation of a flexed head and neck position (position 7), which could explain the less profound effects on IP detected for position 7.

Healthy horses develop exercise-induced arterial hypoxemia, which is mainly caused by ventilation-perfusion mismatch, diffusion limitations, and lack of compensatory hyperventilation.[18] Although the horses in the present study performed moderate exercise, with the maximum HR reaching only 128 ± 11 beats/min during canter, they developed a significant decrease in Pa_{O_2} related to the exercise phase. When horses were lunged in position 1 during canter, a mean Pa_{O_2} of 65.6 ± 8.5 mm Hg was reached, which was even lower than the Pa_{O_2} of 69.0 ± 6.1 mm Hg developed by horses, with an HR of 201 beats/min, in another study.[19] This low Pa_{O_2} could have been caused by the high breathing frequencies in the present study, which suggests an inefficient alveolar-to-dead space ventilation. Furthermore, base level–trained Dutch Warmblood riding horses were used in the present study, as opposed to Thoroughbred horses trained for racing used in the other study.[19]

Several studies[21–23] have demonstrated that upper airway tract abnormalities can cause more severe arterial hypoxemia and hypercapnia during exercise, attributable to an increase in total airway resistance and consequently further impaired alveolar ventilation. Despite the increased IPΔ and more negative inspiratory IP when horses were in position 4 versus 1, there was no significant difference in arterial blood gas values, which suggested that alveolar ventilation remained unaffected. However, the blood gas findings should be interpreted with some caution because the study involved analysis of only 1 arterial blood sample/exercise phase and the horses needed to be stopped for blood sample collection. Although collection was performed quickly, the possibility cannot be excluded that this procedure had some effect on the final results.

We acknowledge that the study would have benefited from the use of a treadmill instead of lunging, which would have made it more practical to obtain multiple blood samples per exercise phase and would have made it possible to use an ultrasonic flow system to measure airflow and tidal volume. However, although considered as an option, in the authors' opinion, the treadmill has some major safety limitations for the handlers and horses when training is conducted in these extreme but realistic head and neck positions accomplished by use of side reins.

Changes in the head and neck position of horses indeed appeared to have influence on IP parameters. The effect was largest in those positions that are characterized by extreme flexion in the laryngeal region. However, at the moderate level of exercise performed in the present study, no adverse effect of any position on arterial blood gas pressures or Sa_{O_2} was identified. Additional research is needed to investigate whether the effect on arterial oxygenation is different in horses with upper airway tract abnormalities or lower airway disease or when performing more strenuous exercise.

a. Powder free, nitrile, size large, Marigda Industries, Hatyai, Thailand.
b. Polythene, Sims Portex Ltd, Hythe, Kent, England.
c. HS3 TiePie Engineering, Sneek, The Netherlands.
d. Eee PC 900, Asus Computer GmbH, Ratingen, Germany.
e. Conrad Electronics, Enschede, The Netherlands.
f. IntroCan, 20 gauge and 1.25 inches, MILA International Inc, Erlanger, KY.
g. RapidLab 1260, Siemens Healthcare Diagnostics Inc, Tarrytown, NY.
h. Televet 100, Rösch & Associates Information Engineering GmbH, Frankfurt am Main, Germany.
i. SPSS, version 16 for Windows, SPSS Inc, Chicago, Ill.

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