Research Note on Fever Detection

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1 WHAT FOREHEAD THERMOMETERS MEASURE

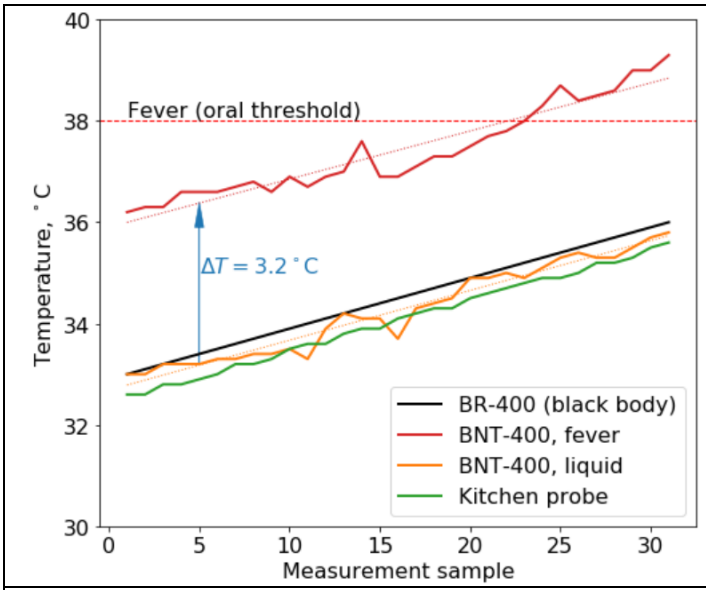


Fig. 1. Comparison of temperature readout from BR-400 black body, BNT-400 Braun No Touch IR thermometer in Fever and Liquid measuring modes, and a kitchen probe resistive thermometer. Dotted lines indicate fitted lines over the BNT-400 samples; the slope is ~0.1 degrees as expected in both cases. The difference of 3.2 degrees between the two lines indicates the assumed difference between oral (fever mode display) and actual (liquid mode display) temperature. Note however, that this difference in real life is due to thermodynamic steady state of heat exchange between forehead skin and ambient temperature. BNT-400 does not seem to have a probe for the ambient temperature.

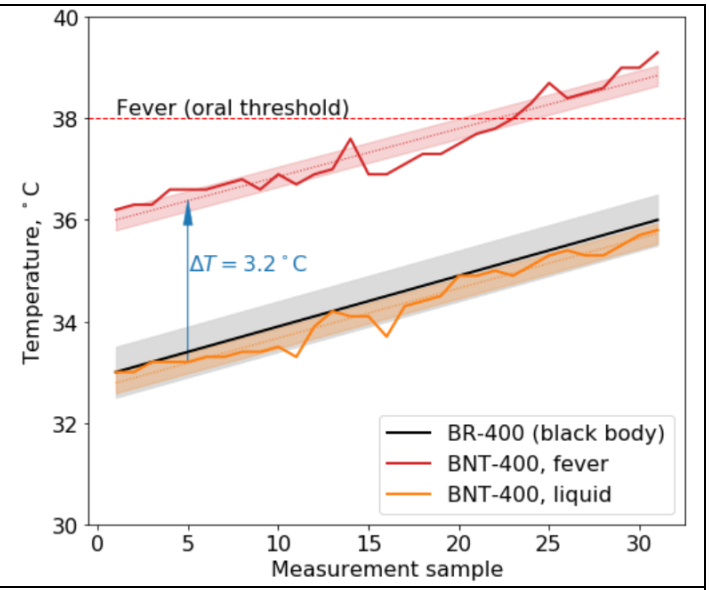


Fig. 2. Illustrating the advertised tolerance by a band around the obtained readout. Note that the fitted measurement from BNT-400 in liquid-measuring mode appears quite accurate (sampling error is ignored, and band is drawn around the fitted lines). Sampling error for BNT-400 is ascribed to great sensitivity with distance, grooved surface of blackbody, and inability to precisely eliminate motion during the 2-second measurement while holding by hand. Kitchen probe has an advertised accuracy of +/- 1 degree, but consistently showed 0.4 to 0.5 degrees below the black-body display and its error band is not shown.

In short, if you're measuring with thermal gun (pointing at the forehead), you should be expecting 36.9 - 3.2 = 33.7 C.

According to BNT-400 manual:

Moderate Fever (yellow): 37.7 => 37.7 - 3.2 = 34.5 (I do see yellow screen on BNT400 at 34.5 on the BR-400 black body).

High Fever (red display on BNT-400): 39.4 => 39.4 - 3.2 = 36.2

However, repeating the measurements today, specifically around the 34.4 to 35.0 C of the Blackbody, I see Fever display around 38.1 to 38.6, so it seems the gap between actual temperature (liquid mode) and display temperature (fever mode) is as large as 3.7 degrees C.

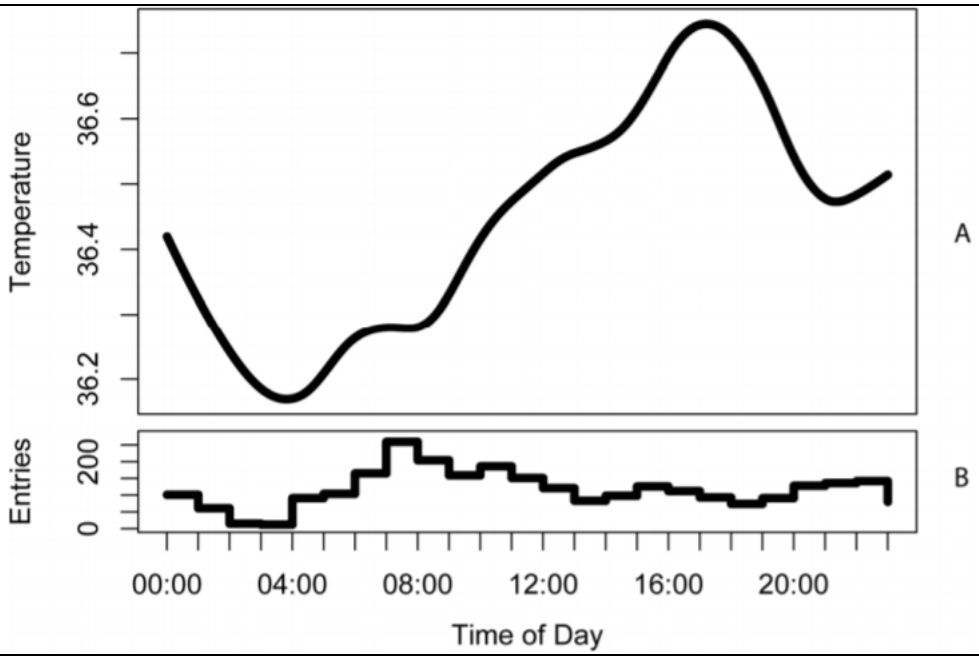
	
Fig. 3. Black body with kitchen probe inserted. Black body has advertised emissivity of 0.97 and accuracy of 0.5 C. Emissivity of human skin and of water (with or without oils – as target for BNT-400) is also 0.97 or above.	Braun BNT-400. Measurement were done at ~ 2cm distance from the black body emitter plate. Thermometer was held by hand. BNT-400 appears to have a near-IR range finder in Fever mode and does not permit measurement if distance to target is > 2 cm. The black body likely does not reflect back the beam from the thermometer, thus precluding experimentation. To enable the measurement in Fever mode, the range-finder was blinded by putting scotch-tape in front of it; thermal sensor was not occluded.

2 Skin Temperature And Its Relation To Core Body Temperature

See also http://www.healthyheating.com/Definitions/facts_about_skin.htm#.XivUNsj_zb1

"...your skin temperature varies **parabolically** **from 28.2 C** at an ambient temperature of 9.5 **C to 37.2 C** at an ambient temperature of 35 C." Dr. K.R. Koehler College Physics for Students of Biology and Chemistry, University of Cincinnati

2.1 Diurnal variation



From []

2.2 SITE DEPENDENCE

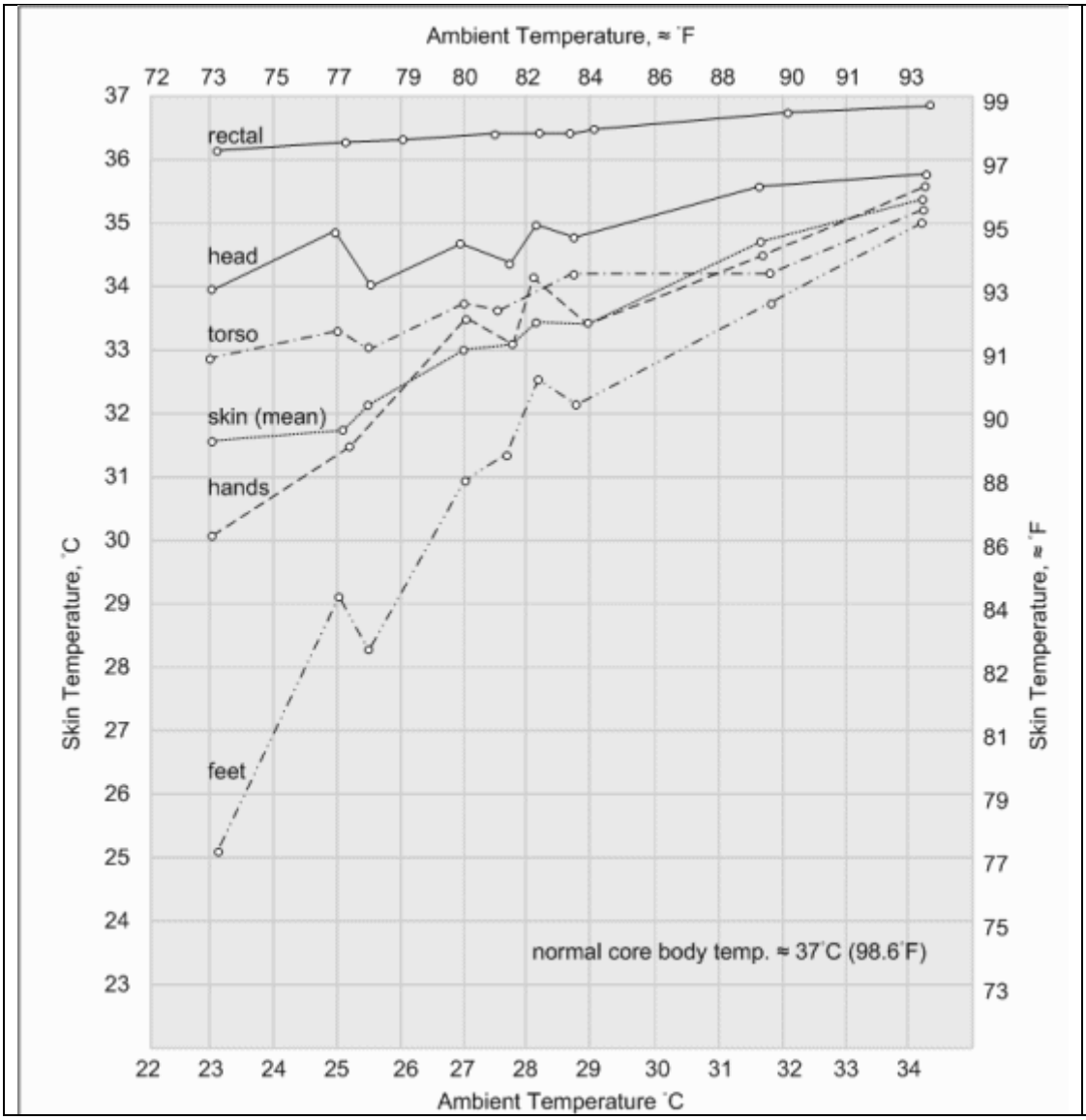


Fig. 5. Skin temperature on different parts of a nude person, measured at different ambient temperatures, adapted from Olesen, B.W., 1982, Thermal Comfort, Technical Review, Bruel & Kjaer.

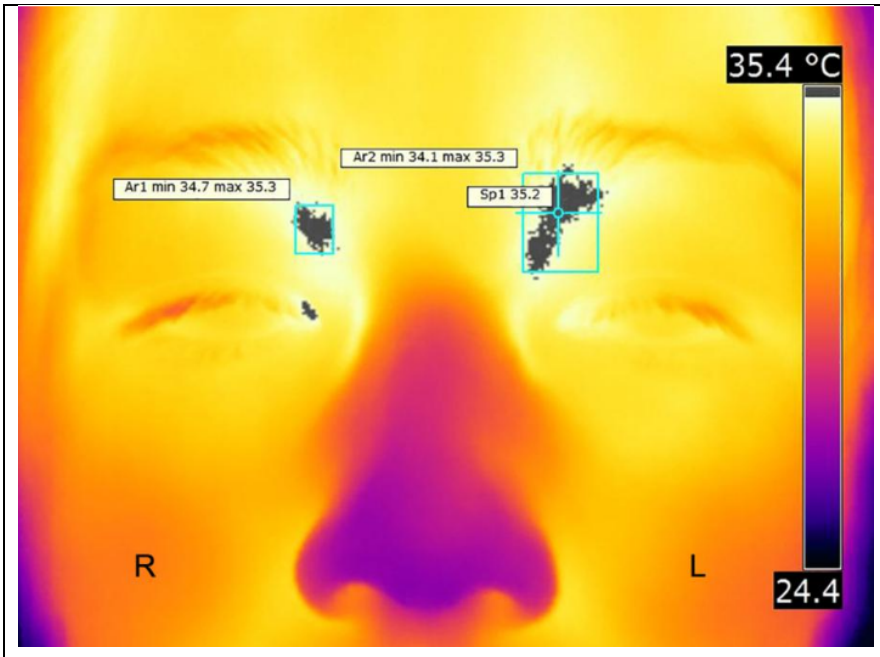
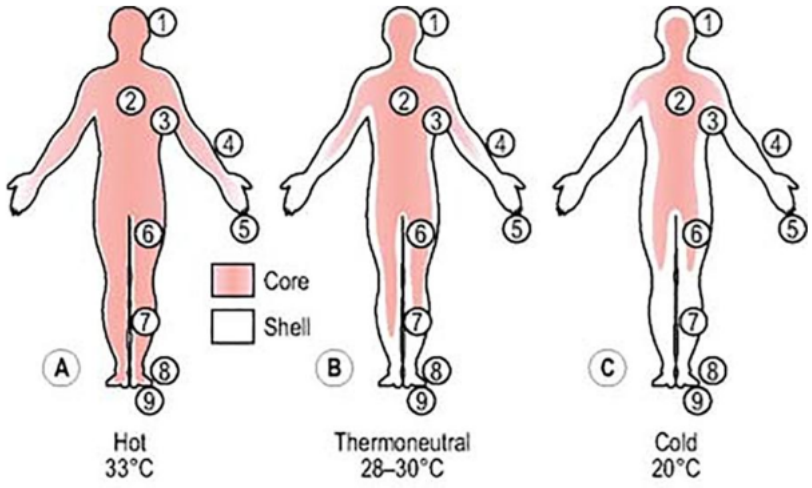
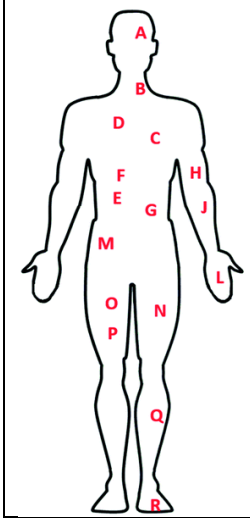


Fig. 6. Infrared thermal image of the face of a healthy subject showing temperature of region of the inner canthus. Gray regions represent the highest temperature pixels of the thermogram. Color temperature key is given to the right of the image. Right (R) and Left (L) inner canthus; the pixels colored “grey” are the highest values in this thermogram; R at maximum 35.5 o C and L, highes t value, 35.2 o C. (Childs and Low, unpublished data.)
From [1].
Changes in temperature of the inner canthus directly correlate to brain temperature (within 0.5 C) [1].



	Site	A (°C)	B (°C)	C (°C)
1	Scalp	36.0	34.8	32.8
2	Chest	35.8	34.5	31.3
3	Axilla	36.5	36.4	36.4
4	Arm	35.9	33.5	27.6
5	Finger	35.9	33.2	21.0
6	Thigh	35.2	33.4	27.8
7	Leg	35.3	30.1	25.2
8	Foot	35.5	29.7	22.7
9	Toe	36.2	29.1	21.4

Fig. 7. The cocept of Core-Shell. Core produces heat, shell serves to regulate heat loss/dissipation. Skin surface temperature at nine body sites in hot (**A : 33°C**) thermoneutral (**B : 28–30°C**), and cool (**C : 20°C**) ambient conditions showing size of body core. Relative to shell, core increases from cool to
hot ambient conditions. Table shows core temperature and temperature
of the skin surface at nine sites in a hot, a thermoneutral, and a cold environment. (Figure manikin representation based on an original figure
by Aschoff and Wever, cited in Stainer et al., 1984, with additional data
from Childs, 2006.)



Skin Location	Cold (15°C)	Room (27°C)	Hot (47°C)
Forehead (A)	31.7	35.2	37
Back of Neck (B)	31.2	35.1	36.1
Chest (C)	30.1	34.4	35.8
Upper Back (D)	30.7	34.4	36.3
Lower Back (E)	29.2	33.7	36.6
Upper Abdomen (F)	29.0	33.8	35.7
Lower Abdomen (G)	29.2	34.8	36.2
Tricep (H)	28.0	33.2	36.6
Forearm (J)	26.9	34.0	37.0
Hand (L)	23.7	33.8	36.7
Hip (M)	26.5	32.2	36.8
Side thigh (N)	27.3	33.0	36.5
Front Thigh (O)	29.4	33.7	36.7
Back Thigh (P)	25.5	32.2	36.0
Calf (Q)	25.1	31.6	35.9
Foot (R)	23.2	30.4	36.2

From [10]

3 MASS SCREENING FOR FEVER

From [1]: *"Sensitivity of fever for detecting H1N1-2009 cases upon arrival was estimated to be 22.2% among 9 `confirmed H1N1-2009 cases, but 55% of the H1N1-2009 cases had taken antipyretic medication upon arrival. Sensitivity and specificity of infrared thermography using thermal scanners to detect raised temperature ranged from 50 to 70% (sensitivity) and 63 to 81% (specificity). The positive predictive value appeared to be as low, 37–68% (Nishiura and Kamiya, 2011)."*

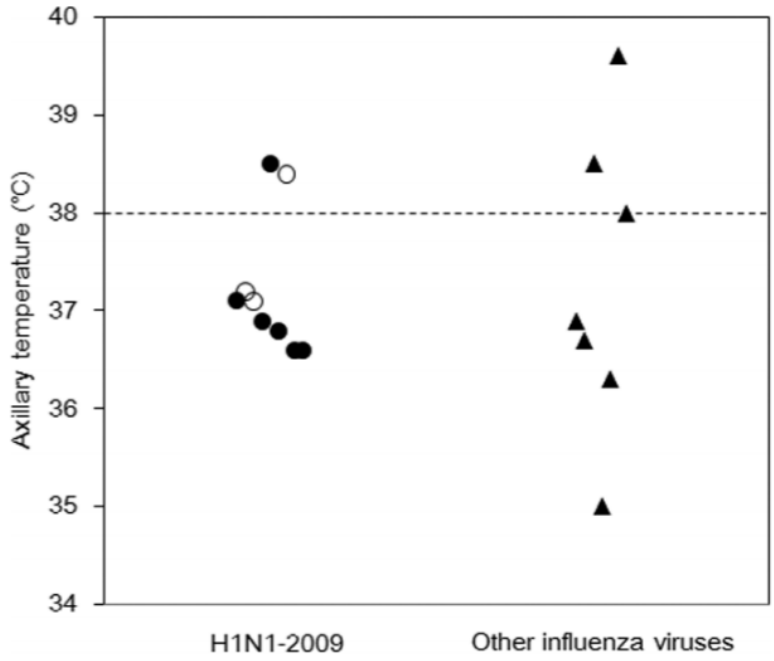
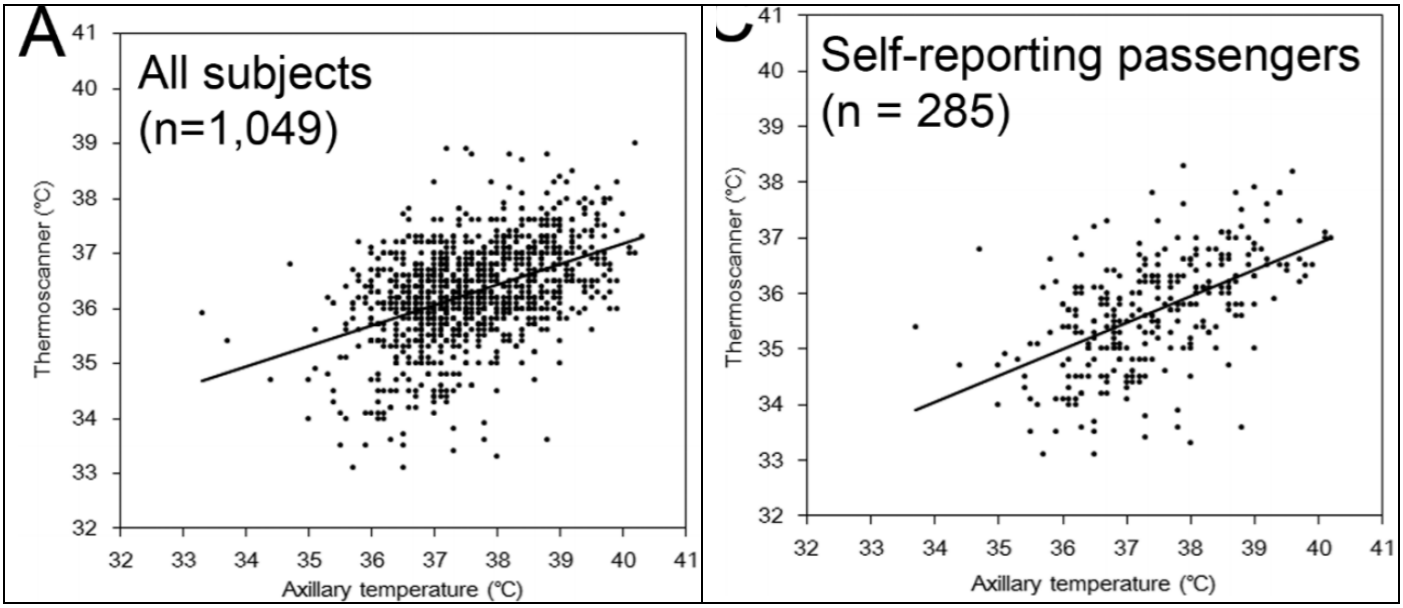


Figure 3 Distribution of the axillary temperatures among the confirmed influenza cases. The axillary temperatures upon arrival were compared between the cases with H1N1-2009 (n = 9) and the cases with other influenza viruses (n = 7). The confirmed cases represent patients whose diagnosis took place at Narita International Airport from 28 April to 18 June 2009. Unfilled symbols represent passengers without medications upon arrival and filled symbols represent passengers with medications. The horizontal dashed line is the reference line of 38.0°C, above which cases may be regarded as having hyperthermia.

From Nishiura, 2011 [8]. Axillary == Armpit temperature (normally 35.9 to 36.7; typically 1 degree lower than oral temperature and up to 2 degrees below rectal temperature)



4 Discussion

The review of [1] to [8] identified a major shortfall in the reports. In not a single case was reported the exact point of measure by the infrared thermographic equipment, and if any averaging or maximal values were reported.

The notion of parabolic dependence of skin temperature on the ambient temperature must be investigated. It likely has physical (heat-transfer related) roots to do with average body mass (heat capacity) and surface area, as well as the phenomena of heat exchange with environment.

It is worth exploring forehead segmentation and analysis of the statistics, to go beyond the (likely only reported) maximal temperature in the field of view of the thermal imager in previous studies.

It is important to measure:

- Distance
- Ambient temperature
- Ambient humidity
- Temperature of a reference object (black body or a radiator, e.g. PTC with a known temperature)
- Time of the day (0.6 C variation over 24 hours depending on metabolic rates dictated by circadian rhythm)
- Assess the age of subjects, if possible (negative correlation; 0.3 on average lower for > 60 yo)
- Limit assessment to adults (>18 yo)

It may be possible for measurement at short distances to estimate geometric patterns of iso-therms (or semi-iso-thermal regions) and correlate these with physiological state, as done for post-match athletic trauma [9]. However, at higher distance there may not be enough pixels to do that. Also, these patterns are likely specific to each individual – the question is will they become exaggerated or on the contrary – levelled out, in the state of illness.

It is important to find a heat-transfer model, so that if distance to subject is known we can establish size and infer subjects heat capacity, hence estimate health-state temperature and make inference based not only on measurement, but difference between measurement and health state estimate.

Apparently, such models exist in literature at least for certain specific cases [11], [12], [13].

Some relevant equations may be found in: https://www.zuniv.net/physiology/book/chapter21.html near the bottom of the page.

Try to find [14]: “Real-time human skin temperature analysis using thermal image recognition for thermal comfort assessment” and read [15] – plenty of modelling and data.

From [15] it seems that forehead temperature is least affected by ambient temperature changes, compared to a number of other sites where skin temperature was measured. Contrary however, most of models aiming at mean skin temperature exclude the forehead site datum. Why?

Also from [15], male subjects display distinctly higher temperatures throughout. This is ascribed to generally higher metabolic rates. But could it actually be due to mass/surface ration (heat capacity to heat flux?) – typically higher in males by virtue of volume being power of 3 while surface being power of 2. However, the difference between male and female subjects is smallest for the forehead temperature and is ~0.3 degrees at 21 degrees ambient, and ~0 at 29 degrees ambient, which is consistent with either causes of the presence of a difference.

5 References

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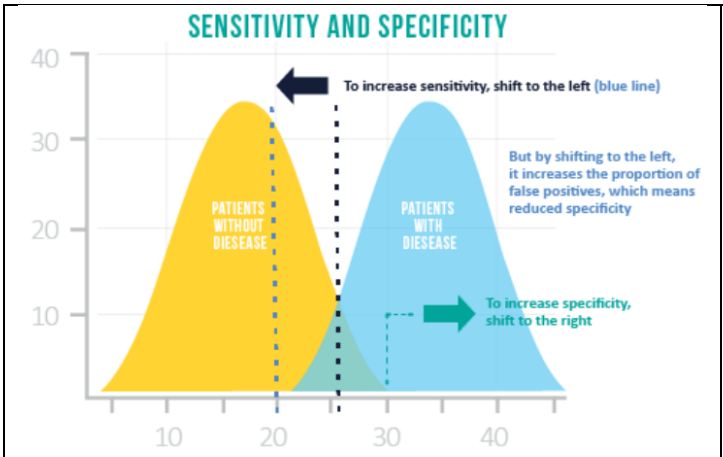
[16] Hausmann et al.: Crowdsourcing to Redefine Temperatures in Adults (JGIM, 2018)

6 APPENDIX I

6.1 SENSITIVITY VS SPECIFICITY

Sensitivity (TruePositiveRate): $TPR = \frac{\#TP}{\#TP+\#FN} = \frac{\#TP}{\#AP}$, where TP is True Positive, FN is False Negative; AP is All Positive in population

Specificity (TrueNegativeRate): $TNR = \frac{\#TN}{\#TN+\#FP} = \frac{\#TN}{\#AN}$, where TN is True Negative; FP is False Positive; AN is All Negative in population



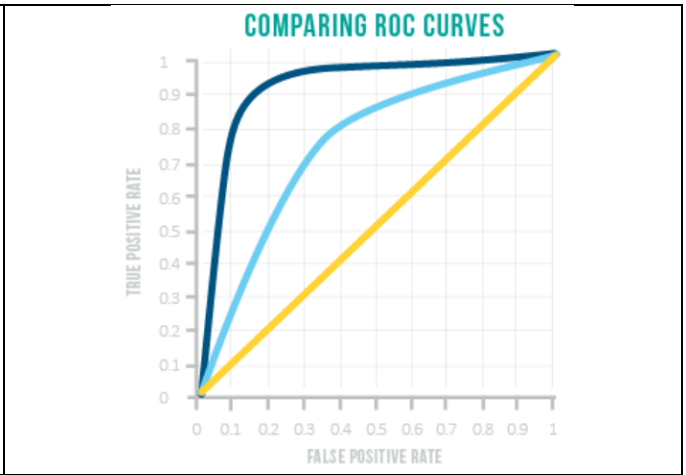
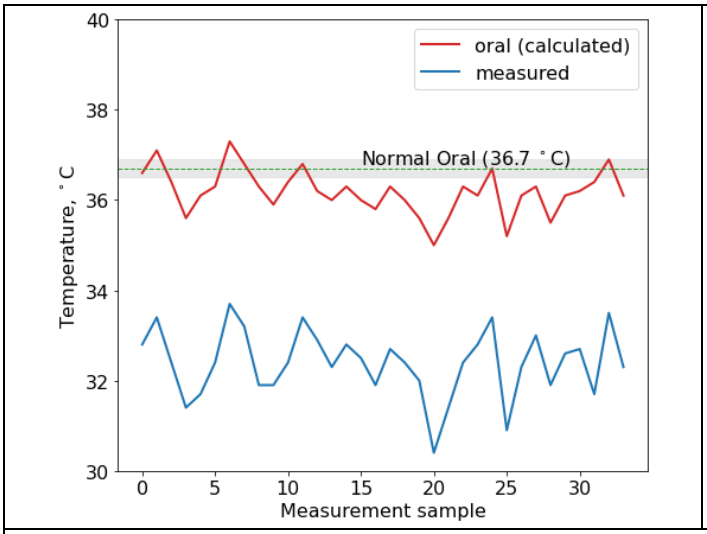
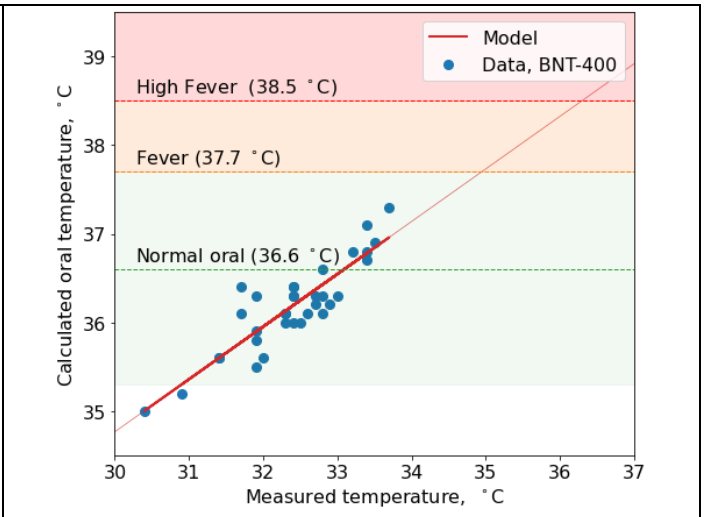


Fig. ?. Left: sensitivity and specificity are essentially requiring a compromise. Right: ideally, a good compromise with a good test/sensor is around the knee of the ROC curve, where TPR is maximised while maintaining a very low FPR.

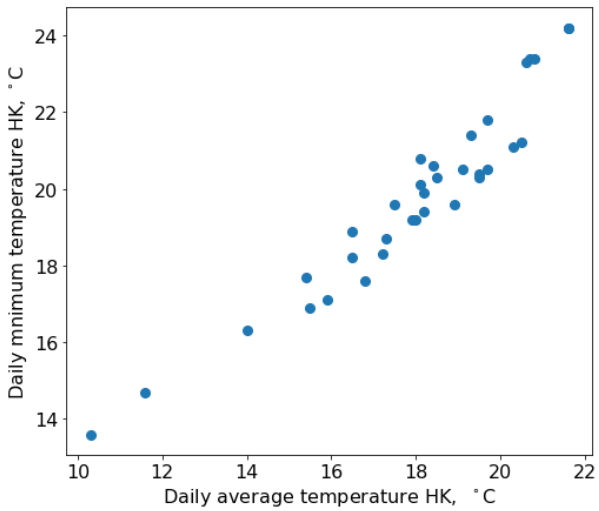
7 APPENDIX II

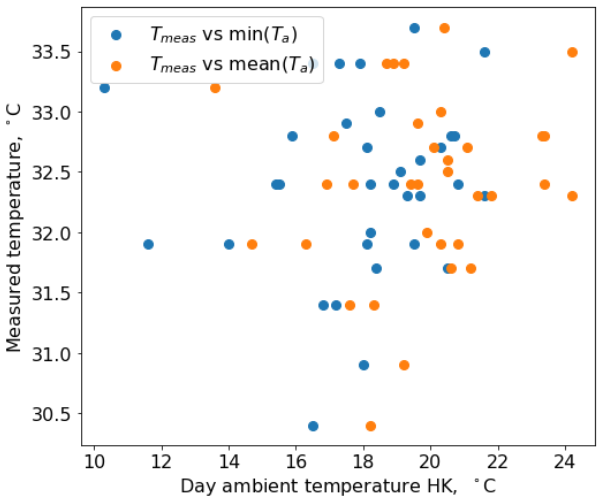
7.1 BNT-400 MEASURED VS CALCULATED ORAL TEMPERATURE





Temperature obtained with BNT 400 over a number of days (5 samples per week) of the same subject, in the morning, between 8:30 AM and 11 AM after about 1 to 7 min exposure to outdoor ambience (walking, lightly dressed, no direct sunshine) and 3 min acclimatisation while moving in office building and elevator.





Stron correlation between min and average outside temperature for HK (daily values). Correlation with measured temperature is not strong but perceptible. Note that there was a different exposure to outside temperature on different days, which may lead to loss of correlation even if relevant physical reasons exist for it.