A Layperson's Guide to Understanding Human Temperature Taking

Notice: We are neither medical professionals nor FDA certified or approved vendors and nothing in this article should be used to evaluate medical or health-related outcomes nor diagnose specific disease(s). Rather, this article is intended to be a useful guide for those who are looking to understand the accuracies associated with various temperature taking mechanisms in their pursuit of creating a safer environment for employees and visitors.

If you are reading this, odds are good that you are someone responsible for the safety and productivity of your workplace and for visitors to your office -- whether in a general office environment, a medical clinic, a school, an eldercare facility or elsewhere. And, odds are also good that you're still in research mode, trying to figure out whether you want to (or don't want to) take employee and visitor temperatures, if you ***do*** want to take temperatures what that might mean and whether you should ***only*** take temperatures or go beyond.

According to a CDC paper (1), ***among symptomatic*** COVID-19 subjects, 96% had one of a fever, cough, or shortness of breath. That's a very high percentage and suggests that identifying individuals who have this combination of symptoms could be very helpful to both keep a particular organization relatively safe while also helping society "flatten the curve" during the pandemic.

It's relatively easy to screen for cough and shortness of breath -- simply ask the subject. Temperature, however, typically requires some type of measurement. Many forms of measurement are at our disposal -- this paper attempts to outline each of them from the standpoint of a relative layperson who has been tasked with understanding the options and coming up with a temperature screening approach.

Two Basic Approaches to Measuring Temperature

At a very high level two different approaches to taking a person's temperature exist:

- Use an internal body probe, typically rectal or oral, sometimes tympanic (ear)
- Use an external body measurement tool such as another person's hand, a digital thermometer (contact-based or non-contact based), or thermal camera.

In terms of accuracy, the internal body probe mechanisms are far more accurate than the external body measurement tools for one primary reason: the human body.

The human body wants to regulate itself within a very tight temperature range of 97.4 to 99.7 °F (36.3 to 37.6 °C), according to the National Institute of Health(2). While many of us may have grown up hearing that 98.6 °F was the “accurate” temperature for “normal”, the truth is that there is no real “accuracy” of an individual’s internal core temperature -- it’s always a range, even within the same day. As we know, our human bodies are highly complicated and all kinds of factors affect our body temperatures ranging from age and gender to time of day, external temperature factors, and the amount of exercise we’re currently undergoing. Our ***skin*** is the primary regulating factor as it’s the primary interface between the core and the (typically) cooler outside. Different parts of our body are closer to the core or farther from the core and some parts of our body (the tear ducts, for example) are less-shielded by the skin than other parts of our body. By removing the skin-to-air interface, measurements that are taken rectally, orally, or tympanic are closer-to-inside than they are closer-to-outside and, thus, much more accurate and representative of “the true temperature” for the subject in question.

It’s also worth noting that ***no measurement device exists*** that directly measures temperature. Each measurement device actually translates some other very well-known element (volume of a substance -- a la mercury thermometers; light wave associated with a substance - a la thermal cameras; or energy/heat associated with a substance - a la digital thermometers). It’s for this reason that accuracies for any particular measurement approach can vary widely based on the engineering precision used by the manufacturer in their process of converting known-quantity A into temperature B.

Mercury Thermometers	Digital Thermometers	Thermal Cameras
Translates volume of a substance	Translates energy/heat associated with a substance	Translates light wave associated with a substance

The “gold standard” of internal body core temperature measurement is to insert a probe next to the heart(3).

Super accurate. Not very practical for everyday use cases.

Rectal probes are very similar in the sense that they’re very-close-to-inside the body and highly accurate. And, again, not very enjoyable or practical for everyday use cases. Maybe at the doctor’s office when they’re highly certain you have some type of illness, but not generally an every-day kind of measurement approach. Typical measured range for men is 98.1 - 99.5 °F (with women having a slightly narrower range).

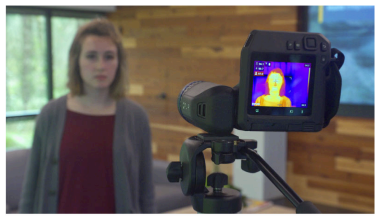
Which is why so many of us have come to know oral thermometers so well over the decades: more accurate than most of the alternatives and ***much more*** practical and accessible in almost every use case. Typical measured range for women is 91.8 to 100.6 °F (with men having a narrower range). (Ear thermometers have a slightly wider range than oral.). And, temperatures taken with oral thermometers are typically 0.5 to 1 °F lower(4) than rectal temperatures.

Each of these measurement approaches are fairly “accurate” when it comes to measuring the internal core body temperature - because they’re closer-to-inside. Sadly, in times of a highly communicable disease, each of them is also a measurement approach that requires close human to human contact and increases the likelihood of communicable spread.

To avoid contact many of us are turning to non-contact approaches which, necessarily, require one to measure outside-the-body. And, once one starts measuring outside-the-body the accuracy of various measurement approaches starts to drop.

Three basic approaches exist for outside-the-body temperature measurement:

- Non-contact Infrared Thermometers (a.k.a. digital thermometers)
- Standalone Thermal Cameras
- Thermal Cameras with Reference Source



Non-contact Digital Thermometers

Non-contact Infrared Thermometers work on the principle of heat, typically from your forehead, coming in contact with two different types of metal within the thermometer that creates a measurable electrical variation (technically, “a thermopile”).

The largest accuracy challenge facing digital thermometers is associated with the distance and orientation of the thermometer to the subject’s forehead. Heat decays rapidly with distance, so the difference in a temperature reading of the same digital thermometer 1” away from a subject’s forehead and 4” away can be dramatic. If obstacles exist (hair being the most common), the obstacle can further erode the heat coming off the forehead and skew the reading. Importantly, if someone **is** ill then does someone else want to have to stand so that the thermometer is 2” away from the other person’s forehead (because it *cannot* read 4” away, or a foot, or…). And, finally, the angle of incidence of the heat -- whether it’s straight on to the sensors in the digital thermometer or angled -- also has an effect on how much heat is transferred to the digital thermometer.

Some digital thermometer manufacturers go through extensive processes at their factories to “calibrate” the thermometer by scanning the thermometer against known temperatures and storing the electrical variations associated with those temperatures. Over time the metal inside the thermometer can change - expand, shrink, decay - which changes the physical properties which, in turn, changes the calibration -- all of which means that, even physically, a digital thermometer -- even one that is diligently calibrated -- can lose its accuracy over time.

Furthermore, each manufacturer must make an estimate of what the average difference is between the average person's "core body temperature" and the "measured skin temperature" of the forehead. Typically this variance is between 0.5 and 1 °F(4). As you can see, though, the temperature range(s) for those taken with oral thermometers are reasonably large (± 2 °F), so manufacturers have to decide what type of "offset" to utilize that represents the temperature difference between the forehead and the core -- this could introduce a specific offset factor of as much as 3 °F -- so the digital thermometer screen might say 98.5 °F but, internally, it could really be reading 95.5 °F.

Lastly, and unfortunately, most digital thermometers are held by humans and, often, by humans without training or knowledge of many of these accuracy factors, which introduces yet more accuracy error. "Most people wielding thermometer guns hold them too far from or too close to the subject, yielding temperature measurements that are either too hot or too cold, according to experts who spoke with The New York Times."(5)

For these reasons: the digital thermometer, while being a highly affordable and highly flexible approach to measuring body temperatures, just isn't very accurate. As Dr. James Lawler, a medical expert at the University of Nebraska's Global Center for Health Security, told The New York Times: "Lawler said that thermometer guns had suggested he was dying of hypothermia as he traveled through West Africa during the 2014-2016 Ebola outbreak." (4)

Which brings us to thermal cameras - be they standalone or coupled with a reference temperature source.

Thermal Cameras

Thermal Cameras work on the principle of light being absorbed by hundreds of thousands of tiny electrical detectors in the camera, and then being turned into an electrical value. Each resistor is a pixel in the image -- just like your 4-megapixel visible-light spectrum camera in your smartphone captures a light value, so too does a thermal camera capture a light value. The difference is the light is in the invisible spectrum -- the infrared light spectrum.

Thermal cameras have a couple of advantages over digital thermometers -- specifically, the distances at which heat decays vs. light decays (inches vs. feet) and the area of temperature(s) to be read (very small section of the forehead vs. the entire face). We get more "social distancing" with thermal cameras and we get more measurement points.

One of the advantages of having so many thermal data points is that we can pick and choose the hottest data points. Research has shown that the "inner canthus" -- what you and I would call "the tear duct" -- is the part of the face that is the closest to inside-body-temperature. So, when we have relatively high-resolution cameras (320 x 240 pixels) we can capture enough data points for that region of the face in about a 20" square area. The farther away the subject being tested, the fewer pixels we have as data points.

Like digital thermometers, thermal cameras are *also* subject to variations depending on the distance between the camera and the subject under test. For this reason, no thermal camera solution can legitimately claim to be ***both*** accurate ***and*** work from a variety of distances. So, their accuracy is a function of how precisely you set them up in the first place (just as digital thermometers accuracies are a function of how precisely you use them).

However, according to Markus Tarin, CEO of MoviTherm (thermal engineering experts for more than 20 years): “The absolute accuracy of a thermal camera depends on many factors. Considering all factors [listed], the expected accuracy of these cameras ***is no better than ±2° Celsius or ±3.6 °Fahrenheit***. It technically can’t be better, unless you are placing the thermal camera into a very tightly controlled thermal chamber under laboratory conditions.” Why? Due to ambient temperature drift and increased heat generated by the camera itself. (6)

Markus goes on to talk about Thermal Cameras ***with external reference temperature devices***. He also describes how a thermal camera, without an external reference device, ***can*** become accurate if it has captured known baseline temperatures from a group of people (10 at minimum according to Markus). Most thermal camera solutions these days have ***neither*** a process for asking you, the operator, to take thermal photographs of 10 subjects and store them nor do they supply an external reference temperature source. Now, granted, Markus is trying to sell you on his companies expertise and relationship with one of the oldest thermal camera companies in the world, FLIR -- so he has somewhat of a vested interest.

It turns out, though, the Federal Drug Administration agrees with Markus (or, Markus agrees with the FDA) -- in their guidelines for thermographic devices they explicitly call out the need for an external temperature reference device at a specific distance(7).

These solutions (Thermal Cameras with Reference Source(s)), according to Markus and several other sources, can get to ± 0.5 °C accuracy.

Like digital thermometers, Thermal Cameras with Reference Source(s) must be calibrated. The external temperature reference source is the key to the accuracy of the whole system. Because the external reference source is a) at a known distance (and the same distance as the subject being scanned), and b) at a known temperature the camera itself can measure the temperature of all aspects of the human’s face. If the Reference Source is ***not*** calibrated -- and not consistently recalibrated to accommodate thermal drift over time -- then, like digital thermometers, the accuracy of the solution is substantially eroded.

Does Accuracy Even Matter?

Much has already been written by the Centers for Disease Control and the World Health Organization about the number of COVID-19 carriers who are asymptomatic (different reports put this at between 14% and 40% according to the WHO) and whether temperature, alone, is a good predictor of the potential for infection. As mentioned above, 96% of those in a sampling of symptomatic carriers taken by the

CDC had one of three symptoms (fever, cough, shortness of breath) so screening ***for all three*** may make some sense while screening purely for temperature may only identify a small portion of the potentially infectious population.

And, a high-temperature reading -- which a medical professional might confirm as a fever and might further confirm as some type of diagnosis of illness -- is really all we're looking for. So, does it matter whether someone's temperature is 96.8, 97.4, 98.6, 99.5 or 100 °F? Not really. Does it matter whether someone's "true" temperature is within any of the ranges cited above for rectal, oral or tympanic measurement approaches -- ***if*** what we're really trying to do is spot someone that's "abnormally high"? Again, no, it likely doesn't matter.

What *does* matter, for those of us not in the medical field but tasked with the safety of our business, employees, and visitors, is that we have a relatively high degree of confidence in our measurement system that it can identify people with elevated body temperatures ***for the purpose of subsequent handling.*** And, presumably do so in a manner that doesn't falsely allow too many people with elevated temperatures past our screening nor present too many people who have been falsely identified as having an elevated body temperature. In truth, this is probably where accuracy plays any role at all -- in whether too many people who ***might*** pose a problem are allowed entry or too many people who pose no risk at all consume the time of a secondary screener.

Conclusion

We can summarize the options reasonably succinctly in terms of descending order of accuracy and a couple of other parameters in this table:

Rk	Method	Contactless?	Practicality?	Cost?
1	Cardiac Probe	No	Low	$$$
2	Rectal Probe	No	Low	$
3	Oral Probe	No	High	$
4	Tympanic Probe	No	High	$
5	Thermal Camera with Ref. Source	Yes	Medium	$$
6	Standalone Thermal Camera	Yes	Medium	$$
7	Digital Thermometer	Yes	High	$
8	Human Hand Assessing Another's Head	No	High	$0

Clearly, each solution has its own level of accuracy and associated advantages and disadvantages. Your situation will either be able to withstand the level of exposure risk that the contact-bearing (or close-by) temperature measurements bring with them or you'll want the additional safety of distant contactless measurement systems.

Endnotes:

(1) https://www.cdc.gov/mmwr/volumes/69/wr/mm6928a2.htm?s_cid=mm6928a2_x
(2) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6456186/
(3) https://en.wikipedia.org/wiki/Human_body_temperature
(4) https://www.mottchildren.org/health-library/tw9223
(5) https://www.businessinsider.com/thermometer-guns-screening-for-coronavirus-notoriously-not-accurate-2020-2

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