P. A. Brühwiler, R. Stämpfli, R. Huber,
M. Camenzind,
EMPA, St. Gallen, Switzerland

CO_2 and O_2 Concentrations in Integral Motorcycle Helmets: Cause for Alarm?

Abstract

The average CO_2 concentrations relevant to a motorcyclist wearing an integral helmet were measured twenty years ago and found to be alarmingly high. The present study examined gas concentrations typically inhaled by a motorcyclist. Average concentrations of CO_2 for persons (n=4) wearing integral motorcycle helmets were measured in the laboratory and the field to facilitate comparison to previous work, and similarly high average concentrations were found: above 2% when stationary, well below 1% for speeds of 50km/h or more. Detailed measurements of the time-dependent CO_2 concentrations during normal inhalation showed levels of about half of the corresponding average concentrations, including 1% at standstill, though higher concentrations (4% or more) are inhaled at the beginning of each breath. Opening the visor at standstill lowered the average inhaled concentration only to about 0.8%. The oxygen deficiency is equal to the CO_2 concentration, and could also contribute negatively to motorcyclist cognitive abilities.

Notation

RH relative humidity

Introduction

Motorcycle rider safety depends primarily on the cognitive faculties of the rider. A motorcycle is inherently unstable in comparison to a four-wheeled vehicle, and requires a much higher level of sustained alertness. Several studies have shown that in two-vehicle collisions involving motorcycles the other driver is found to be at fault in about 60% of the cases; commonly, other motorists overlook motorcycles and cause accidents by, e.g., turning in front of them. A motorcyclist is therefore in constant need of a high level of concentration and quick reactions, and any influence which could reduce the cognitive abilities of a motorcyclist is therefore cause for alarm.

Helmets reduce the level of injury sustained by riders involved in accidents. On the other hand, it is not always possible to establish that helmets do not contribute to accidents. For integral helmets, e.g., which completely encase the head, the visual field could be limited, and present standards address this problem. Questions of excess heat or exhaled CO_2 [1, 2] are, however, not yet covered in motorcycle helmet standards, and may pose a hazard [3, 4]. To the extent that exhaled CO_2 is retained in a helmet, a deficit of O_2 must also be considered, and these issues are the subject of this paper.

Equipment and Methods

The measurements of the gas concentrations in the helmet dead space were conducted in the following two phases: (1) the average CO_2 concentrations were studied in subject tests in the laboratory and in the field, and compared to values obtained with a headform; (2) the detailed time-dependent CO_2 and O_2 concentrations during each breathing cycle were recorded. Phase 1 served to establish a connection between laboratory and field tests, and Phase 2 to elucidate the inhaled gas concentrations in the helmet dead space under varying conditions.

Equipment

For Phase 1, a stationary and a portable device were employed. For subject tests, a battery-

Fig. 1: Headform used to measure CO_2 concentrations. Barely discernible is a hole to which the gas detector tube was connected, between nose and mouth opening

powered infrared sensor was chosen (OEM-NDIR Gassensor Serie EGC, Pewatron AG). With the stationary system (Jaeger Oxycon Alpha, ViaSys Healthcare GmbH), both CO_2 and O_2 concentrations could be measured simultaneously. In Phase 2, therefore, the Oxycon Alpha was used to record detailed time-dependent variations in both of these gases.

Methods

The laboratory tests in Phase 1 were carried out in a climate chamber at 20°C/65% RH. The headform or subject sat at the end of a small wind tunnel; further details and an illustration of these aspects are given elsewhere [5]. For the subject tests, only CO_2 was measured, and the inlet tube was taped to the upper lip so as to place the inlet at the middle of the lip. The helmeted subjects placed their heads in the middle of the wind flow, and wore typical motorcyclist clothing. Subjects were instructed to breathe through the mouth only, and remained at rest throughout the measurements. The headform was placed so as to simulate the position of the subjects. The inlet of the measurement tube was connected to the opening in the face between the nose and upper lip. Only the exhalation portion of the breathing cycle was simulated, using an artificial lung. To ensure that both the Oxycon and NDIR values agreed, headform data were taken with both. For Phase 2, a very short home-built mouthpiece (with virtually no additional dead space) was used, in order to measure the air entering and leaving the mouths of the subjects using the Oxycon, and nose-breathing was avoided. The O_2 concentration was measured simultaneously.

The field tests in Phase 1 were carried out during motorcycle trips by the same subjects, using the NDIR instrument and a similar measurement configuration. Breathing through the nose was permitted for these tests. The trip parameters (distance, speed, temperature, altitude, etc.) were also recorded, using a bicycle computer of model SPY 300H, SteiNamic. Motorcycle speed was equated with wind speed when comparing to laboratory measurements. Further details on the experiments are given elsewhere [4].

Results and Discussion

Average CO_2 Concentrations

A typical average headform result for the CO_2 concentration in one helmet is compared with a measurement using (n=4) human subjects in figure 2. The subject studies in the laboratory and field conditions yielded similar results, although the speeds used were not identical: “City traffic” was 36km/h (50km/h) and “Highway” was 62km/h (80km/h) for laboratory (field) measurements. The

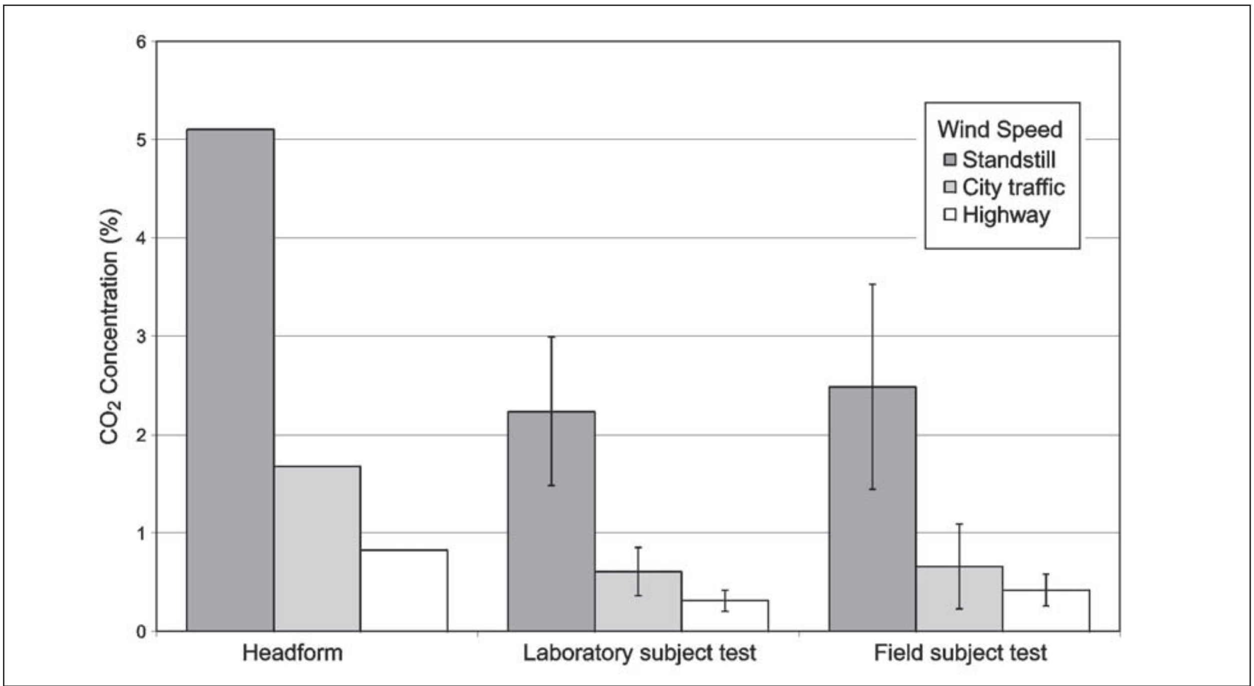

Fig. 2: Average CO_2 concentrations measured for the indicated subjects and wind speeds

good agreement shows that laboratory measurements as carried out here are directly relevant for motorcyclists in traffic. A similar variation with speed is found for all three measurement configurations, but the headform results are higher. The subject values are similar to those found by [1], though larger than those of [2], a difference previously explained as likely due to the subject clothing [2]. We tested this assumption by taking measurements without a scarf, and found that this indeed lowered the values to approach the results of [2]. One drawback of these measurements is that average values may not reflect the concentration of the gas actually inhaled by a helmet-wearer, since ventilation generally removes CO_2 and supplies O_2 before inhalation has taken place [6, 7]. The act of inhalation itself also brings fresh air into the deadspace.

Time-Dependence of the CO_2 and O_2 Concentrations

To check the effects of the helmet ventilation on the inhaled gas concentrations, the full breathing cycles of subjects in the laboratory were recorded in Phase 2. The results of one measurement are shown in detail in figure 3. In the upper figure, it is apparent that the CO_2 and O_2 concentrations are highly complementary, down to details of the pressure fluctuations. Hence we focused on the CO_2 concentrations, equating them to the O_2 concentration decreases.

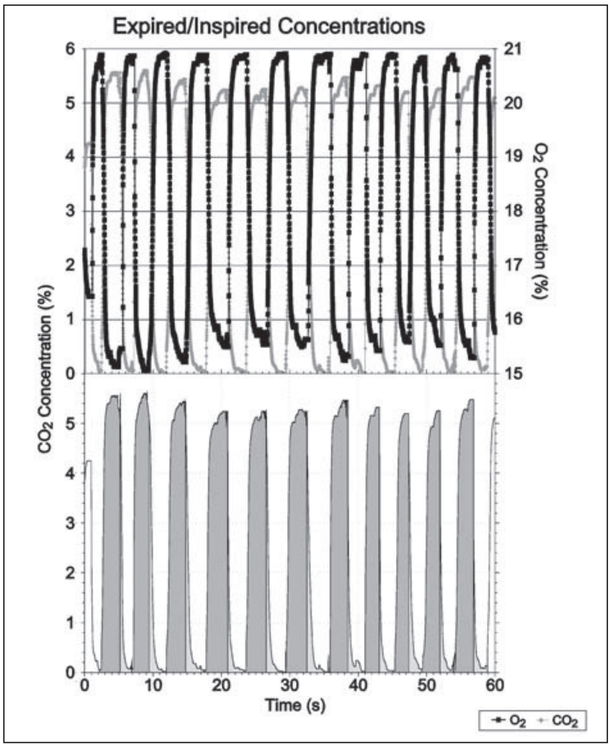

Fig. 3: Upper: Time-dependent concentrations of the indicated gases at the mouth of a subject wearing an integral helmet with visor closed and zero wind. Lower: The CO_2 concentration analyzed for exhalation and inhalation portions of the breathing cycle, as described in the text

The lower part of figure 3 shows the same CO_2 measurement, but now divided into exhalation (dark) and inhalation (light) portions of each breathing cycle. We could not directly measure the direction of breathing, but because the dead space of the mouthpiece employed was so small, the start of inhalation was associated with the decrease in CO_2 concentration, and was identified using a computer algorithm. The increase in CO_2 concentration associated with exhalation was similarly identified. To account for the fact that exhalation begins with the expulsion of gas from the body's dead space, which has the same concentration as was inhaled immediately prior, we chose an arbitrary offset of 0.3s before the concentration increase as shown, which appears to be reasonable from the data in figure 3 and other data, and is consistent with similar measurements done elsewhere [6]. Nevertheless, this introduces an uncertainty into the evaluated inhaled gas concentrations. These were evaluated by averaging the concentration in the inhalation portion of each cycle. Since the highest concentrations are inhaled first, and since the lowest concentrations (inhaled last) are to some extent not available for gas exchange due to the body's dead space, these average concentrations are not completely comparable to concentrations steadily supplied for breathing in other tests. A better measure of the effective inhaled concentration would require much more detailed analysis of the final gas distribution and exchange in the lungs, which is beyond the scope of the present work. Because of the large initial concentrations in each inhalation, a slight upward revision of the present concentrations from the Phase 2 measurements for comparison to constant value studies is probably reasonable. Table 1

Condition	Inhaled CO_2 Concentration (%)	
	Mean	σ
Without helmet	0.16	0.04
With helmet, visor open	0.77	0.21
With helmet, visor closed	1.08	0.27
With helmet, visor closed, scarf, wind (50km/h)	0.27	0.19

Tab. 1: Average inhaled CO_2 concentrations under the indicated test conditions for one subject. Similar results were obtained with other subjects

shows the present results for one subject, for which a series of breathing cycles were evaluated.

The results shown in table 1 are qualitatively consistent with those given in figure 2 and elsewhere [1, 2], but much lower. Putting a helmet on and keeping the visor open leads to inhaled CO_2 concentrations which slightly exceed the norm limits for workers exposed over periods of hours (0.5% in several countries). Closing the visor tends to raise the concentration even further. When moving at reasonable speed, however (visor closed), the concentration falls back towards the values for normal breathing. This matches with the experiences of many riders wearing integral helmets, who rarely experience breathing discomfort except when standing still. Thus, previous suggestions [2, 1] of values much higher than 1% are not supported by the present analysis. The complementary lowering of the oxygen concentration in the helmet dead space is therefore also at most about 1% (to about 20%) during inhalation, a level which lies well above the values at which strong physiological effects have been observed.

Typically, the maximum allowed concentration of CO_2 in workplaces is 0.5%. In addition, values of 1% are allowed for exposures of 15 minutes or less in Sweden, for example. The degree to which exposures as high as 1% or higher occur when wearing an integral helmet is unclear, since motorcyclists often raise their visors when stopped, which should bring the concentration below that level. Thus, it does not appear that the official safe levels of CO_2 are exceeded by motorcyclists. However, the effects of low concentrations of CO_2 (and lowered concentrations of O_2) on cognitive abilities relevant to the control of a motorcycle are unknown. Recent studies [8, 9] suggest that perception of motion and stereoacuity are noticeably reduced after short periods of exposure to 2.5% CO_2, and as reviewed elsewhere [4], other phenomena related to the good functioning of the brain are similarly sensitive on short timescales. Hence research directed specifically at the question of the physiological effects of wearing an integral helmet on the ability to control a motorcycle are required to understand whether such helmets contribute to the accident statistics.

Summary and Outlook

The present work has confirmed that both the CO_2 and O_2 concentrations deviate from the atmospheric ideal for the wearer of an integral helmet, especially at standstill, but with a maximum deviation of about 1%, i.e., to an extent below that previously reported. It remains to be established whether the short periods of exposure normally expected for a typical motorcyclist (e.g. when stopped at a traffic light) are enough to affect cognitive performance, and thereby contribute to the accident probability. In cooler weather, the drive to lift the visor when stopped can be reduced, suggesting that natural feedback mechanisms will not automatically eliminate the problem, and therefore that future work on the cognitive aspects of exposures at these levels is warranted.

References

[1] ALDMAN, B., BALLDIN, U., GUSTAFSSON, H., NYGREN, Å., SPORRONG, A., ÅSTRAND, I.: Carbon dioxide retention inside motorcycle helmets, IRCOBI, Salon-de-Provence (France), 1981, pp. 128-137

[2] IHO, L., JONASSON, H., PETERSSON, J.-I., STRIDH, G., LJUNG, C.: Measurement of aerodynamically generated noise and concentrations of carbon dioxide and oxygen in protective helmets for motorcycle riders, Report SP-RAPP 1980:31, Statens Provningsanstalt, Sweden, 1980

[3] CHINN, B., CANAPLE, B., DERLER, S., DOYLE, D., OTTE, D., SCHULLER, E., WILLINGER, R.: Final report of the action COST 327: Motorcycle safety helmets, European Commission, Directorate General for Energy and Transport, Brussels, 2003, pp. 44-53

[4] BRÜHWILER, P. A., STÄMPFLI, R., HUBER, R., CAMENZIND, M.: CO_2 and O_2 Concentrations in Integral Motorcycle Helmets (submitted)

[5] BRÜHWILER, P. A.: Heated, Perspiring Manikin Headform for the Measurement of Headgear Ventilation Characteristics, Measurement Science and Technology, 14 (2003) 217-227

[6] MICHEL, E. L., SHARMA, H. S., HEYER, R. E.: Carbon Dioxide Build-up Characteristics in Spacesuits, Aerospace Medicine, 40 (1969) 827-829

[7] WARKANDER, D. E., LUNDGREN, C. E. G.: Dead Space in the Breathing Apparatus - Interaction with Ventilation, Ergonomics, 38 (1995) 1745-1758

[8] SUN, M., SUN, C. N., YANG, Y.: Effect of low-concentration CO_2 on stereoacuity and energy expenditure, Aviation Space and Environmental Medicine, 67 (1996) 34-39

[9] YANG, Y. D., SUN, C. N., SUN, M.: The effect of moderately increased CO_2 concentration on perception of coherent motion, Aviation Space and Environmental Medicine, 68 (1997) 187-191