Comparison of ventilation during exercise in horses wearing half- and full-face masks

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Submitted 14 May 2006: Accepted 18 May 2006 Research Paper

Abstract
Several studies have shown that the placement of a face mask on a horse can have effects on ventilation, gas exchange and the cardiovascular system during exercise. The aim of the present study was to determine if airflow and ventilation measured with the same ultrasonic flowmeters were different during exercise between horses wearing half- (HM) and full-face (FM) masks. Five clinically healthy Thoroughbred horses with no history of respiratory disease were studied in an unbalanced crossover design. They were exercised on a treadmill at speeds between 1.7 and 11 m s\(^{-1}\) on a 3\(^{\circ}\) incline wearing both masks. The following variables were recorded: peak inspired (PIF) and peak expired flow rates (PEF), inspiratory tidal volume (\(V_T\)), respiratory rate (\(f_R\)), inspiratory minute ventilation (\(V_E\)), inspiratory time (\(T_I\)), expiratory time (\(T_E\)), total breath time (\(T_T\)), end tidal oxygen (ETO2), end tidal carbon dioxide (ETCO2) and heart rate (HR). A mask by speed of exercise interaction term was not significant for any of the models. The PEF (mean difference 12.9 l s\(^{-1}\); lower and upper 95% CI 7.6 and 18.2 l s\(^{-1}\), respectively; \(P = 0.0001\)) and ETO2 (mean difference 0.77%; lower and upper 95% CI 0.48 and 1.00%, respectively; \(P = 0.0001\)) were significantly greater and ETCO2 was significantly lower (mean difference 2.1.3%; lower and upper 95% CI 2.0 and 0.7%, respectively; \(P = 0.0001\)) with the FM compared with the HM. There was also a trend for inspired \(V_E\) to be higher with the FM compared with the HM (mean difference 102 l min\(^{-1}\); lower and upper 95% CI 26 and 178 l min\(^{-1}\), respectively; non-significant). We conclude that the HM may impair ventilation in the horse during exercise compared with the FM, despite the latter having a greater deadspace.

Keywords: treadmill; Thoroughbred; flowmeters; ultrasonic; mask design

Introduction
Published studies by different groups have shown that the placement of a face mask on a horse can alter ventilatory, gas exchange and cardiovascular variables during exercise\(^{1,4}\). Furthermore, the effect on these variables can vary according to mask design and/or the resistance of the flow measuring device\(^{5,6}\). A number of different types of pneumotachometer have been used to measure respiratory airflow rates during exercise in horses, including conventional mask-mounted Fleisch pneumotachometers\(^{7,8}\), large-diameter screen pneumotachometers\(^{9}\), pneumotachometers based on force generated by airflow\(^{10,11}\) and ultrasonic flowmeters\(^{12-14}\). The advantage of the ultrasonic flowmeters is that these have a much lower resistance than conventional pneumotachometers\(^{14}\).

The system for measuring airflow in horses during intense exercise first described by Woakes et al.\(^{12}\) is different from most other systems in that the ultrasonic flowmeters are fitted to a half-face mask (HM), whereas most other systems have been based around a full-face mask (FM). It has previously been reported that leakage from the half-mask design of Woakes et al. was minimal\(^2\). This was investigated by
constructing a lower ‘under-tray’ that was fitted to
the face mask. Airflow through the lower half of
the mask, measured with a separate flowmeter when
the upper mask was in place and sealed to the face, was
reported to be only 3.6% of the flows measured by
the ultrasonic flowmeters attached to the upper
mask. Thus, it was concluded that the half-mask
design did not significantly underestimate ventilation
due to leakage. However, whereas the HM has the
advantage of a lower deadspace, the FM is tighter fit-
ing around the nostrils than most FM. We considered
the possibility that this may interfere with respiratory
airflow either by compression of the unsupported
soft tissue covering the nasomaxillary notch or by lim-
iting the movement of the nares.

The aim of the present study was to determine if air-
flow and ventilation measured with the same ultra-
sonic flowmeters were different during exercise
between horses wearing HM and FM.

Materials and methods

Animals

Five clinically healthy Thoroughbred horses (three
geldings, two mares; 7 ± 3 years of age; 475 ± 30 kg)
with no history of respiratory disease were used. The
horses were individually stabled on shredded paper
with daily access to pasture and fed ad libitum a
diet of haylage (Marksway Horsehage, Devon, UK),
mixed feed (Spellers Competition Mix, Spellers Special-
ity Feeds, Milton Keynes, UK) with 28 g supplemental
salt and water. All horses were vaccinated against influ-
enza and tetanus and wormed every 4 months. The
horses were exercised daily on a horsewalker for
at least 3 months prior to the start of the study. Four
weeks prior to the start of the study, the horses were
made to exercise for 2 min at 8 and 10 m s⁻¹ on a 3°
incline, three times a week.

Study design and experimental protocol

The study was approved by the Ethical Committee of
the Animal Health Trust. Each horse was studied on
two occasions in an unbalanced crossover design,
3 days apart. On each occasion, the horse was fitted
with either the standard Birmingham Research and
Development Ltd (BRDL) HM or a custom-made FM.
The fit of the mask was examined visually to confirm
that the flow outlets were aligned with and did not
obstruct the nostrils. The order of mask use was deter-
mined randomly and horses were exercised on a tread-
mill for 2-min walk at 1.7 m s⁻¹, 4-min trot at 3.7 m s⁻¹,
2-min canter at 8 m s⁻¹ and 2-min gallop at 11 m s⁻¹ on
a 3° incline. The horses then walked for 2 min at
1.7 m s⁻¹ on a 0° incline. Exercise was conducted in
an air-conditioned room (~20°C and 60% relative
humidity). Measurements of heart rate, ventilation
and respired gases were made during the last 30 s of
each speed.

Face masks

The BRDL HM (Fig. 1) has a deadspace of approxi-
mately 500 ml and a weight of 700 g and has been
described previously. A FM was constructed in the
author’s laboratory in fibreglass from a mould con-
structed from a head taken from the cadaver of a
530 kg Thoroughbred horse (Fig. 1). The deadspace
measured by water displacement was 1204 ml and
the weight was 733 g. An inflatable rubber tube was
used to seal the mask to the upper face and it was
secured to the head by a headpiece over the poll.

Data measurement and collection

Airflow was measured using ultrasonic flowmeters
(model FR-41eq, BRDL, Birmingham, UK). The align-
ment of the flowmeters in each mask was standardized
by marking both the mask and flowmeters. The ultra-
sonic path was set at an angle approximately +25°
from the horizontal when the mask was viewed from
the front. These marks can be seen on the grey fittings
that accept the flowmeters in the front view of the
BRDL mask in Fig 1. Respired gases (CO₂ and O₂) were
measured by respiratory mass spectrometry
(MGA2000, Clinical and Scientific Equipment, Biggin
Hill, Kent, UK). The sampling capillary of the mass spec-
trometer was inserted into the centre of the right flow-
meter through a small hole 2 cm distal to its opening.
Heart rate was obtained from an ECG recording by tele-
metry (LifeScope 8, Nihon Kohden, Brentford, UK). Ana-
logue outputs from the flowmeters, mass spectrometer
and ECG system were digitized at 500 Hz using the Po-
Ne-Mah data acquisition and analysis system (Gould, Hai-
nault, Essex, UK). Peak inspired (PIF) and peak expired
flowrates (PEF), inspiratory tidal volume (VT), respirat-
ory rate (fR), inspiratory minute ventilation (VE), inspira-
tory time (Ti), expiratory time (Te), total breath time
(TBt), end tidal oxygen (ETO₂), end tidal carbon
dioxide (ETCO₂) and heart rate (HR) were determined
by algorithms within the software. Inspiratory time to
total breath time (Ti/TBt) was calculated. Rectal tempera-
ture, ambient temperature, humidity and barometric
pressure were recorded prior to and 5 min following the
exercise test. VT and VE are expressed at BTPS.

Statistical analysis

The effect of mask was assessed using linear regression
models with exercise as a fixed categorical effect
(gallop was the referent category). The models were
built using a forward selection approach using PROC
GENMOD in SAS. Mask was included in the models if
it significantly improved model fit (likelihood ratio
test) or was significantly associated with the outcome (Wald test). Horse was also included in all models as a fixed effect to control for the clustering of observations within horse. Biologically meaningful two-way interaction terms were tested between the main effect variables. Model fit was checked by an examination of the residuals. The level of significance was set at $P \leq 0.004$ using Bonferroni’s correction for multiple comparisons ($0.05/k$ where $k$ is the number of comparisons $= 12$).

**Results**

Mean data for each variable for the FM and HM are shown in Table 1. The effect of exercise was significant and was included in all models. A mask by exercise interaction term was not significant for any of the models. Mask had a significant effect on four of the 12 variables, PEF, $V_E$, ETO$_2$ and ETCO$_2$ (Fig. 2). All levels of exercise were significant in all four models except for ETO$_2$, where canter was not significant. There was also a trend in the exercise effect with increasing exercise intensity, with the greatest difference being between walk and gallop. The PEF and ETO$_2$ were significantly greater and ETCO$_2$ was significantly lower with the FM compared with the HM. An examination of the residuals for these four models suggested an adequate fit to the data. For the remaining variables where mask was not included in the model, one can only conclude that, given the observed

![Fig. 1](image1.png)

**Fig. 1** Top, front, side and bottom/back views of the original BRDL half mask (upper panels) and the full mask (lower panels)

![Fig. 2](image2.png)

**Fig. 2** Peak expired flow (PEF), inspiratory minute ventilation and end tidal oxygen (ETO$_2$) and end tidal carbon dioxide (ETCO$_2$) in five Thoroughbred horses during treadmill exercise whilst wearing either a HM (open circles) or a FM (solid circles). Data are presented as mean ± SD
Table 1  Heart rate and respiratory variables in five Thoroughbred horses during treadmill exercise wearing either a HM or FM

<table>
<thead>
<tr>
<th></th>
<th>Walk 1.7 m s^{-1}</th>
<th>Trot 3.7 m s^{-1}</th>
<th>Canter 8 m s^{-1}</th>
<th>Gallop 11 m s^{-1}</th>
<th>Walk (Recovery) 1.7 m s^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HM</td>
<td>FM</td>
<td>HM</td>
<td>FM</td>
<td>HM</td>
</tr>
<tr>
<td>HR (b.p.m)</td>
<td>84 ± 26</td>
<td>82 ± 19</td>
<td>127 ± 20</td>
<td>125 ± 21</td>
<td>171 ± 18</td>
</tr>
<tr>
<td>PIF (l s^{-1})</td>
<td>20 ± 4</td>
<td>21 ± 4</td>
<td>36 ± 8</td>
<td>37 ± 5</td>
<td>63 ± 12</td>
</tr>
<tr>
<td>PEF (l s^{-1})</td>
<td>19 ± 2</td>
<td>28 ± 7</td>
<td>39 ± 9</td>
<td>52 ± 5</td>
<td>62 ± 15</td>
</tr>
<tr>
<td>V_{I} (l)</td>
<td>5.4 ± 1.1</td>
<td>5.3 ± 1.9</td>
<td>8.0 ± 3.2</td>
<td>8.7 ± 1.2</td>
<td>11.0 ± 1.6</td>
</tr>
<tr>
<td>V_{E} (l min^{-1})</td>
<td>324 ± 126</td>
<td>328 ± 104</td>
<td>626 ± 180</td>
<td>744 ± 123</td>
<td>1289 ± 191</td>
</tr>
<tr>
<td>f_{R} (b min^{-1})</td>
<td>59 ± 17</td>
<td>55 ± 22</td>
<td>87 ± 19</td>
<td>89 ± 20</td>
<td>117 ± 3</td>
</tr>
<tr>
<td>T_{I} (m s)</td>
<td>503 ± 64</td>
<td>465 ± 110</td>
<td>378 ± 86</td>
<td>380 ± 58</td>
<td>234 ± 39</td>
</tr>
<tr>
<td>T_{E} (m s)</td>
<td>323 ± 96</td>
<td>345 ± 108</td>
<td>364 ± 75</td>
<td>296 ± 64</td>
<td>256 ± 15</td>
</tr>
<tr>
<td>T_{R}/T_{I}</td>
<td>0.46 ± 0.09</td>
<td>0.42 ± 0.12</td>
<td>0.50 ± 0.03</td>
<td>0.49 ± 0.13</td>
<td>0.50 ± 0.02</td>
</tr>
<tr>
<td>ETO_{2} (%)</td>
<td>15.7 ± 0.6</td>
<td>16.5 ± 0.7</td>
<td>15.8 ± 0.3</td>
<td>16.4 ± 0.5</td>
<td>14.5 ± 0.9</td>
</tr>
<tr>
<td>ETCO_{2} (%)</td>
<td>4.4 ± 0.8</td>
<td>2.8 ± 1.3</td>
<td>4.7 ± 1.3</td>
<td>3.5 ± 1.4</td>
<td>6.2 ± 1.0</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. All exercise was conducted on a 3° incline apart from walking recovery (0°).
differences, there were not enough horses to show a statistically significant effect of mask. Although the $P$-value of 0.008 is close to the $P$-value of 0.004 (corrected for multiple comparisons) for the effect of mask on $V_E$, the wide confidence interval indicates a lack of power for this comparison.

**Discussion**

This study demonstrates that, even with a small number of horses and low power, there was a significant effect of a HM compared with a FM on PEF, ETO2 and ETCO2, and possibly $V_E$. The Bonferroni correction is a conservative approach and, with a larger group of horses, a true effect of mask on $V_E$ would probably be identified. The higher PEF with the FM indicates that the HM impeded ventilation. This interpretation is also supported by the finding that ETO2 was lower and ETCO2 was higher with the HM. In addition, this is despite the FM having a greater deadspace than the HM. Of the respiratory variables measured, PEF is the only true expired flow variable, as $V_T$ and $V_E$ were calculated from inspired flow. The performance of the BRDL FR-41eq ultrasonic flowmeter is more reliable on inspiration than expiration (Marlin, unpublished observations). This is most likely due to the fact that the ultrasound window does not cover the full cross-sectional area of the flowmeter. Thus, the assumption is that the window represents airflow in all parts of the tube, not just in the window itself. This is much more likely to be true for inspiration, when air is ‘pulled’ through the tube. On expiration, the flow is likely to be much more turbulent and chaotic. Hence, $V_T$ and $V_E$ are calculated from inspired ventilation, not expired.

The data for the HM from the present study are not inconsistent with the data obtained with this system and published previously$^2$. The negative effect of the HM on ventilation could have been due to a difference in the resistance of each mask. However, the same size and length of fittings were used in each mask to connect the flowmeters, so this would seem unlikely. Thus, we believe the negative effect of the HM on ventilation is most likely due to restriction of the movements of the nares and or the compression of the soft tissue covering the nasomaxillary notch.

In conclusion, the BRDL HM gave lower PEF and ETO2 and higher ETCO2 than a custom-made FM. We believe that these differences are physiologically as well as statistically significant. Thus, values for ventilation in horses measured with the BRDL system and reported in the literature may slightly underestimate true absolute ventilation.

**Acknowledgement**

The authors would like to thank William Henley for offering statistical advice.

**References**


