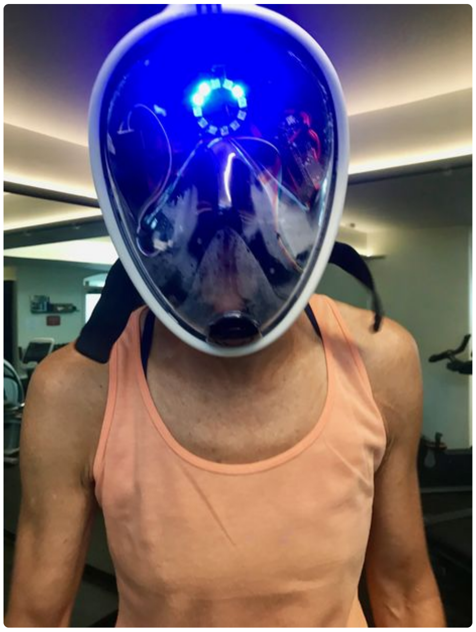
instructables

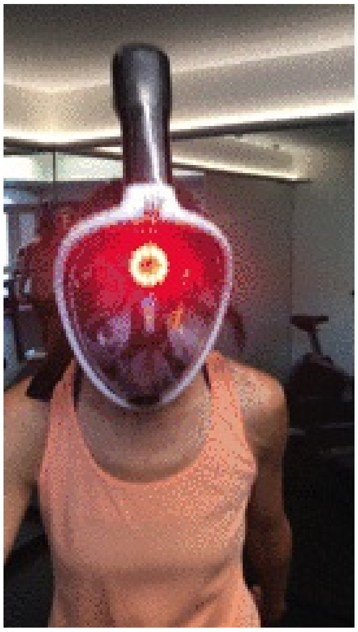
CO2 Measurement in Snorkels

by rabbitcreek

In Minnesota, where I grew up, the winter used to bring sudden deaths by snow shoveling and if I were back there I would be putting myself at risk. So here I stay on the beaches of Hawaii where older men have recently been found to be at risk from snorkeling. Many have expressed a concern that something in the design of some snorkels makes these deaths much more common than they should be. While waiting for the authorities to round up the usual suspects I decided to investigate CO2 levels in several snorkel designs.

I don't usually put a disclaimer on my Instructables but this is a rather volatile issue involving grieving people so I will say that I am not a scientist nor an epidemiologist just a tinkerer who builds things. For those of you that are on this site for the first time these Instructables are written not usually as scientific studies but to give people as much information on how to build things and that is the reason for this writeup. If you're not interested in this detail you can skip to the results page.





Step 1: Gather Materials

There are several devices for measuring CO_2 on the market for those that want to experiment. I am using a NDIR which uses an infrared light source in a tube for checking the concentration of CO_2 that enters it by absorption. It is sold by Sandbox Electronics--a wonderful place that provides an interface board for I2C hookup and a great set of software on Github to get you up and running. You will have to do some mild soldering to change the board from 5 volts I/O to 3 volts used on the feather board. The manufacturer of the sensor says its rated to +/-5% and it seems extremely sensitive. It is factory calibrated and good for 6 months and recalibration is done on the Sandbox board. There are three sensor levels--get the one rated to 50,000 PPM. The only expensive part is the sensor--about $67--the rest of the parts are about $30.

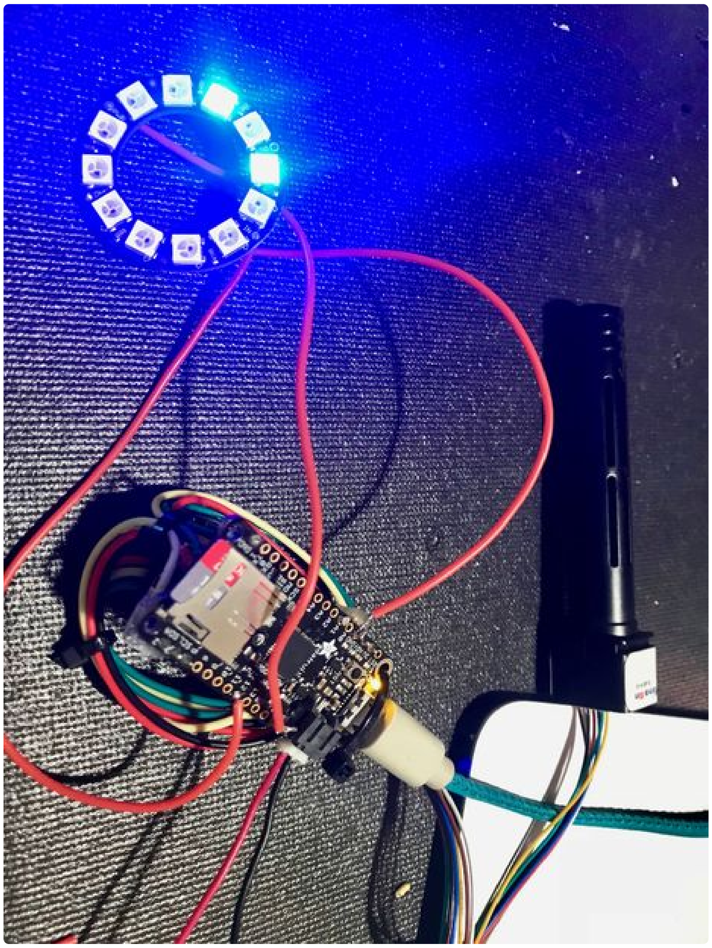
1. http://sandboxelectronics.com/?product=50000ppm-m...

2. Adafruit Feather 32u4 Adalogger--A wonderful board very easy to use.

3. NeoPixel Ring - 12 x 5050 RGB LED with Integrated Drivers

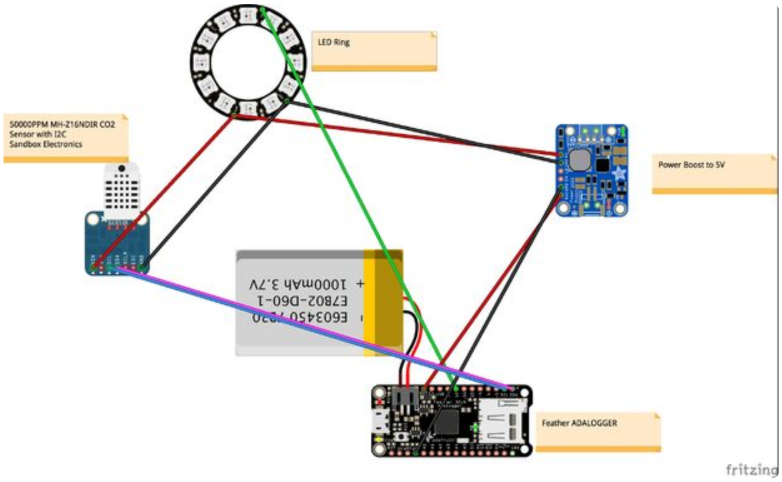
4. Lithium Ion Polymer Battery - 3.7v 1200mAh

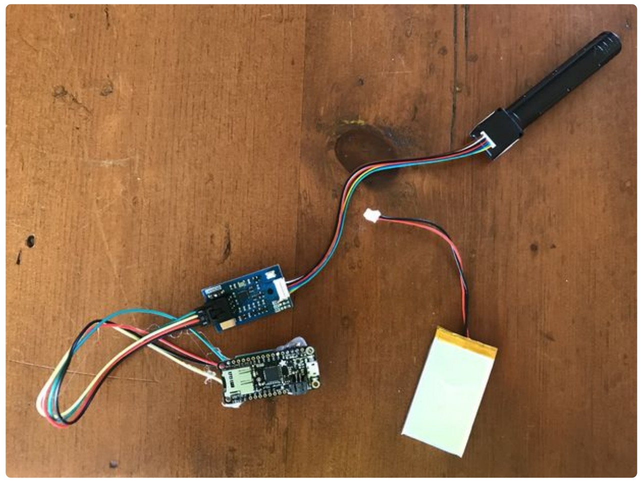
5. PowerBoost 1000 Basic - 5V USB Boost @ 1000mA from 1.8V+

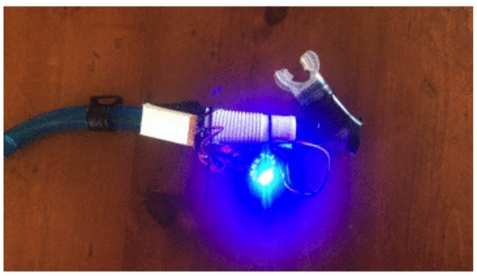


Step 2: Wire It

The wiring is very simple--just follow the Fritzing diagram. The I2C inputs on the Feather board should be pulled up to 3 volts as usual with small resistors. Follow Sandbox Electronics information for modifying their board for 3 volt sensors. You have to move the 0 ohm resistor over to change this on the board. Make sure your toggle switch on the board is set for I2C instead of Uart. The CO2 sensor module relies on 5 volts so that is the reason for the Boost board. The whole unit is put together in dead bug style because I was going to move the components between so many test chambers and I needed the sizing flexibility.







Step 3: Program It

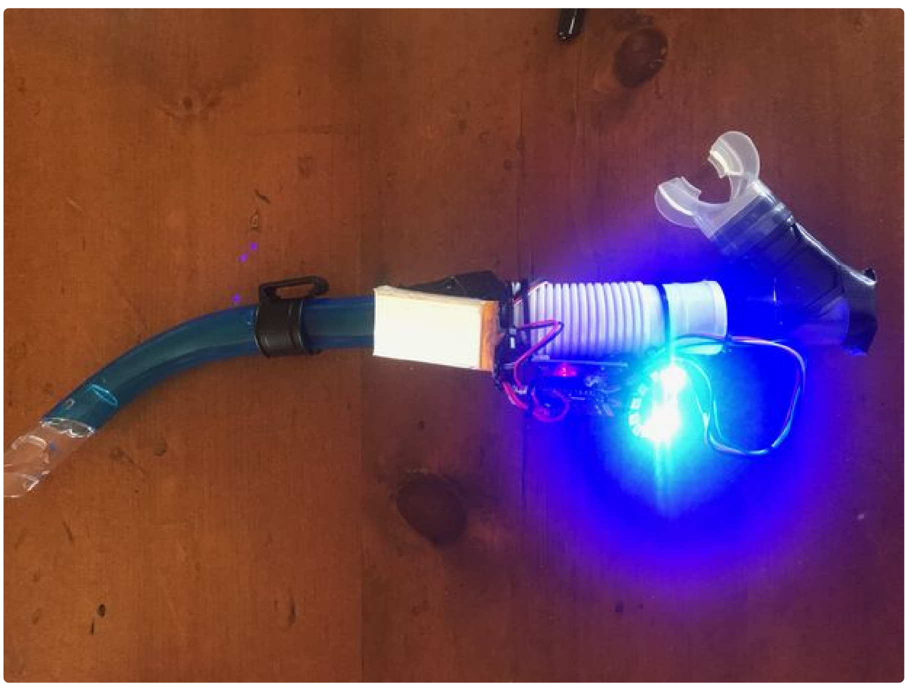
The program uses the example program from Sandbox as well as a basic data logging example from Adafruit for the Feather board. The additions I made were for a visual readout of CO2 levels on the instrument while we were doing the measurements. The ring of LED's has a spinning light that circuits the rings and changes color with upticks in the CO2 level. A level indicator light goes up or down clock style with the level. If CO2 is present at over 30,000 level the whole ring flashes red--this happened a lot. The sensor was queried once a second but this can be easily changed. The data logger builds a new numbered file each time the Feather is reset. The battery lasts for a long time in spite of the current demand of the sensor and logging board. At the close of each experiment the data file is ejected and loaded onto a laptop where Excel is used in the minimal data manipulation. Most of the graphs consist of CO2 levels on the Y axis and sensor readings in seconds on the X axis.

Step 4: Build It

It was easy to install the sensor as well as the various boards inside a full face mask using double sticky tape. The Sensor is about a 3 inch long tube that fits well in the lower part of the mask--outside of the inner mask area that is supposed to enclose your mouth and nose. This area in the full face mask that I am using does not seal completely and allows the entire inside of the mask to have continuous flow. But on the chance it offered some isolation we placed the sensor on the input side of the snorkel thinking that if it did function it would show much lower readings of CO2 there. These masks other than tightening in the back offer no other way to adjust them for different face types. The conventional snorkel was modified to accommodate the sensor by enclosing it in a plastic tube that did not diminish the flow diameter of the original snorkel. The electronics were secured on the outside of the tube. The sensor was placed as close to the mouthpiece as possible.

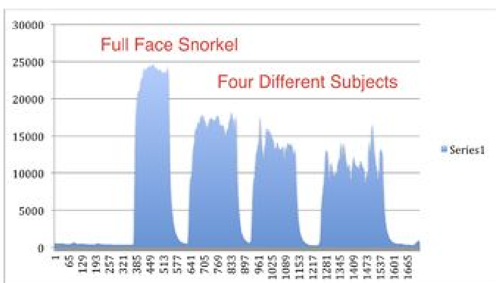
I was curious about measuring CO2 with variation in the design parameters of each type of snorkel. A series of conventional snorkels were built using very short to very long tubes retaining the original diameter of 3/4 inch opening. The full face snorkel design parameters were varied using a series of bowls whose volume varied from small to very large. A sealed cover on their top accommodated a mouthpiece and small ventilation tube. The sensor and electronics were placed inside the bowl. Both series of modified designs were tested three times at each size level and an average of CO2 measured was calculated.

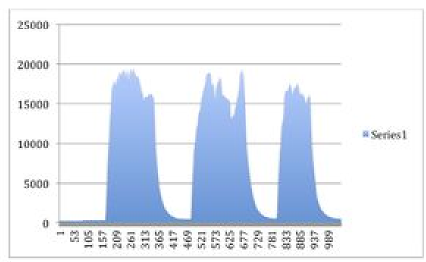




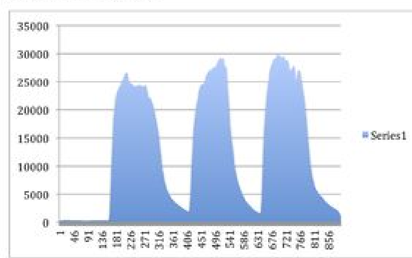

Step 5: How Snorkels Work

It seems obvious right? I will tell you I still don't understand the subject but let me give you some information anyway. The lungs contain about 6 liters of gas that it exchanges with the outside air in little bites of about 1/2 liter--really not much. Air you breath contains about 21% O2 very little CO2 (<0.05%) and the rest Nitrogen--inert gas. The air in your lungs contains about 4% CO2 and 17% O2--and anything connected to your lungs also is at this gas equilibrium--like a snorkel. The CO2 sensor measures the ebb and flow of mixed air from your lungs with the outside air--this equilibrates rather fast and the level of CO2 becomes dependent on several factors--some related to the design of the snorkel. In spite of what our President's nominated Chief Environmental Advisor says CO2 should probably not be considered "The Gas of Life!". The levels measured by the sensor are in PPM--10,000 PPM is 1%. The literature on how much CO2 is ok for you is vast. Much of the research has to do with submarines and spacesuits. But in each of these cases there is plenty of oxygen to go with it. In the snorkel it forms an inverse relationship--the more CO2 trapped the less O2 available. OSHA has a lot of standards for work levels of CO2 and you can look these up but I will summarize--its not good if you go over 3%. In our measurement environment the highest levels of CO2 you can get (and low O2) are when the sensor detects that the air your breathing in is the same as that which is already in your lungs....4% or 40,000 PPM. So all the graphs tend to max out at that level.

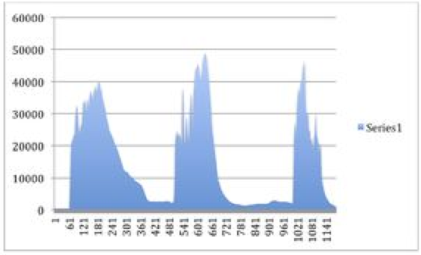




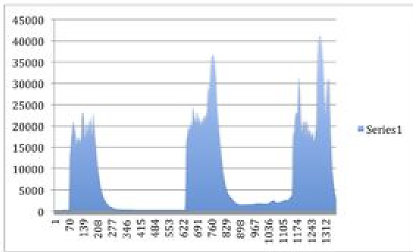
Full Face Snorkel 470 CC



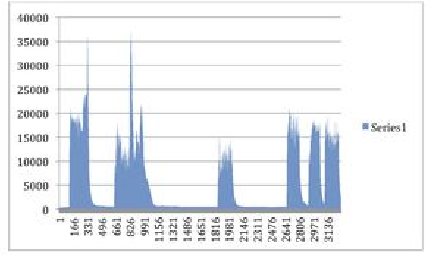
Full Face Snorkel 950 CC



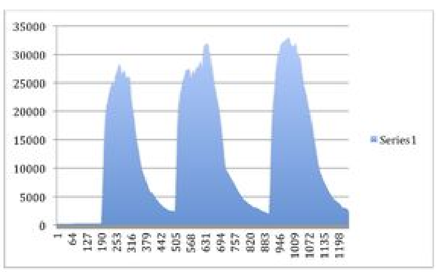
Conventional Snorkel 450 CC



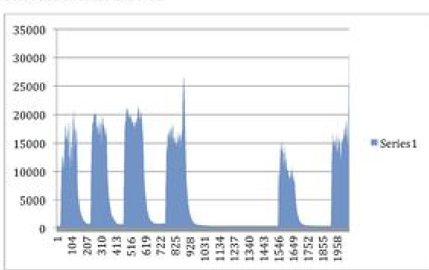
Conventional Snorkel 270 CC



Six trials with conventional 180 cc snorkel



Full Face Snorkel 1400 CC



Initial 3 Trials Conventional Snorkel 180 CC

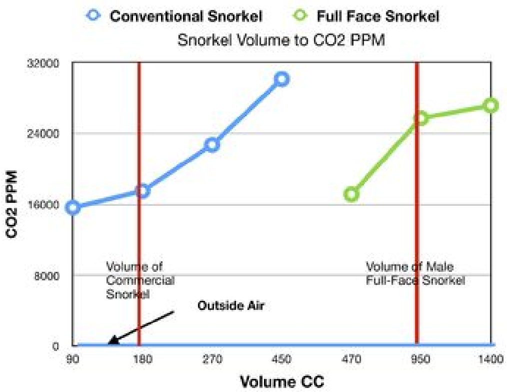
Next 3 Trials Conventional Snorkel 90 CC

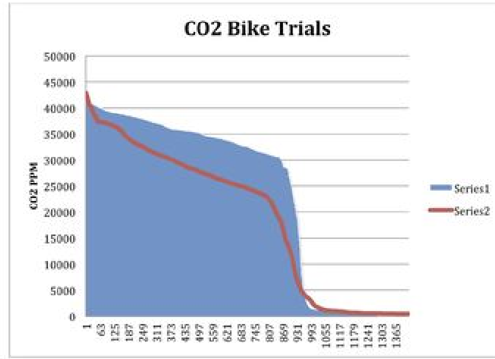
Step 6: Results

The design of snorkels both full face and conventional is dependent on "Dead Space" -- the area enclosed by a device between your mouth and the outside air source. Your respiration is a finely tuned machine that has evolved with sensors and feedback mechanisms that keep the most needed nutrient in the body (O_2) at a fixed level. Dead space screws with this: https://www.ncbi.nlm.nih.gov/pubmed/12740732. The volume in a conventional snorkel was measured by filling it with water and carefully measuring it: 180 cc. The full face snorkel is built so the dead space will vary with the physiognomy of the face wearing it. I filled the larger size mask with water and pushed my face into it and measured the resulting amount at about 900 cc my wife did the same with the smaller mask and got about 500 cc. Full face snorkels have attempted to eliminate this extra dead space inherent in their design by having an inner enclosure for the mouth and nose and a set of one-way air valves. Unfortunately this failed to seat properly in all of our trials allowing gas to move freely and form a very large dead space. The way this dead space is arranged is also important. CO_2 is heavier than air and so it sinks inside the space. Tubes have a way of trapping the CO_2 at the bottom and so you end up "backwashing" the contents of the tube with each breath rather than getting fresh air. The above graph which summarized the design change experiments bears this out. While the dead space in the conventional snorkel group varied from only 90 to 450 it basically maxed out with a four foot narrow tube sending the sensor to very high levels. (I was curious after this experiment about how giraffes breathe with their long snorkel neck--it seems that they have very little dead space and extremely large lungs to compensate). The full face snorkel mock ups had dead spaces of between 470 to 1400--much larger than the snorkel tube types but only went very high on the largest size--1400cc. I felt sick and lightheaded on both of these trials that resulted in the max values. Dead space in the two snorkel designs can be thought of as the difference between walking with friends who are smoking versus driving in a closed car with them.

The masks themselves were then tried with a variety of people. These trials were done in a sitting position and the person was asked just to "breath normally". The results of course varied but produced levels between 10,000 and 25,000 for both snorkels--there was no clear winner and no evidence of dangerous levels at rest.

Under aerobic stress however, interesting things began to happen. A bike course of around 1.5 miles with one large hill going up 175 feet was done with each snorkel in place. As you can see from the graph very high readings were recorded with both masks but the full-face mask showed maximum CO_2 levels consistent with unmixed exhalation air. This progressively increased with the ride until it plateaued. The conventional snorkel showed a sawtooth pattern which was more consistent with mixing of air. I nearly passed out with the full-face mask on this trial and had to take it off at the top of the hill. I didn't feel very good with the conventional snorkel either but was able to finish the test. My wife got on the treadmill for 5 min with each mask running/walking at a easy 4 mph clip. She felt fine for each but her CO_2 levels immediately maxed on the full face snorkel and were again sawtoothed and with only moderate elevation in the conventional snorkel.

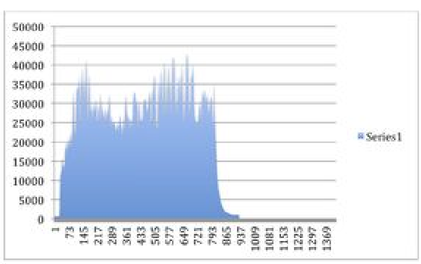




Sensor Readings

Series1: Full Face Mask

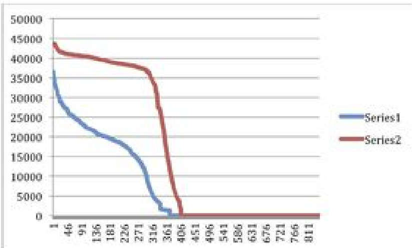
Series2: Conventional Snorkel



Snorkel Mask Conventional –Bike Ride

Full Face Mask 1.5 mile bike course

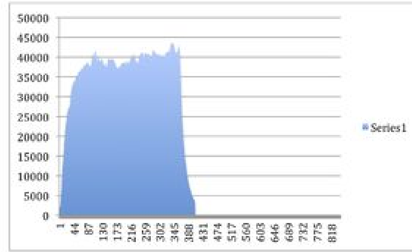
5-Minute Treadmill



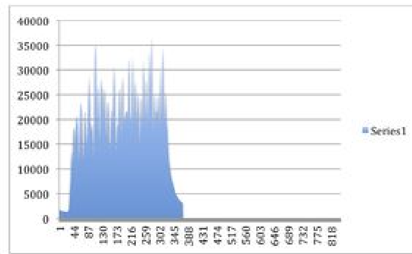
Series 1: Conventional Snorkel

Series 2: Full Face Snorkel

Five-Minute Treadmill at 4 MPH



Full Face Snorkel



Conventional Snorkel

Step 7: Discussion

CO_2 is really not considered a toxic gas and making judgments about levels that may effect you in the ocean I leave up to others. There is some interesting evidence that even low level elevation(2500 PPM) may effect higher thinking processes: https://ehp.niehs.nih.gov/1104789/ You can regularly find levels in the 1000-2000 range in schools and buildings where sacrifices in heating/ventilation are made to make a "tight" building. Inside snorkels we are dealing regularly with CO_2 levels of 10 times as much. The planet is changing radically from only an increase of 40 PPM.

The limitations of this Instructable are obvious and include:

1. Limited Data from a variety of people coded for age, health risks

2. No measurements of concurrent O_2 levels in subjects

3. No on water measurements--none of the instrumentation was waterproof

4. No monitoring of vital signs including O_2 sat, HR and tidal volume

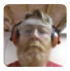
5. No testing of sensor to make sure it is accurate

6. More accurate analysis of dead space in the full-face snorkel

7. Trials of other full-face snorkels to see if inner seal is functional

8. I should have repeated the bike trial multiple times, but I will never do that again....

While prior studies have been done on conventional snorkels and better designs suggested (https://www.ncbi.nlm.nih.gov/pubmed/12740732) this work shows that perhaps a well defined study should be done of these commonly used devices to better identify their risks (great science fair project!). My sense from doing these experiments is that I would not perform biking or fast walk/run in any type of snorkel mask ever again. However, snorkeling in the ocean beats the risk of snow shoveling every time and I wouldn't hesitate to use either model.



Citizen science at its best! A great study with real health implications. Do the OSHA rules for confined spaces cover carbon dioxide? Thinking people want to know.

Yea...here is a good source: https://inspectapedia.com/hazmat/Carbon%20_Dioxid...

Lots of information--the real worry is how low the oxygen gets inside these things under exertion------!!!!!!

This is really interesting! I had no idea full-face masks even existed and now I want to research.

Yea Costco has them!