Full-face snorkel masks increase the incidence of hypoxaemia and hypercapnia during simulated snorkelling compared to conventional snorkels

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Abstract
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Introduction: Air flow in full-face snorkel masks (FFSMs) should be unidirectional to prevent rebreathing of exhaled air. This study evaluated rebreathing and its consequences when using FFSMs compared to a conventional snorkel.
Methods: In a dry environment 20 participants wore three types of snorkel equipment in random order: Subea Easybreath FFSM; QingSong 180-degree panoramic FFSM; and a Beuchat Spy conventional snorkel (with nose clip), in three conditions: rest in a chair; light; and moderate intensity exercise on a cycle ergometer. Peripheral oxygen saturation, partial pressure of carbon dioxide (PCO_2) and oxygen (PO_2) in the end tidal gas and FFSM eye-pockets, respiratory rate, minute ventilation, were measured continuously. Experiments were discontinued if oxygen saturation dropped below 85%, or if end-tidal CO_2 exceeded 7.0 kPa.
Results: Experimental runs with the FFSMs had to be discontinued more often after exceeding 7.0 kPa end-tidal CO_2 compared to a conventional snorkel e.g., 18/40 (45%) versus 4/20 (20%) during light intensity exercise, and 9/22 (41%) versus 3/16 (19%) during moderate intensity exercise. Thirteen participants exhibited peripheral oxygen saturations below 95% (nine using FFSMs and four using the conventional snorkel) and five fell below 90% (four using FFSMs and one using the conventional snorkel). The PCO_2 and PO_2 in the eye-pockets of the FFSMs fluctuated and were significantly higher and lower respectively than in inspired gas, which indicated rebreathing in all FFSM wearers.
Conclusions: Use of FFSMs may result in rebreathing due to non-unidirectional flow, leading to hypercapnia and hypoxaemia.

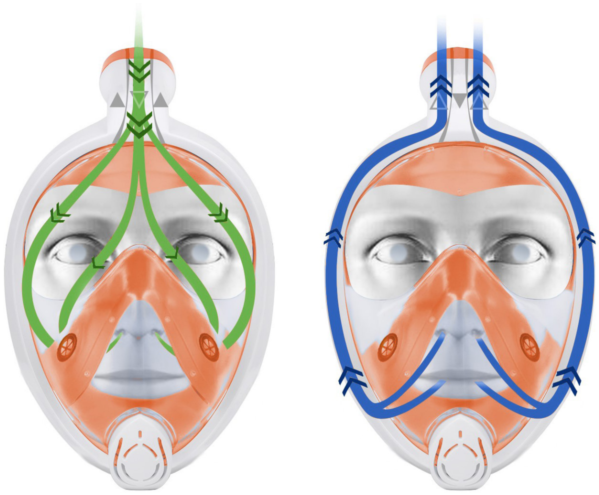
Introduction

Full-face snorkel masks are widely used, particularly by ‘tourist divers’ and were adopted as protective personal equipment during the COVID-19 pandemic. While these masks provide an ‘easier’ alternative to the traditional mask and snorkel combination, there are concerns about the potential for rebreathing exhaled gas high in carbon dioxide (CO_2). There have been several snorkelling accidents including fatalities associated with the use of full-face snorkel masks.[1–3] Accumulation of CO_2 in the mask resulting in hypercapnia is a possible contributor to these fatalities. Hypoxia may also be a contributing factor.

When breathing through a full-face snorkel mask, inhaled air is drawn down the snorkel, through the eye-pocket, and then into a sealed oronasal compartment through one-way valves designed to isolate the oronasal compartment from the eye-pocket during exhalation. When exhaling, the expired gas passes through another one-way valve and is expelled up the snorkel via a separate expiration channel (Figure 1). When the mask is functioning as intended, unidirectional air flow should occur, with no mixing of inhaled and exhaled gas. A ‘normal’ tube snorkel has a dead space of about 160 mL. The dead space in the oronasal compartment of a full-face snorkel mask is about 250 mL and can increase to up to 1,470 mL depending on the brand, if the seals or valves are not working properly.[4] A larger ‘equipment dead space’, effectively an extension of the anatomic dead space, results in more rebreathing of exhaled gas before breathing fresh air,[5] which may lead to hypercapnia or hypoxia. Hypercapnia can cause dizziness, shortness of breath, headaches, and loss

Figure 1

Schematic design of a full-face snorkel mask. Left: inhalation through the one-way valve in the snorkel through the eye-pocket and one-way valves into the oronasal pocket. Right: exhalation through separate tubes on the side from the oronasal pocket back to the snorkel, exiting through one-way valves in the snorkel (not mixing with inhaled air)



of consciousness, while hypoxia may cause confusion and ultimately loss of consciousness. These effects can be both distressing and dangerous while snorkelling.

One study has evaluated the partial pressure of CO_2 (PCO_2) in the oronasal pocket of a full-face snorkel mask.[6] Inspired PCO_2 levels of 1–2 kPa and increased breathing resistance with any water intrusion were recorded, however participants were able to maintain expired CO_2 levels of 4–6 kPa. Although no increase in respiratory rate was observed, tidal volume and minute ventilation were not measured. Minute ventilation usually increases with hypercapnia, but this may be achieved by a larger tidal volume rather than an increased respiratory rate.[7] Other papers typically involving small numbers of participants, examined adapted full-face snorkel mask for use as personal protection equipment against COVID-19,[4,8–11] or to ventilate patients with COVID-19.[12,13] The studies that measured CO_2 all noted an increase of inspired or expired CO_2 while wearing the full-face snorkel mask.[4,8,10,12,13] It is important to note that adaptations to those full-face snorkel masks by adding filters, may have influenced the gas flow dynamics. None of the existing studies have evaluated the gas composition in the eye-pocket during use.

The primary aim of this study was to evaluate oxygenation and CO_2 levels while wearing full-face snorkel masks or a conventional snorkel at rest, and during light and moderate exercise. We also evaluated the potential for rebreathing during use of these devices.

Methods

The study protocol was approved by the University of Auckland Human Participants Ethics Committee (Reference UAHPEC3497).

TRIAL DESIGN AND PARTICIPANTS

This was a randomised, intervention study conducted in the Exercise Physiology Laboratory at the University of Auckland during December 2020 and February 2021. Twenty healthy participants aged 18 to 60 years old were recruited. Participants were eligible when no health concerns were ticked on the Recreational Scuba Training Council screening questionnaire for diver training candidates. All participants provided written informed consent.

SNORKEL AND MEASUREMENT EQUIPMENT

Three items of snorkel equipment were tested: SUBEA Easybreath full-face snorkel mask (Decathlon, Lille, France); QingSong 180-degree panoramic full-face snorkel mask (QingSong, China); Beuchat Spy conventional snorkel. The SUBEA mask represents a recognised market leader in the full-face snorkel mask space, and the Qing-Song mask is more typical of cheaper products marketed on-line. Both full-face snorkel masks had two sampling lines ported, one to the eye-pocket and one to the oronasal compartment. The conventional snorkel had a sampling line ported approximately 5 cm from the mouthpiece. The sampling lines were connected to two respiratory gas analysers (ML206, AD Instruments, Dunedin, New Zealand), to measure the partial pressures of CO_2 and oxygen (PCO_2 and PO_2). Participants were fitted with an earlobe peripheral oxygen saturation sensor connected to an oximeter pod (AD Instruments, Dunedin, New Zealand), and an Equivital eqO_2 + LifeMonitor belt (Equivital, Cambridge, UK) to measure ECG and chest expansion.

Chest expansion was calibrated to measure minute ventilation using a pneumotachometer (MLT1000L, AD Instruments, Dunedin, New Zealand) during one minute of normal breathing while resting in a chair. The addition of a pneumotachometer to the full-face snorkel masks would have altered mask volumes and functionality. We therefore calculated minute ventilation based on chest expansion during the experiments.

All data were sampled continuously at 1 kHz using a Powerlab 16/35 and acquired via LabChart Pro data acquisition software version 8.1.24 (AD Instruments, Dunedin, New Zealand).

EXPERIMENTAL PROCEDURES

Participants performed spirometry (forced vital capacity [FVC] and forced expiratory volume in one second [FEV_1], from which the FEV_1/FVC ratio was calculated). All participants used all three types of snorkel equipment with the order of full-face snorkel mask type randomised. The Beuchat conventional snorkel was always last. Participants were fitted with the correct full-face snorkel mask size, based on distance between the top of their nose to the bottom of their chin. Mask fitting was tested by drawing negative pressure from the full-face snorkel mask while blocking the snorkel. Participants wore a nose clip whilst wearing the Beuchat conventional snorkel.

Participants underwent baseline measurements while resting in a chair and not wearing any snorkel equipment. Baseline values for gas composition in the eye-pocket were assumed equivalent to room air values since the eye-pocket should only contain atmospheric air if gas is flowing correctly.

Each item of snorkel equipment was tested for five minutes in three conditions (unless a safety threshold was breached): 1) rest in a chair; 2) light intensity exercise on a cycle ergometer at four metabolic equivalents (MET) to simulate slow finning; and 3) moderate intensity exercise at 6 MET to simulate swimming against a current. We determined a 5-minute duration to be long enough to achieve a steady state ventilation at the chosen workloads and therefore ensured participants experienced peak ventilatory rates and respiratory gas concentrations for each workload. Any experimental run was discontinued if peripheral oxygen saturation dropped below 85% or end-tidal CO_2 exceeded 7.0 kPa. Before the next type of snorkel equipment was tested participants rested until all parameters returned to baseline.

OUTCOME MEASURES

The primary endpoint measures were the proportion of participants with hypoxaemia below 95% and 90%, and the measured end-tidal CO_2 during the last 10 seconds of each condition.

Secondary outcome measures included end-tidal PO_2 in the oronasal compartment, PCO_2 and PO_2 in the eye-pocket of the mask late in exhalation, respiratory rate, calculated minute ventilation and heart rate averaged during the last 10 seconds of each condition. If the condition was discontinued early because of hypoxaemia below 85% or end-tidal CO_2 exceeded 7.0 kPa, time till discontinuation was noted.

While participants were wearing the full-face snorkel masks the seal of the internal skirt between the eye and oronasal pocket was classified as adequate (no visible gaps and no exhalation condensation) or inadequate (visible gaps or exhalation condensation). Participants were asked to describe their experiences with the snorkel equipment, immediately after removal.

STATISTICAL ANALYSIS

Descriptive statistics were generated to characterise study participants and reported as mean and standard deviation (SD). Normality of outcome measures was established with the Kolmogorov-Smirnov test. Differences between the different snorkel equipment were tested with a one-way ANOVA. Significant results were analysed with a post-hoc test with LSD correction. All tests were two-sided, with α set at 5%. Mean differences with their 95% confidence intervals (CI) are reported. All data were analysed using SPSS Statistics version 25.0 (IBM, Armonk, NY, USA).

Results

Participants were on average 33 years old (11.7), 14 of the 20 participants were female, average body mass index (BMI) was 24.3 $kg \cdot m^{-2}$ (4.1), and average FEV_1/FVC was 0.79 (0.16). Nineteen identified as experienced snorkelers, one participant had used a full-face snorkel mask before. A range of ethnicities were reported being 13 European/New Zealand, three Chinese, two South-East Asians, one Brazilian, one North American. No participant had facial hair.

Participants who completed the whole experiment wore each item of snorkel equipment for a total of 15 minutes. Some experimental runs were discontinued prematurely because the safety threshold of 7.0 kPa end-tidal PCO_2 was exceeded (Table 1). No terminations occurred in the resting condition. During light intensity exercise 22 of 60 (36.7%) experimental runs were stopped prematurely, and these participants did not continue to moderate intensity exercise. During moderate intensity exercise another 12 of 38 (31.6%) experimental runs were stopped prematurely. Experimental runs where participants were wearing full-face snorkel masks had to be discontinued more often compared to wearing a conventional snorkel e.g., 18/40 (45%) versus 4/20 (20%) during light intensity exercise, and 9/22 (41%) versus 3/16 (19%) during moderate intensity exercise (Table 1 and Figure 2). This resulted in less total time in experimental runs using the full-face snorkel masks compared to the conventional snorkel (respectively 1.8 and 2.4 minutes shorter). Early termination in the full-face snorkel masks was usually associated with an inadequate seal of the internal skirt of the mask. Even with good external fit, the internal skirt did not always seal adequately for all facial types.

Although no condition was discontinued early because of hypoxaemia, 13 participants experienced hypoxaemia below 95% (five Subea full-face snorkel mask, four QingSong full-face snorkel mask, and four conventional snorkel). Of those, five experienced hypoxaemia below 90% (three Subea full-face snorkel mask, one QingSong full-face snorkel mask, and one conventional snorkel), with two participants

Table 1

Average values during baseline (no snorkel equipment), and during rest, light and moderate exercise during use of snorkel equipment; baseline (no snorkel equipment) values for the eye-pocket are environmental air values. FFSM – Full-face snorkel mask; PCO_2 – carbon dioxide partial pressure; PO_2 – oxygen partial pressure; P_ECO_2 – carbon dioxide pressure late in exhalation; P_EO_2 – oxygen pressure late in exhalation

Parameter	Equipment	Baseline	Rest	Light	Moderate
Started in condition (*n*)	FFSM Subea	20	20	20	12
	FFSM QingSong	20	20	20	10
	Snorkel	20	20	20	16
Discontinued (*n*)	FFSM Subea	0	0	8	5
	FFSM QingSong	0	0	10	4
	Snorkel	0	0	4	3
		Total	**Rest**	**Light**	**Moderate**
Time in each condition (min)	FFSM Subea	10.9 (0.8)	5 (0)	3.8 (0.4)	2.1 (0.5)
	FFSM QingSong	10.3 (0.8)	5 (0)	3.5 (0.4)	1.8 (0.5)
	Snorkel	12.7 (0.8)	5 (0)	4.3 (0.3)	3.4 (0.5)
		Baseline	**Rest**	**Light**	**Moderate**
Oxygen saturation (%)	FFSM Subea	99.8 (0.4)	99.9 (0.8)	99.3 (1)	98.9 (1.8)
	FFSM QingSong		100 (0.4)	98.5 (2.2)	97.9 (1.9)
	Snorkel		99.8 (0.7)	98 (3.2)	97.1 (3.3)
End-tidal PCO_2 oronasal pocket (kPa)	FFSM Subea	5.76 (0.37)	5.55 (0.51)	6.13 (0.25)	6.49 (0.5)
	FFSM QingSong		5.83 (0.32)	6.29 (0.36)	6.61 (0.61)
	Snorkel		5.69 (0.24)	5.84 (0.34)	5.81 (0.57)
End-tidal PO_2 oronasal pocket (kPa)	FFSM Subea	14.55 (1.29)	14.88 (0.92)	14.33 (0.5)	14.02 (1.1)
	FFSM QingSong		14.4 (0.73)	14.04 (0.45)	13.85 (1.1)
	Snorkel		14.79 (0.71)	14.42 (0.63)	14.83 (0.71)
P_ECO_2 eye-pocket (kPa)	FFSM Subea	0.03 (0.0)	3.13 (1.2)	2.61 (0.87)	2.62 (1.27)
	FFSM QingSong		3.14 (0.88)	3.48 (1.28)	3.75 (1.46)
P_EO_2 eye-pocket (kPa)	FFSM Subea	21.0 (0.0)	17.72 (1.33)	18.35 (1.1)	18.32 (1.55)
	FFSM QingSong		17.5 (0.96)	17 (1.19)	16.67 (1.51)
Respiratory rate (breaths·min^{-1})	FFSM Subea	12 (4.1)	15.4 (4.3)	18.4 (3.6)	19.4 (5.3)
	FFSM QingSong		15.3 (4.1)	21.6 (5.9)	22.9 (7)
	Snorkel		13.5 (3.9)	19.4 (3.4)	22.6 (4.9)
Minute ventilation (L.min^{-1})	FFSM Subea	18.4 (4.8)	23.9 (13.3)	35.4 (10.2)	42.8 (13.6)
	FFSM QingSong		23.7 (10.6)	36.8 (8.2)	38.4 (8.6)
	Snorkel		22.3 (12.5)	30.6 (11.6)	34.4 (9)
Heart rate (beats·min^{-1})	FFSM Subea	66.3 (14.1)	71.7 (13.5)	106.8 (14.5)	128.3 (27.4)
	FFSM QingSong		70.4 (19.2)	105.4 (23.9)	128.2 (28.4)
	Snorkel		76.9 (16.7)	112.8 (15.4)	141.3 (16.7)

Figure 2

Survival curve showing exercise termination while wearing each type of snorkel equipment; FFSM – Full-face snorkel mask

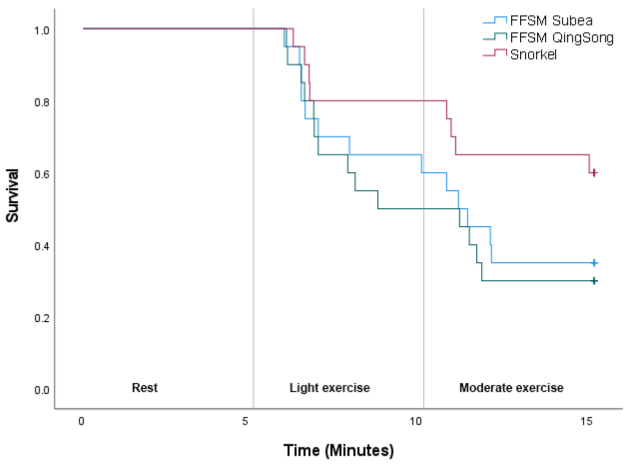


Figure 3

Typical inhale and exhale patterns in the eye-pocket and oronasal compartment of the full-face snorkel masks; the eye-pocket values should only be static lines representing atmospheric air (PCO_2 of 0.03 kPa and PO_2 of 21.0 kPa) if gas was flowing correctly (unidirectional flow). E_T – end tidal; PCO_2 – carbon dioxide partial pressure (kPa); PO_2 – oxygen partial pressure (kPa); s – seconds

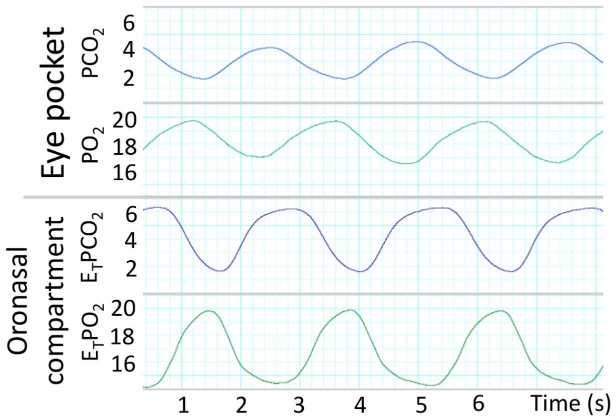


Table 2

Differences between full-face snorkel masks and the conventional snorkel. Overall differences were tested with a one-way ANOVA (overall P-value). Significant results were analysed with a post-hoc test with LSD correction and reported as mean difference (MD) with 95% confidence intervals (CI). Differences in the eye-pocket are comparisons between pressures of carbon dioxide and oxygen in the eye-pockets of the full-face snorkel mask and environmental air values. FFSM – Full-face snorkel mask; PCO_2 – carbon dioxide partial pressure; PO_2 – oxygen partial pressure; P_ECO_2 – CO_2 pressure late in exhalation; P_EO_2 – oxygen pressure late in exhalation

Parameter	Overall *P*-value	FFSM Subea		FFSM QingSong	
		MD (95% CI)	*P*-value	MD 95% CI	*P*-value
Time in each condition (min)	< 0.001	-1.8 (-3.0 to -0.5)	0.007	-2.4 (-3.7 to -1.1)	< 0.001
End-tidal PCO_2 (kPa)	0.004	0.3 (0.0 to 0.5)	0.019	0.4 (0.2 to 0.6)	0.001
End-tidal PO_2 (kPa)	0.024	-0.4 (-0.9 to 0.1)	0.092	-0.7 (-1.2 to -0.2)	0.007
P_ECO_2 eye-pocket (kPa)	< 0.001	3.2 (2.8 to 3.6)	< 0.001	3.8 (3.4 to 4.2)	< 0.001
P_EO_2 eye-pocket (kPa)	< 0.001	-3.4 (-3.9 to -2.9)	< 0.001	-4.5 (-4.9 to -4.0)	< 0.001

desaturating to 86% for half a minute after respectively 0.5 and 3.0 minutes of wearing the Subea full-face snorkel mask during light intensity exercise.

The end-tidal PCO_2 in the oronasal pocket of the Subea and QingSong full-face snorkel masks was significantly higher compared to the conventional snorkel (mean difference respectively, 0.3 kPa (95% CI 0.0 to 0.5) and 0.4 kPa (95% CI 0.2 to 0.6). The end-tidal PO_2 measured in the oronasal compartment of the QingSong full-face snorkel mask was significantly lower compared to the conventional snorkel (mean difference, 0.7 kPa [95% CI 0.2 to 1.2] [Table 2]).

In the full-face snorkel mask eye-pockets, the PCO_2 was higher, while the PO_2 was lower (both about 3 kPa) compared to atmospheric air in both full-face snorkel masks (Table 2). The PCO_2 and PO_2 in the full-face snorkel mask eye-pocket fluctuated with each inhalation and exhalation in all subjects, even where there was a seemingly adequate internal skirt fit (Figure 3).

There was no overall difference in hypoxaemia ($P = 0.528$), respiratory rate ($P = 0.201$), minute ventilation ($P = 0.451$) or heart rate ($P = 0.379$) between the different types of snorkel equipment.

Despite an excellent external fit of the mask, the internal skirt between eye-pocket and oronasal compartment did not always seal adequately as noted by either a gap between the skirt and the face or fogging in the eye-pocket. Seven participants had an inadequate internal seal between the pockets while wearing the Subea mask, and 11 had an inadequate seal while wearing the QingSong mask. The majority of those experiencing an inadequate seal were female (seven Subea, nine QingSong). All five participants of Chinese or South-East Asian ethnicity experienced an inadequate internal seal.

All participants reported a subjectively higher work of breathing during use of both full-face snorkel masks compared to a conventional snorkel (e.g., "*harder-*" or "*difficult to breathe*", "*more resistance*", "*takes more effort*"). Participants were divided in their rating of highest work of breathing when comparing both full-face snorkel masks (seven Subea, seven QingSong, six equal). Some participants expressed discomfort while wearing a full-face snorkel mask: e.g., hot on their face (two Subea, five QingSong, "*this is a sauna*"); claustrophobic (three Subea, one QingSong); headache (two Subea); lightheaded (two Subea); nauseous (one QingSong).

Discussion

We investigated the development of hypercapnia and hypoxaemia during rest and exercise whilst wearing full-face snorkel masks and a conventional snorkel. Thirteen participants experienced mild hypoxaemia, and our safety endpoint of 7.0 kPa end-tidal CO_2 was reached more frequently and earlier when wearing a full-face snorkel mask compared to a conventional snorkel. All participants experienced a significant increase in end-tidal CO_2 accompanied by a decrease in end-tidal oxygen in the oronasal compartment, compared to a conventional snorkel. We also measured a significant increase in PCO_2 and decrease in PO_2 in the eye-pocket of both full-face snorkel masks compared to atmospheric air. This latter finding suggests that the internal oronasal mask seal is not completely competent, and that rebreathing occurred when wearing these full-face snorkel masks.

Previous studies that measured CO_2 noted an increase in inspired and/or end-tidal fractions in participants while wearing a full-face snorkel mask.[4,6,8,10] Some authors argue that short term exposures to higher inspired CO_2 fractions are physiologically inconsequential. The British Standard for respiratory protective devices including full-face snorkel masks considers an inspired PCO_2 of 1 kPa the safe limit.[14] Most humans respond to an inspired PCO_2 of 1 kPa by subconsciously increasing their minute ventilation to maintain normocapnia, but from about 2 kPa onwards increased ventilation is perceptible.[7,15] This in turn may be uncomfortable for the wearer as indicated by the experiences of our participants that it was "*difficult to breathe*", "*more resistance*", or "*taking more effort*". Previous studies that have examined the subjective effects of wearing full-face snorkel masks have included similar reports of shortness of breath[9] and perceived discomfort according alongside higher inspiratory pressures.[4]

Rebreathing seems a common and undesirable consequence of using full-face snorkel masks.[6,8] Even when the full-face snorkel mask was used as a ventilation device on healthy volunteers, inspired PCO_2 increased up to about 3 kPa, while inspiratory PO_2 decreased.[12,13]

Two of the three existing studies assessing oxygen saturation did so in a non-continuous manner with long intervals.[10,11] If we had taken a similar approach instead of continuous monitoring, we might have failed to detect hypoxaemia in our participants, as the average values were similar in this study. We acknowledge that there is a form of survival bias in our study since we stopped multiple exposures due to high end-tidal CO_2. Perhaps if we had allowed hypercapnia to progress, the effect of lower inspired oxygen concentrations on hypoxaemia would have become more pronounced. Our results are in line with the other snorkelling simulation study,[6] although oxygen saturations were not measured in all their participants. They reported one participant with mild hypoxaemia (peripheral saturation 93%), who was a smaller female.

In our study we noted that females and participants of Chinese or Asian ethnicity more frequently experienced an inadequate oronasal seal, and subsequently rebreathed expired gas within the mask. This is consistent with a previous study in which participants with higher inspired PCO_2 and lower inspired PO_2 were all of Asian ethnicity.[8] Since facial size and proportion vary greatly by ethnicity and gender,[16] a three-size-fits-all approach to designing full-face snorkel masks may require reconsideration.

In theory, full-face snorkel masks are designed to produce unidirectional airflow. However, our measurements spanned the respiratory cycle in the eye-pocket for all participants, demonstrating failure of unidirectional flow. If the oronasal mask seal and one-way valves were truly competent, the gas in the eye-pocket should conform to the composition of inspired atmospheric air. Our findings suggest that this is not the case, and that exhaled gas mixes with incoming air resulting in rebreathing to various degrees. Even when there were no obvious signs of leakage through either the internal skirts or valves, such as fogging, lowered PO_2 and elevated PCO_2 in the eye-pocket were observed. The consequently larger dead space probably explains why full-face snorkel masks performed worse than conventional snorkels in this and the other snorkel study.[6] If this tendency to rebreathing is combined with a smaller tidal volume, as would be the case in children, a greater tendency to hypercapnia and hypoxia might be apparent. Tidal volume in small adults or children might not be sufficient to offset the effects of rebreathing and dead space (the latter which may be as large as 0.7 to 1.5 L in full-face snorkel masks).[4]

There are several limitations to this study which need to be acknowledged. Firstly, participants were predominately healthy, experienced divers. Considering most divers are familiar with breathing through regulators and snorkel equipment, it is possible that participants may have been more aware of, and able to control their breathing more confidently, maintaining normal tidal volumes and ventilation and experiencing less CO_2 accumulation, therefore performing better than novice snorkelers. This is largely speculation, but at the very least we need to acknowledge that our study cohort were not novice snorkelers who are the most frequent users of full-face snorkel masks. Similarly, our subjects were adults, and as discussed above, there are plausible reasons to believe that children might be more adversely affected by rebreathing in full-face snorkel masks. Second, snorkelers with underlying co-morbidities which may affect breathing, like asthma or chronic obstructive pulmonary disease, may influence the performance of full-face snorkel masks. Third, exercise was completed on a cycle ergometer rather than in water. While levels of exertion should be comparable, there was no hydrostatic pressure. It is possible that the negative static lung load associated with head-out immersion may reduce lung compliance, increase work of breathing, and negatively impact CO_2 sensitivity thus blunting the ventilatory response to rebreathing.[17] On the other hand, it is also possible that when submerged in water, the pressure on the mask might result in a better oronasal seal, possibly reducing airflow between the pockets. Fourth, we only tested two full-face snorkel mask brands, other brands may perform differently. However, no mask on the market takes into account all different facial types for a perfect internal skirt fit and all seem to use the same technology to create one-way valves. We therefore hypothesise that this is an issue applicable to more full-face snorkel mask brands than the two tested in our study. Lastly, we could not add a pneumotachometer to directly measure minute ventilation without altering the functionality of the full-face snorkel masks. We calculated minute ventilation indirectly from the measured chest expansion.

This study also had a number of strengths, including a head-to-head comparison of two full-face snorkel masks with a conventional snorkel, a relatively large sample size, a randomised order of the full-face snorkel masks, and measurements at rest, light intensity exercise (comparable to normal snorkelling) and moderate intensity exercise (comparable to fighting a current).

Conclusions

These results suggest that at least some full-face snorkel masks enhance the risk of hypercapnia and possibly hypoxia due to rebreathing arising primarily from communication between the eye and oronasal pockets. Manufacturers and future snorkelers should be made aware of this new information to prevent unsafe situations.

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