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Rebreathing in a subject wearing an integral crash helmet

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Abstract

The respired air of a volunteer was analysed while he was wearing a variety of integral crash helmets. Observations were made with and without a protective balaclava, bib or scarf, or both. Rebreathing occurred and the peak inspired oxygen tension fell as low as 16.0 kPa (120 mm Hg) with a minimum inspired carbon dioxide of 2.1 kPa (16.0 mm Hg).

Accessories worn or attached to the helmet which restrict airflow into the helmet should not be used. Attention should be paid to the "air conditioning" of helmets when worn with flameproof balaclavas and bibs.

Introduction

The value of protective headgear in reducing the incidence of head injuries in motorcycle and autosport racing accidents has been established.¹⁻³ The design of crash helmets was pioneered by neurosurgeons and other accident surgeons with head protection as the prime purpose. Schultz and Karlin in the USA have also argued the case for "full face" (integral) helmets.⁴

One of us (RD) observed that in a small number of motorcycle accidents a transient light-headedness or blackout may have preceded the accident and that in each of these cases, the victim was wearing an integral crash helmet with a scarf wrapped around his neck for protection against the cold. We therefore investigated the possibility that the wearing of integral crash helmets and accessories might lead to rebreathing.

Methods

The features of the helmets tested and accessories are illustrated in fig 1. All the helmets were of integral design and some incorporated a vented visor or vents. The Stadium Achilles was unique in that it incorporated an anti-misting device a "mouth cone" which resembled a full anaesthetic face mask (fig 1a). A motor racing driver may wear a flameproof balaclava and bib (e and f), and a motorcyclist

Helmets and accessories tested. (a) Achilles helmet made by Stadium Ltd, Caerphilly, Glamorgan (complies with BS 2495 integral design, incorporates anti-mist mask). (b) Bell Star made by Bell Helmets Inc, California (complies with BS 2495, no vents). (c) Jetstar JHP made by Griffin Helmets, Halesowen (complies with BS 2495, vented or non-vented visor). (d) RXM-1 made by Simpson Sports, Torrance, California (complies with Snell Foundation (USA) standard, flame filtration in nose piece). (e) Flameproof balaclava. (f) Bell Star helmet with protective balaclava and bib.

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Mean ($\pm$ SD) maximum inspired oxygen tensions and minimum inspired carbon dioxide tensions (kPa)

Helmet	Helmet alone		With scarf or bib			With balaclava and scarf or bib		
	Static	Fan	Static	Fan	Exercise	Static	Fan	Exercise
Stadium Achilles								
P ₁ O ₂	17.4 (0.1)	17.3 (0.2)	16.9 (0.1)†	17.2 (0.2)	17.8 (0.3)§			
P ₁ CO ₂	0.8 (0.1)	0.3 (0.1)*	1.0 (0.1)†	0.6 (0.2)	1.0 (0.3)			
Bell Star								
P ₁ O ₂	18.0 (0.1)	19.2 (0.1)*				16.0 (0.2)†	17.3 (0.2)*	16.8 (0.3)‡
P ₁ CO ₂	0.7 (0.1)	0.0*				2.1 (0.2)†	1.3 (0.2)*	1.4 (0.2)‡
Griffin Jetstar JHP (with vented visor)								
P ₁ O ₂	16.9 (0.4)	19.4 (0.1)*	17.1 (0.3)	17.8 (0.3)*				
P ₁ CO ₂	0.8 (0.2)	0.0*	1.3 (0.3)†	0.5 (0)*				
Griffin Jetstar JHP (non-vented visor)								
P ₁ O ₂	17.0 (0.4)	19.4 (0.1)*	17.1 (0.3)	17.8 (0.3)*				
P ₁ CO ₂	1.8 (0.1)	0.3 (0.1)*	1.7 (0.2)	0.8 (0.1)*				
Simpson RXM-1								
P ₁ O ₂	16.9 (0.1)	19.2 (0.1)*				17.2 (0.2)†	18.2 (0.1)*	17.5 (0.1)‡
P ₁ CO ₂	0.7 (0.1)	0.0*				1.3 (0.2)†	1.3 (0.2)*	1.4 (0.2)‡

Statistical significance $p = 0.001$ comparing *static with fan; †accessories with helmet only; ‡exercise with fan (with accessories); §exercise with fan (with scarf or bib).
Conversion: SI to traditional units—O₂ and CO₂: 1 kPa $\approx$ 7.5 mm Hg.

may improve his comfort and reduce draughts by wearing a knitted balaclava or head scarf around his neck. The helmets were tested incorporating these accessories.

Respiratory gases were analysed using a Medishield Multigas Medical Monitor MS2 with the tip of the analytical catheter fixed at the subject's nose in such a position to permit continuous breath-by-breath analysis of respired air. The instrument was calibrated using 5.6% carbon dioxide in nitrogen and room air and was accurate to $\pm 0.2\%$ oxygen (or carbon dioxide). The 90% response time of the whole system to a 5% step change in oxygen or carbon dioxide concentration was less than 100 ms. Repeat calibrations were done after each test. Tracings were taken of oxygen and carbon dioxide for alternating 30-second periods with the helmet visor up, and the results were recorded on a chart recorder. The visor was then closed and recordings were continued for three to five minutes after a stable state had been reached.

Each helmet was studied with and without the accessories appropriate for the particular helmet (balaclava, scarf, or bib) both in a static condition and with a fan providing an airflow over the helmet of 5 to 7.5 m/s (10–15 mph). Finally, tests were done on the subject during 10 minutes of exercise on a treadmill (speed 1.5 m/s with a 20° incline). The means (and standard deviations) were calculated from 10 peak (maximum) inspired oxygen tensions and 10 minimum carbon dioxide tensions. We then compared the differing conditions when the volunteer wore each helmet (see table).

Results

In normal use under static conditions (table) all helmets permitted some rebreathing. The P₁O₂ varied from 16.9 to 18.0 kPa (127–135 mm Hg) and the P₁CO₂ from 0.7 to 1.8 kPa (5.0 to 13.0 mm Hg). Tests using a fan showed that rebreathing was almost abolished, except with the Stadium Achilles. The addition of a scarf or bib significantly worsened rebreathing with the Stadium Achilles, but not with the Griffin Jetstar JHP (non-vented or vented). A fan produced a significant improvement in rebreathing except with the Stadium Achilles. When a balaclava, scarf, or bib was worn under static conditions there was a significant worsening of rebreathing with the Bell Star. Rebreathing lessened, however, with the Simpson RXM-1. Again the addition of the fan significantly lessened the rebreathing.

Exercise lessened rebreathing with all helmets compared with static values, probably due to deeper breathing and greater movement of gases in and around the helmet.

The Bell Star helmet (with balaclava and bib under static conditions) led to the lowest P₁O₂ (mean 16.0 kPa (120 mm Hg)) and highest P₁CO₂ (mean 2.1 kPa (16.0 mm Hg)) and was associated with a rise in ventilatory frequency to 26 per minute.

Discussion

The use of integral full-face crash helmets may lead to a rise in P₁CO₂ with a corresponding fall in P₁O₂. This is clear evidence of rebreathing. We are currently evaluating the effect of the

rebreathing in subjects by measuring arterial oxygen and carbon dioxide tensions and ventilation. The airflow of 5 to 7 m/s that we used may not reflect airflow over a helmet. On the open road it may be greater, or the effective design of fairing, cowl, or streamlining may minimise or even eliminate this flow of air.

As only the peak inspired oxygen tensions were measured the results overestimate the true mean inspiratory oxygen tension. Interference with visual discrimination, night vision, and a worsening of performance on complex psychomotor tests occur with inspired oxygen concentrations between 16% and 18%.^{5,6} Nevertheless, these effects have been seen at high altitude with subsequent hyperventilation, resulting in hypocapnia, and may not occur when hypercapnia is present. If these effects occur in riders or drivers wearing integral crash helmets there are extremely important implications for safety on the road and motor racing circuit.

Our results cannot be interpreted as condemning the use of crash helmets. The incidence of head injuries in Kansas rose by 70% when the law requiring compulsory wearing of helmets was repealed. The mortality in those not wearing crash helmets was increased threefold. The British Standards specifications for crash helmets^{7,8} state protective aspects of helmets' design: there is no consideration of helmet ventilation. We would recommend that motorcyclists should not wear anything that restricts airflow into the helmet. If flameproof balaclavas and bibs are to be worn we would recommend a "vented" helmet to minimise rebreathing. Attention must be given to improving the "air conditioning" of integral helmets with accessories as worn by racing drivers.

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