Animal Welfare Science and Bioethics Centre

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OIE *Collaborating Centre for Animal Welfare Science and Bioethical Analysis: Founding Partner*

http://animalwelfare.massey.ac.nz

Breathlessness as an overlooked welfare insult in equine athletes

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Key Published Sources

- Hinchcliff, K.W., Kaneps, A.J. and Geor, R.J., Eds (2014). *Equine Sports Medicine and Surgery: Basic and clinical sciences of the equine athlete*, 2nd ed., Elsevier, New York, USA.
- Beausoleil, N.J. and Mellor, D.J. (2015). Introducing breathlessness as a significant animal welfare issue. *N. Z. Vet. J.* 63, 44-51.
- Mellor, D.J. and Beausoleil, N.J. (2017). Equine welfare during exercise: An evaluation of breathing, breathlessness and bridles. *Animals* 7, 41; doi:10.3390/ani7060041 – open access/no cost

  Integrates the content of 164 publications on the physiology, pathophysiology and other features of equine athletic performance

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Areas considered

- High performance horses are supreme athletes
  - Domestication, breeding and principal outcomes
  - Physiological foundations of superior athletic performance
- Key features of respiratory function
  - Upper respiratory tract (URT) – general information / jowl angle / URT disorders
  - Changes in blood gas levels and pH
  - Lower respiratory tract (LRT) disorders – e.g. EIPH (NPPO, IAD)
- "Breathlessness" and its three types
  - Key Factors
  - Respiratory effort and high airflow resistance
  - Air hunger and chemoreceptor-induced drive to breathe
  - Simultaneous occurrence of both types
  - Chest tightness and LRT inflammation (equine asthma)
- Concluding comments

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High Performance Horses are Supreme Athletes

Domestication **– from ~6,000 years ago**

Breeding for sports prowess **– for the last 300-400 years**

- ***Key breeding objectives*****: speed, agility, endurance and power**
- ***High performance breeds*** **include:**
  - **Thoroughbreds**
  - **Arabians**
  - **Quarter Horses**
  - **Standardbreds**
  - **Anglo-Arabians**
  - **Warmbloods**

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***Principal breeding outcomes*:**

- ***Supreme athletes:*** **exceptional athleticism and sports versatility**
- ***Sports events*:** **flat racing, steeplechase, harness racing, endurance, cross-country, show jumping, barrel racing, roping, polo and other such competitive events**

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High Performance Horses are Supreme Athletes

Foundations of high athletic performance – maximum exercise

- **Musculoskeletal system:**
  - **Fit-for-purpose conformation, power and capacity**
  - **40-fold increase in O_2 consumption and CO_2 production**

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- **Respiratory system:**
  - **25-27 fold increase in air breathed/min to 1800-2000 L/min**
  - **~10 fold increase in breathing rate to 110-130 breaths/min**
  - **2-3 fold increase air breathed per breath to 12-15 L**

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  - ~10 fold increase in breathing rate to 110-130 breaths/min
  - 2-3 fold increase air breathed per breath to 12-15 L
- **Cardiovascular system:**
  - 7-8 fold increase in blood pumped by the heart to 285-310 L/min
  - 7-8 fold increase in the heart rate to 210-230 beats/min
  - 1.5 fold increase in O_2 carried in red cells per L blood
  - 5 fold increase in O_2 extracted from the blood by muscle

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High Performance Horses are Supreme Athletes

Maximum athletic performance:

- Far exceeds the performance of most other terrestrial mammals
- It is reduced by impaired physiological support for maximum exercise:

  Especially impaired O_2 supply to and CO_2 disposal from working muscles

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- Full function of the cardiorespiratory systems is required:

  In particular, *a fully functioning respiratory system* is imperative

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- Full function of the cardiorespiratory systems is required:

  In particular, a *fully functioning respiratory system* is imperative

- Breathing problems lead to poor performance or 'exercise intolerance'
- Numerous breathing problems have been identified – some are common

We will therefore focus on the respiratory system

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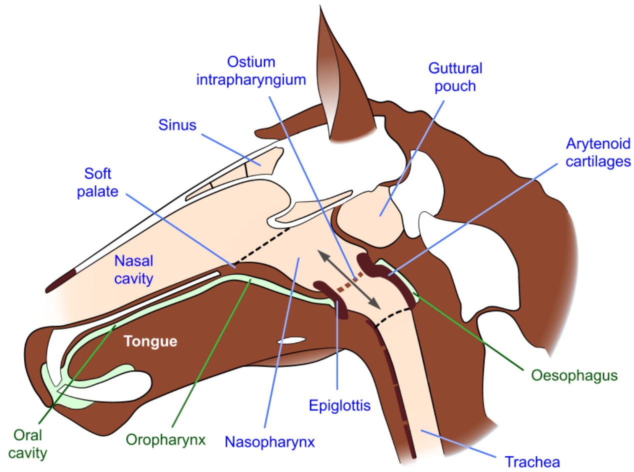
Key Features of Respiratory Function

Upper Respiratory Tract



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Key Features of Respiratory Function

Upper Respiratory Tract (URT) – General Information

Important principle:
Obstruction of any part of the URT will *increase airflow resistance* which, if significant, will *impede airflow* and hinder *respiratory gas exchange in the alveolae*

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- **The horse is an obligate nasal breather**
- **For fully effective respiration it must breathe through its nose**
- **At maximum, *1800-2000 L of air* must flow *in and out* per minute**

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- **The *nasopharynx, larynx and trachea* are responsible for:**
  - **95% airflow resistance on *inspiration* – negative air pressure**
  - **45% airflow resistance on *expiration* – positive air pressure**

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  - **45% airflow resistance on *expiration* – positive air pressure**

- **Any obstruction makes:**
  - **Inspiratory airflow resistance *more negative***
  - **Expiratory airflow resistance *higher***

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Key Features of Respiratory Function

Upper Respiratory Tract – The obstruction-breathlessness cascade

- **The *greater the obstruction:***

  The *greater will be*:
  - **The work or effort of breathing, i.e. *respiratory effort* AND**

  The *greater will be*:
  - **The reduction in *airflow*, AND THUS**

  The *greater will be*:
  - **The reduction in *respiratory gas exchange in the alveoli*, AND**

  The *greater will be*:
  - **The induced *arterial hypoxaemia/hypercapnia/acidaemia* AND**

  The *greater will be*:
  - **The chemically-induced drive to breathe i.e. *air hunger***

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  The *greater will be*:
  - **The induced *arterial hypoxaemia/hypercapnia/acidaemia* AND**

  The *greater will be*:
  - **The chemically-induced drive to breathe i.e. *air hunger***

The overall outcome is breathlessness of two types

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Key Features of Respiratory Function

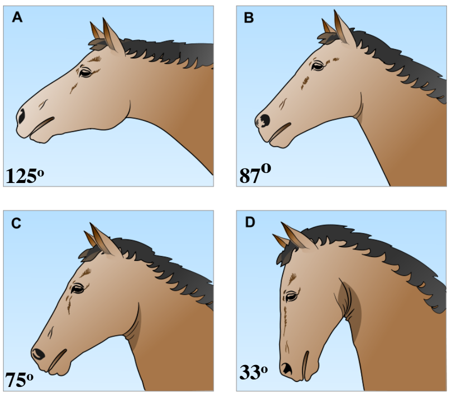
Upper Respiratory Tract – Jowl Angle

Gallop:
low rein tension
NPA = 100%

Gallop:
moderate rein tension
NPA = ~90%

Show jumping:
strong rein tension
NPA = ~55%

Dressage:
Very strong rein tension
NPA = ~30%
LCA = 92% (-8%)



NPA = Nasopharyngeal area
LCA = Laryngeal cross-sectional area

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Key Features of Respiratory Function

Upper Respiratory Tract – Jowl Angle

- **The 'at rest' jowl angle is ~90º**
- **The jowl angle is controlled by the rider or driver *using rein tension***

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Key Features of Respiratory Function

Upper Respiratory Tract – Jowl Angle

- The 'at rest' jowl angle is ~90º
- The jowl angle is controlled by the rider or driver *using rein tension*

A. 'Low rein tension, extended jowl angle' (~125º):

- **Straightens and widens *nasopharynx***
- **Stretches and straightens the *extrathoracic trachea* making it less subject to dynamic narrowing during inspiration**
- **This *disproportionately decreases airflow resistance* compared to that at ~90º**

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B. 'Moderate rein tension, reduced jowl angle' (~87°):
- **Reduces the nasopharyngeal area by ~10%**
- ***Disproportionately increases airflow resistance***

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Key Features of Respiratory Function

Upper Respiratory Tract – Jowl Angle

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B. 'Moderate rein tension, reduced jowl angle' (~87°):
- Reduces the nasopharyngeal area by ~10%
- *Disproportionately increases airflow resistance*

C. 'Strong rein tension, markedly reduced jowl angle' (~75°):
- **Reduces the nasopharyngeal area by ~45%**
- ***Markedly increases airflow resistance***

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Key Features of Respiratory Function

Upper Respiratory Tract – Jowl Angle

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- Reduces the nasopharyngeal area by ~10%
- *Disproportionately increases airflow resistance*

C. 'Strong rein tension, markedly reduced jowl angle' (~75°):

- Reduces the nasopharyngeal area by ~45%
- *Markedly increases airflow resistance*

D. 'Very strong rein tension, severely reduced jowl angle' (~33°)
– Rollkur position (< 33°)

- **Reduces the nasopharyngeal area by ~70%**
- **Reduces laryngeal cross-sectional area by 8%**
- ***Very markedly increases in airflow resistance***

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Key Features of Respiratory Function

Upper Respiratory Tract (URT) – Nasopharyngeal Obstruction

- ***Low jowl angles*** **may** ***induce*** **or** ***exacerbate*** **some** ***URT disorders***

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Key Features of Respiratory Function

Upper Respiratory Tract (URT) – Nasopharyngeal Obstruction

- ***Low jowl angles*** **may** ***induce*** **or** ***exacerbate*** **some** ***URT disorders***
- **Two soft palate disorders** ***obstruct the nasopharynx*** **and impede airflow:**
  - ***Palatal Instability (PI)*** **and**
  - ***Dorsal Displacement of the Soft Palate (DDSP)***
- **Both** ***PI*** **and** ***DDSP*** **are associated with** ***reduced athletic performance***

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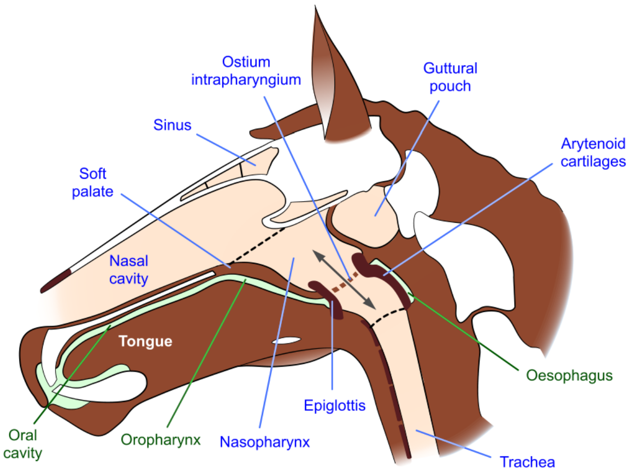
Key Features of Respiratory Function

Palatal Instability and Dorsal Displacement of the Soft Palate



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  - ***Palatal Instability (PI)*** **and**
  - ***Dorsal Displacement of the Soft Palate (DDSP)***
- **Both** ***PI*** **and** ***DDSP*** **are associated with** ***reduced athletic performance***
- **A third disorder also** ***obstructs the nasopharynx*** **and impedes airflow:**
  - **Pharyngeal collapse**
- ***Pharyngeal collapse*** **is also associated with** ***reduced athletic performance***

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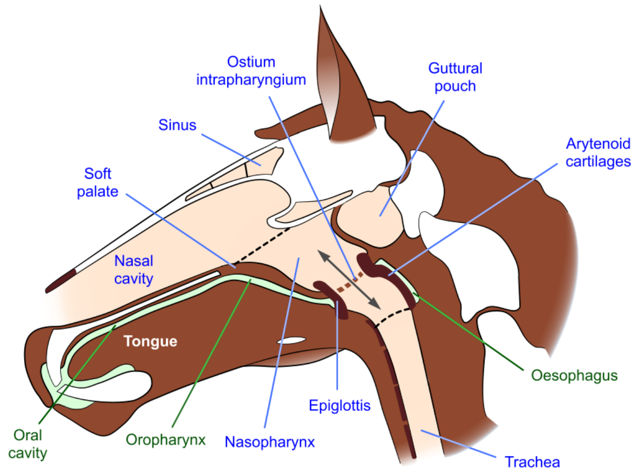
Key Features of Respiratory Function

Pharyngeal Collapse



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Key Features of Respiratory Function

Upper Respiratory Tract (URT) – Laryngeal-glottal Disorders

- **Dynamic laryngeal collapse included:**
  - **Laryngeal hemiplegia – one-sided paralysis**
  - **Laryngeal hemiparesis – one-sided weakness**
  - **Vocal cord collapse – bilateral laryngeal collapse**
- **Epiglottal disorders include:**
  - **Epiglottal entrapment**
  - **Flaccid epiglottis**
- **Other disorders**

Upper Respiratory Tract (URT) – Dynamic Tracheal Collapse

- **Dynamic collapse of the *extrathoracic* trachea:**
  - **Rostral obstructions demand *stronger inspiratory suction***
  - **This *negative/suction pressure* acts to collapse the extrathoracic trachea**
- **Dynamic collapse of the *intrathoracic* trachea**
  - **Rostral obstructions demand *stronger intrathoracic pressure* to expel air from the lungs**
  - **This *forced expiration* acts to compress the intrathoracic trachea.**

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Key Features of Respiratory Function

Upper Respiratory Tract (URT) – Clustering of Disorders

Note

The various nasopharyngeal, laryngeal-glottal and tracheal disorders may appear *individually* or in *clusters* of two or more specific problems

Each disorder, individually or clustered with others, *increases airflow resistance*

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Changes in Blood Gas Levels and pH

- PaO_2 reflects the balance of lung O_2 uptake and tissue O_2 use
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- **Chemoreceptors are located in the aortic arch, carotid bodies and medulla**
- ***Peripheral*** **chemoreceptors detect changes in PaO_2, $PaCO_2$ and pH**
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- *Peripheral* chemoreceptors detect changes in PaO_2, $PaCO_2$ and pH
- *Medullary* chemoreceptors detect changes in only $PaCO_2$ and pH
- ***Strenuous exercise*** **in high performance horses leads to hypoxaemia, hypercapnia and acidaemia**
- **These conditions in various combinations stimulate the chemoreceptors**
- **This chemoreceptor stimulation drives respiratory activity**

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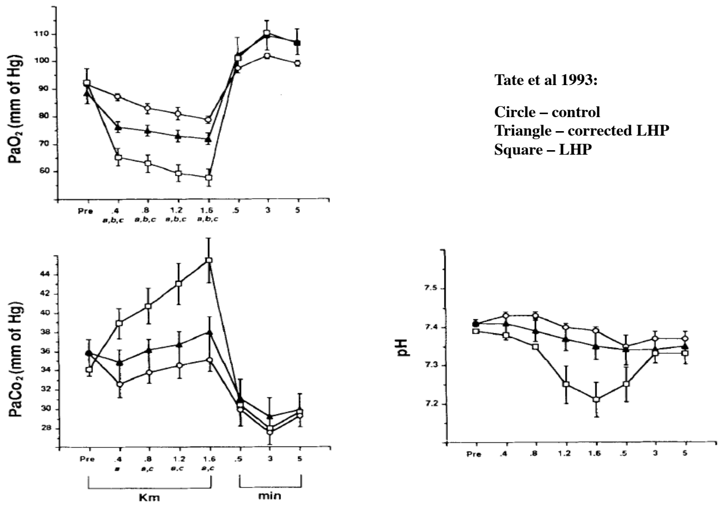
Key Features of Respiratory Function

Changes in Blood Gas Levels and pH during exercise



Key Features of Respiratory Function

Changes in Blood Gas Levels and pH

- **The exercise-induced hypoxaemia is likely due to:**
  1. **High cardiac output *reducing alveolar capillary transit time* and thus impairing gas diffusion**
  2. **Very low PO_2 in blood entering the lungs, representing *very marked degrees of O_2 desaturation* that cannot be corrected in *a single transit***
  3. **The maximum breathing capacity being inadequate due to limitations on *peak tidal volume* and the *breathing rate being locked 1:1 with stride frequency* in galloping horses**

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- ***Recovery***: **hypoxaemia & hypercapnia *corrected by 2-3 min after exercise***
  - **Hypoxaemia to normoxaemia**
  - **The hypercapnia to hypocapnia due to CO_2 'washout'**
  - **Restoration of normal blood pH takes longer**

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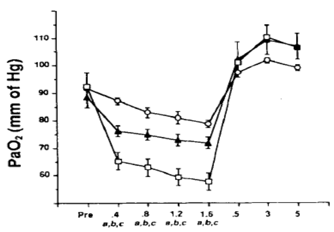
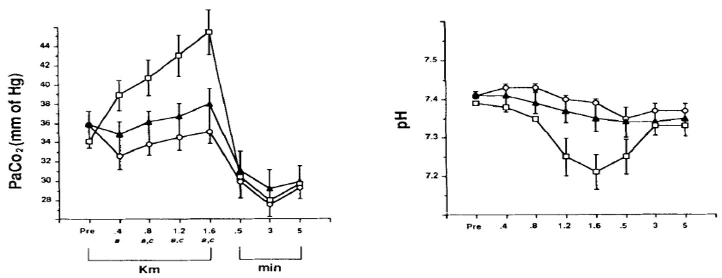
Key Features of Respiratory Function

Changes in Blood Gas Levels and pH after exercise



Tate et al 1993:

Circle – control
Triangle – corrected LHP
Square – LHP



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  - Hypoxaemia to normoxaemia
  - The hypercapnia to hypocapnia due to CO_2 'washout'
  - Restoration of normal blood pH takes longer
- **URT pathophysiology leads to *earlier onset* and *worse* hypoxaemia, hypercapnia and acidaemia in galloping horses**

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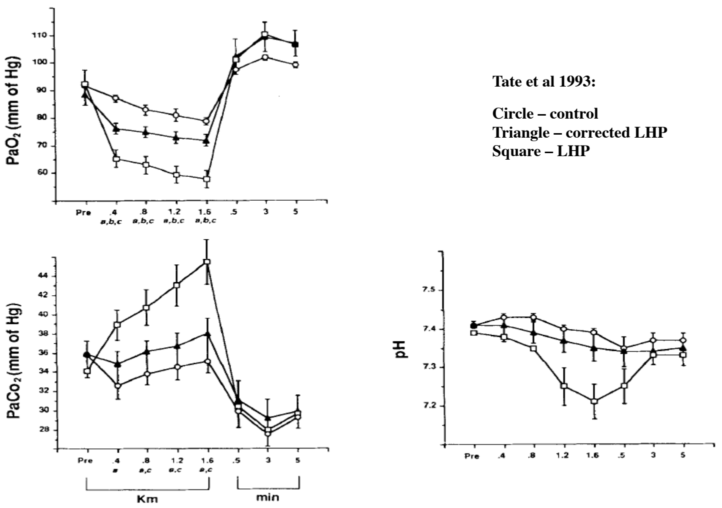
Key Features of Respiratory Function

Changes in Blood Gas Levels and pH – URT pathophysiology



Tate et al 1993:

Circle – control
Triangle – corrected LHP
Square – LHP

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Areas considered

- High performance horses as supreme athletes
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- **Key features of respiratory function**
  - Upper respiratory tract (URT) – Nasopharyngeal disorders
  - Changes in blood gas levels and pH
  - Lower respiratory tract (LRT) disorders – e.g. EIPH (NPPO, IAD)
- "Breathlessness" and its three types
  - Key Factors
  - Respiratory effort and high airflow resistance
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  - Chest tightness and LRT inflammation (equine asthma)
- Concluding comments

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Key Features of Respiratory Function

Lower respiratory tract (LRT) disorders – EIPH

- **Exercise-Induced Pulmonary Haemorrhage (EIPH)**
  - ***Observed*** **in 70-90%** ***of strenuously exercised horses – severity score 1-4***
  - **Poor athletic performance, i.e. 'exercise intolerance',** ***with scores 3-4***
  - **The** ***ultimate cause*** **is still discussed**
  - ***EIPH is exacerbated or precipitated*** **by high URT airflow resistance**

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  - *EIPH is exacerbated or precipitated* by high URT airflow resistance
  - **The *proximate cause:***
    - ***Markedly negative* intra-alveolar air pressure, *combined with***
    - ***Markedly elevated* alveolar capillary pressure, *leads to***
    - **Transmural pressure *to exceed* the *capillary wall tensile strength***
  - ***Capillary wall ruptures* - bleeding into alveoli, bronchioles and bronchi**

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  - **Impact on *degree of hypoxaemia, hypercapnia and acidaemia* unknown**
  - **Seems likely in markedly affected horses**

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  - Seems likely in markedly affected horses
  - **Extensive and characteristic *pulmonary lesions are apparent***
  - ***EIPH is progressive* and related to the *load of racing***

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Key Features of Respiratory Function

Lower respiratory tract (LRT) disorders – NPPO and IAD

- **Negative Pressure Pulmonary Oedema (NPPO)**
  - ***Develops within 1h of complete or very severe upper airway obstruction***
  - ***Results in very marked increases in negative airflow resistance***
  - ***Precipitates marked increases in alveolar transmural pressure***

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  - ***Very severe DDSP and/or pharyngeal collapse might cause NPPO***
  - ***Such NPPO-like effects* might contribute to *cumulative EIPH effects***

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  - *Such NPPO-like effects* might contribute to *cumulative EIPH effects*
- **Inflammatory Airway Disease (IAD) – Equine Asthma**
  - ***Chronic inflammatory dysfunction*** **of the LRT**
  - **Irritant hypersensitivity / bronchoconstriction / mucus accumulation**
  - **Increases *expiratory airflow resistance / impedes gas exchange in lungs***
  - **Causes *exercise intolerance***

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"Breathlessness" and its Three Types

Key Factors

- **"Breathlessness"**
  - ***Negative affective experiences*** **associated with** ***inadequate respiration:***
    i.e. when ***heightened ventilatory drive*** **is not matched by** ***respiratory response***
  - **In** ***humans*** **these** ***subjective experiences*** **are called** ***"dyspnoea"***
  - **In** ***animals*** **called** ***"difficult or laboured breathing"*** ***i.e. what it looks like***

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- **The** ***neural foundations of breathlessness*** **are well understood:**
  i.e. the related affective neuroscience **or brain processing**
  - **Breathlessness occurs when the** ***total command (voluntary + automatic) to breathe*** **is greater than the** ***respiratory response:***
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    - ***Automatic command via the medullary respiratory nuclei via motor nerves***

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    - *Voluntary command via the motor cortex*
    - *Automatic command via the medullary respiratory nuclei via motor nerves*
  - ***Related sensory (feedback) inputs* are also well understood:**
    - ***Respiratory muscles* – stretch plus metaboreceptors**
    - ***Chest wall and lungs* - stretch**
    - ***Chemoreceptors* – aortic arch, carotid body, brainstem**

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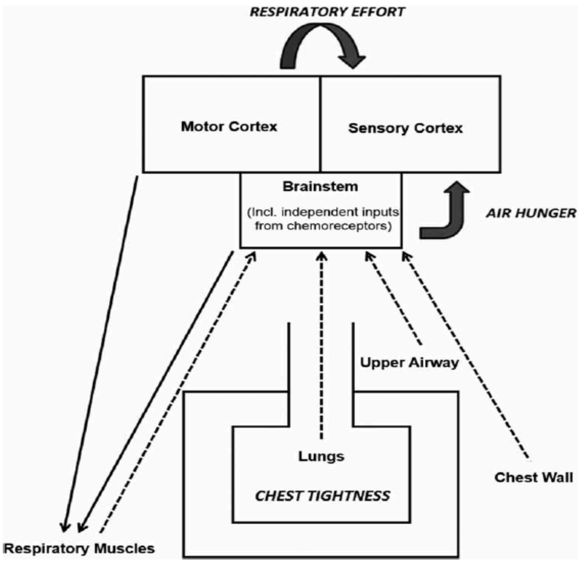
"Breathlessness" and its Three Types



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"Breathlessness" and its Three Types

Respiratory Effort and *High Airflow Resistance*

- **Respiratory effort (RE) or *"work of breathing"* may be *non-aversive* or *unpleasant:***
  - ***Unpleasant* when the *respiratory response does NOT match ventilatory drive***
  - **This is more likely the *higher the required level of exercise***

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- **Some conditions *increase airflow resistance* and likely lead to *unpleasant RE*:**
  - ***Reductions in jowl angle* that *partially obstruct the nasopharynx* and *disproportionately* increase airflow resistance – Rollkur is an extreme**

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  - ***Pathophysiological conditions also obstruct the URT and LRT:***
    - ***Soft palate* – instability (ballooning); dorsal displacement**
    - ***Pharyngeal collapse* – grades 1-4**
    - ***Laryngeal collapse* – hemiplegia, hemiparesis**
    - ***Tracheal collapse* – extrathoracic and intrathoracic**
    - ***Exercise Induce Pulmonary Haemorrhage* (EIPH) – grades 3 and 4**

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    - *Exercise Induce Pulmonary Haemorrhage* (EIPH) – grades 3 and 4
- These conditions often also *decrease alveolar gas exchange*
  - Because the *volume of air breathed per minute* decreases
  - And this leads to *hypoxaemia, hypercapnia and acidaemia*

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"Breathlessness" and its Three Types

Air Hunger* and the *Chemoreceptor-Induced Drive to Breathe

- **Air hunger – *"shortness of breath", "smothering", "suffocation":***
  - **Occurs with an *increased chemoreceptor-induced drive to* breathe AND**
  - **When the *ventilatory drive and respiratory response* are MISMATCHED;**
  - **And MADE WORSE the *higher is the required level of exercise***

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  - **And MADE WORSE the *higher is the required level of exercise***
- **Exercise-induced *hypoxaemia, hypercapnia and acidaemia:***
  - **Detected by *peripheral* (AA, CB) and *central* (M) *chemoreceptors***
  - **Reflects *inadequate alveolar respiratory gas exchange*;**
  - **MADE WORSE by *URT and LRT pathophysiological obstructions:***

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"Breathlessness" and its Three Types

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  - Detected by *peripheral* (AA, CB) and *central* (M) *chemoreceptors*
  - Reflects *inadequate alveolar respiratory gas exchange*;
  - MADE WORSE by *URT and LRT pathophysiological obstructions:*
- **Air hunger likely in *"exercise intolerant"* racehorses – linked to:**
  - **Low jowl angles**
  - **Soft palate problems (PI, DDSP); pharyngeal, laryngeal, tracheal collapse**
  - **EIPH; equine asthma (IAD)**
- **Situation is *unknown* in *healthy racehorses* with *unimpeded performance***

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"Breathlessness" and its Three Types

Simultaneous Occurrence of Two Types

- *Low-to-very low jowl angles* **OR**
- *URT and LRT pathophysiological obstructive conditions:*
  - *Soft palate* – **instability (ballooning); dorsal displacement**
  - **Pharyngeal collapse – grades 1-4**
  - **Laryngeal collapse – hemiplegia, hemiparesis**
  - **Tracheal collapse – extrathoracic and intrathoracic**
  - **Exercise Induce Pulmonary Haemorrhage (EIPH) – grades 3 and 4**
- **OR** *low jowl angle* **PLUS one or more** *pathophysiological conditions*:

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"Breathlessness" and its Three Types

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  - **Exercise Induce Pulmonary Haemorrhage (EIPH) – grades 3 and 4**
- **OR** *low jowl angle* **PLUS one or more** *pathophysiological conditions*:

  - *Increase* **airflow resistance and thus** *unpleasant respiratory effort*
  - *Decrease* **respiratory minute volume and thus** *alveolar gas exchange*
  - *Increase* **the degrees of** *hypoxaemia, hypercapnia and acidaemia*
  - *Increase* **chemoreceptor drive to breathe and thus** *air hunger*

  - **BOTH** *unpleasant respiratory effort* **AND** *air hunger* **likely to be experienced**
  - *Higher exercise levels* **will increase** *the negative intensity of these experiences*

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"Breathlessness" and its Three Types

Chest Tightness and *LRT Inflammation* (*Equine Asthma*)

- *Chronic inflammatory dysfunction* **of the** ***lower respiratory tract*** **(LRT)**
  - **Irritant hypersensitivity / bronchoconstriction / mucus accumulation**
  - **Increases** ***expiratory airflow resistance / impedes gas exchange in lungs***
  - **May cause marked** ***hypoxaemia, hypercapnia and acidaemia***
  - ***Chest tightness*** **likely accompanied by** ***air hunger***
  - **Affected racehorses exhibit** ***exercise intolerance***

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Concluding Comments

- **High performance horses are elite athletes:**
  - **At *maximum speed* they operate at their *full cardio-respiratory capacity***
  - ***Compromised breathing* leads to '*exercise intolerance*', especially at *speed***

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- **High performance horses are elite athletes:**
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  - ***Compromised breathing* leads to '*exercise intolerance*', especially at *speed***
- **Partial obstruction of the URT compromises breathing:**
  - ***Physical* obstruction – Low jowl angles imposed by rein use**
  - ***Pathophysiological* obstruction – e.g. PI, DDSP, PC, LH, TC**
  - **The compromise is *magnified* when *both occur together***
  - **Each causes high *airflow resistance* ➔ impedes *maximum airflow* ➔ reduces *alveolar gas exchange* ➔ leads to *hypoxaemia, hypercapnia and/or acidaemia***

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  - **Each causes high *airflow resistance* ➔ impedes *maximum airflow* ➔ reduces *alveolar gas exchange* ➔ leads to *hypoxaemia, hypercapnia and/or acidaemia***
- **Breathlessness:**
  - ***Unpleasant* respiratory sensations occur when *respiratory responses* do not meet the *total command to breathe***
  - ***Respiratory effort* aligns with *airflow resistance***
  - ***Air hunger* aligns with the *chemical drive to breathe:* PaO_2, $PaCO_2$, pH**
  - ***Chest tightness* – bronchoconstriction due to irritant hypersensitivity (asthma)**

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Concluding Comments - continued

- **High performance horses *at speed*:**
  - **It is NOT known if *exercise tolerant*, *healthy* horses that are *unencumbered* by *low jowl angles* and/or URT *pathophysiology* experience *breathlessness***
  - **It is LIKELY that, in the *absence of pathophysiology*, the *intensity of any breathlessness* experienced would *rapidly decrease once exercise ceases***
  - **BUT *exercise intolerant* horses that do have URT *pathophysiology alone* or are ridden or driven with *low jowl angles* ARE *very likely* to experience both *unpleasant respiratory effort* and *air hunger***

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The likely prevalence and intensity of the different types of breathlessness represent significant animal welfare issues that merit further attention

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