Pulse oximetry works because hemoglobin absorbs light differently when it is oxygenated than when it is depleted of oxygen. Most of us already know this principle: Blood is more blue when depleted of oxygen, arterial blood freshly saturated with oxygen is bright red. This observation sets the stage for using color to determine the amount of oxygen blood contains.

In short, oxygenated blood reflects more red light. Also, blood depleted of oxygen reflects more infrared light. The changing ratio between these two frequencies allows a microprocessor to compare these signals to look-up tables previously established for different O2 saturation levels.

The principals are reasonably simple, but the operation of a pulse-ox sensor depends on accurate comparison of some extremely small signals both optical and electronic. These signals can easily be lost in background noise unless caution is taken to acquire, protect and analyze them.

Patient movement and other things that changes blood-flow have to be considered into the signal analysis. Room lighting, sunlight, and other background signals are all detected by photo-diodes used in pulse oximetry. Electrical interference like background 60 cycle hum, cell phones, electrical motors, etc, each of these external signals must be filtered out somehow so that only the useful signals remain and are available for analysis.

Most of these variables can be eliminated by subtracting the background (non-pulsatile) signal from the changing (pulsatile) signal. This ratio of changing to non-changing data is also an indicator of signal quality and consequently, an indicator of the reliability of the Spo2 value being displayed.

Too low of a signal ratio and the validity of the output becomes suspect. As grandma might have put it: “You're making too much stew from a single oyster.” Just like a photograph with an extremely low contrast ratio, you might be able to tell that the picture is one of a horse... but you might not be able to determine if the horse is alive or not.

Most higher-end pulse oximetry systems include some way of monitoring the quality of the sensor signals. Our studies are being conducted with a Masimo Rad-8 pulse oximeter system. This unit has two meters that indicate signal quality.

The PI (Perfusion Index) meter indicates the ratio of pulsitile to non-pulsatile blood flow at the site being monitored and serves as a sort of “Lie detector” for the displayed data. Any ratio below 1% and the validity of the data becomes suspect.

The Signal IQ (SIQ) meter displays the strength of the changing sensor signal and also serves to display the pulse. If this signal drops below two bars on the bar-graph, the signal strength is too low to get accurate data.

Our methodology has been to first establish baseline data using standard sensors to get a “Feel” for the responses of the system, sensors, and our own physiology.

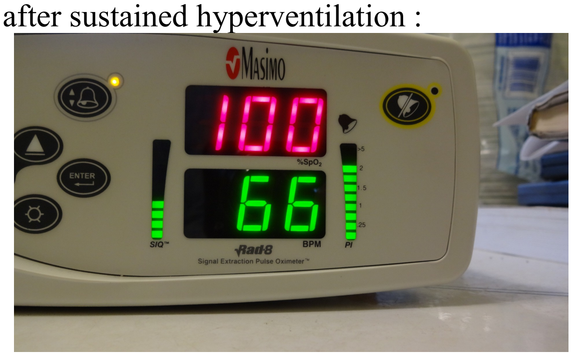
In spite of the fact that at least one of us is mentally unstable and strong doubt that any of us is completely qualified for human trials, we all seem to be relatively healthy as far as O2 saturation goes.

Using the Masimo MPS032A  fingertip sensor, we get nice, strong signals that reliably indicate at the top of the PI meter. The SIQ also indicates a strong dynamic signal as shown in this photograph:


With this sensor attached, the SpO2 meter tends to show each of us in the 96-98% saturation range with the indicated value tracking what would be expected from hyperventilation, breath-holding, etc.

In spite of repeated encouragement, our second test subject failed to hold his breath until he passed out, further demonstrating his unsuitability as a test subject.  However each of us can substantially lower our SpO2 value by holding our breath past the point of comfort.  The lowest readings seem to lag about 15-20 seconds behind our point of maximum discomfort, giving an indication of our bodies response time at the fingertip, as well as filtering being done by the Masimo unit.

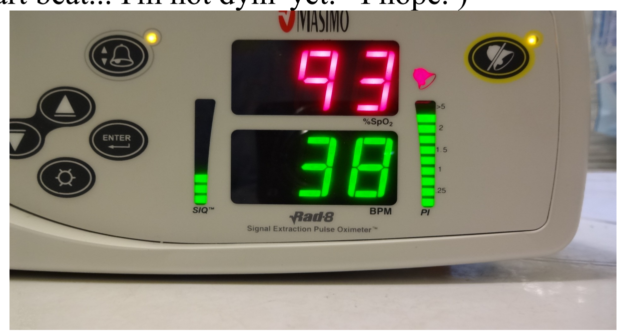
This is a shot of the readings after sustained hyperventilation :



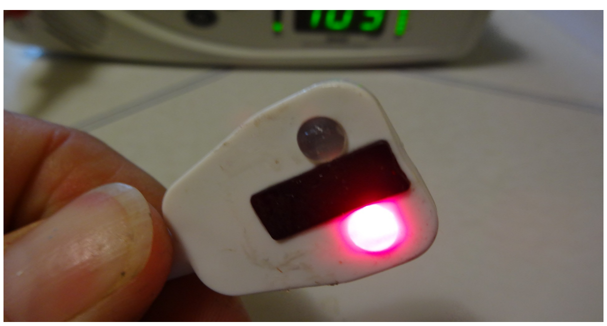
And this, about 20 seconds after maximum discomfort holding my breath:

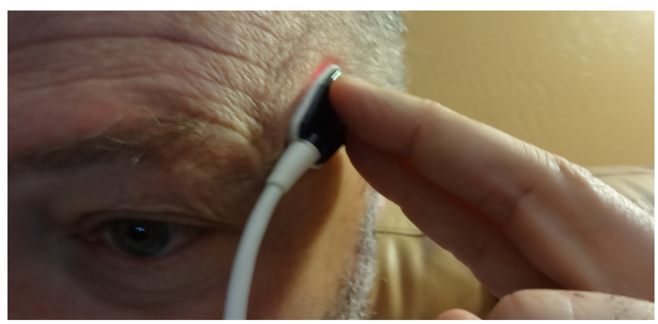

As you can see these responses are what you might expect from these activities.

( I've always had a slow heart beat... I'm not dyin' yet.   I hope. )




This is a shot of the Masimo LNCF TF-1 transflectance sensor and it's placement on the temple:





When mounted on the temple, this sensor gives both signal quality and SpO2 indications that are similar to the fingertip sensor.

# (   Some design specific   Text and photos deleted )

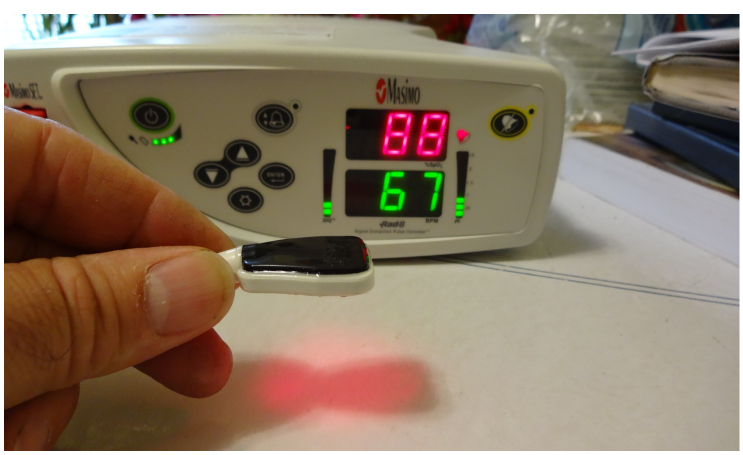
I have no idea if these low readings indicates a true SpO2 value at that position for some physiological reason, or simply indicates the difficulty of the meter interpreting marginal signals.

Speaking of which:

Now... on to the truly “Twilight Zone” stuff...

This is a reading from my leather couch:


And This is a reading from my metal kitchen table:



It is somewhat disconcerting that both of these items register better SpO2 values and pulse rates than I do while writing reports.

I don't believe that these photos indicate that the data available from the transflective sensor are completely bogus, as indicated by the temple mounted data and generally realistic responses

# ( TEXT Deleted)

Searches for relevant technical information on the internet brought up several good articles, but one that seems among the best is a report from Intelesens Ltd in Belfast Northern Ireland: http://cinc.mit.edu/current/preprints/340.pdf

This report details some of the research paths taken and the various methods tried during the development of a chest mounted transflective pulse oximetry sensor. Some of the approaches we might have tried are documented and discussed, notably:

Sensor sensitivity:

The quality of transflective signals increased with the physical size of the photo-diode and also increased with larger separations between the light emitters and the photo-diodes, with distances being compensated for by increasing the drive current to the LED's. This current was increased up to the maximum rating for the devices. With the concept of “More is better” in mind, additional emitter diodes were added, but had to be abandoned due to conflicts in wavelength tolerances.

( I suspect that the instruments were picking up on the interference “Beat Frequencies” in the mismatch of the emitters. Either that, or my leather couch isn't quite dead yet...)

I'm not sure of the exact date of this report, but with LED's being developed for mainstream residential and industrial lighting, HUGE increased in device brightness have been occurring almost monthly. It is possible that recent visible LED designs may have substantial advantages over designs only a year or two old. ( however, I'm not sure if advances have kept pace for infrared emitters )

# (Text deleted )

There is promising research relating to amplification and pre-processing of signals before they are sent to the pulse-oximeter,

# (Text Deleted )

Ken Bash,
BioEmbedded Research LLC