Physiological Measurement

PAPER

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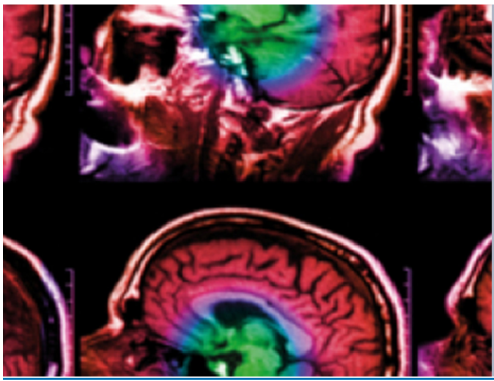

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PAPER

Bilateral assessment of body core temperature through axillar, tympanic and inner canthi thermometers in a young population

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Abstract

There are several sites in which the human body core temperature can be estimated and used to identify febrile states in a threat of pandemic situations at high-populational-traffic places (e.g. airports, ports, universities, schools, public buildings). In these locations, a fast method is required for temperature screening of masses. The most common methods are axillar and tympanic thermometers. However, in addition, measurement of the inner canthi (IC) of the eye with infrared thermal (IRT) imaging has been suggested as a fast mass measurement screening tool. *Objective*: It is the aim of this research to identify the bilateral difference of the available body temperature screening methods with potential use for large-scale fever screening and to verify if such a difference is acceptable. *Approach*: A total of 206 young participants (104 females and 102 males) were recruited, having their temperatures taken with the different methods bilaterally under neutral environmental conditions. The obtained results were statistically processed. *Main results*: Results established absent reference data for site and method in west European populations. The bilateral differences were minor using the IC of the eye monitored with infrared imaging, which was also proved with the Bland–Altmann limits of agreement. *Significance*: Based on the findings of this research, despite all methods being able to estimate body core temperature, it is suggested to use IRT images of the IC of the eye, due to its fast, reliable and reproducible procedure for mass screening. Further research is required to understand the higher bilateral variability in using the traditional thermometer axilla and tympanic membrane assessments, since these are the methods currently used within a clinical setup. The same procedure must be applied to fever cases to establish a decision threshold per method.

1. Introduction

Fever is clinically defined as having an elevated human body core temperature value above 37.5 °C (Impicciatore *et al* 1997). It is a common health alert sign, which is normally associated with a pathological state, causing about 30% of health facilities admissions by children. Fever occurs in up to 75% of adults who are sick. This prolonged state can result in tissue damage due to the catabolism of body proteins. In severe cases, it can lead to death, being also an important indicator of pandemic conditions such as SARS, H1N1, H1N5 or ebola (Ring 2007).

For the abovementioned reasons it is important to assess body core temperature, making it an important health indicator. The gold standards are the oesophagal and rectal temperatures; however, these sites cause discomfort for most people and are not easy to access (Moran and Mendal 2002). Over time, other sites have been proposed and introduced in daily practice such as axillary thermometers, initially of mercury and later digital; but, due to unreliability in their readings, which are dependent on the placement time, they have since been replaced by tympanic membrane thermometers (Perera *et al* 2014).

Childs *et al* (1999) demonstrated that, using tympanic membrane thermometers, there is a potential a measurement error from one recording to the next of about 0.1 °C to 0.2 °C. To limit this, the authors suggested that measurements should be restricted to one of the ears whenever possible, that the same ear should be used throughout the temperature monitoring period, and nurses and parents should take more than one temperature reading each time.

In 1964 Wood (1964) proposed the inner canthi (IC) of the eye site for the estimation of body core temperature. Since the internal carotid passes underneath this skin region in the process of irrigating the brain, this region can be easily read by an infrared thermometer.

Taylor *et al* (2014) demonstrated in their review that tissue temperatures are measured indices, which could have been influenced by local metabolism, tissue conduction and blood flow; they also suggested that a gold standard deep-body temperature does not exist. Similarities or differences can be found in temperature assessment at different sites due to a lack of a mechanistic relationship, unless those sites are in close proximity, are perfused by the same blood vessels and have equivalent metabolic rates.

In 2001, the idea of using infrared thermal (IRT) imaging for fever screening via monitoring the face emerged in China (Teunissen and Daanen 2011), during the SARS outbreak in south-east Asia. Three years later, two technical references for use of the imaging technique for fever screening were developed in Asia through the Singapore Standards authority SPRING (Standards 2003, Mercer and Ring 2009).

Teunissen and Daanen (Standards 2004) researched the use of the IC of the eye in IRT imaging as an appropriate method for core temperature estimation in mass screening of fever. They found that it is not a good estimator of core temperature during exercise and recovery hyperthermia, which may influence febrile states. Although they recommended to properly establish its validity, a reliable method, such as oesophageal or intravenous temperature measurements, should be used as benchmark instead of unreliable tympanic assessments.

In 2006, the International Organization for *Standardization (*ISO) initiated an interest group, ISO/TC121/SC3-IEC62D/JWG8, Project Team 9 on Human Body Screening Thermographs. The effort of this task force resulted in two standard documents, one on their requirements and essential performance, and the other a technical report on their deployment, implementation and operational guidelines to performing febrile identification, which were updated in 2017 (ISO/TR 13154:2009 ISO/TR 8-600 2017, ISO TC121/SC3-IEC SC62D 2017).

Despite the existing references, which advise on distance and angles to the target, most airports or high-pedestrian-traffic facilities fail to comply with the existing standards (Ring *et al* 2015b), placing cameras at inadequate angles and distances, and thus reducing the chance of identifying subjects at high risk of fever.

A piece of research, aiming to verify if the temperature obtained with IRT imaging at the IC of the eye was related to brain temperature taken invasively (Childs *et al* 2012), found strong correlations between the temperatures of both sites, the IC of the eye and of the brain. It also showed that in patients with a lesion in one side of the brain, that the corresponding side had elevated temperature at the respective IC of the eye.

Another research work, aiming to validate the IC of eye temperature obtained with an IRT camera as a non-invasive alternative measurement to intestinal core temperature, consisted in doing repeated measurements using as comparative values those of a gastrointestinal telemetry pill or rectal assessment, during rest, exercise and post-exercise conditions; poor agreement was observed between the non-invasive and the more reliable methods. Therefore, the IC of the eye was demonstrated to not be a valid substitute measurement to invasive core temperature assessments in sports and exercise science settings, being similar to other peripheral measurements (Fernandes *et al* 2016, Towey *et al* 2017).

Ring *et al* (2013, 2015a) have employed the ISO standards with the IC of the eye region of interest (ROI) and successfully identified paediatric febrile subjects with IRT and found good correlation with axillary thermometer measurements.

Despite all these efforts to estimate body core temperature with non- or minimally invasive methods to identify threats in the form of fever to masses, indications on the bilateral differences of these methods are missing. In addition, for IRT imaging of the IC of the eye, reference data is missing for adults about non-febrile subjects, a gap that this research aims to fulfil.

The aim of this present study is to investigate bilateral differences and their measurements' statistical relationship for the three non- or minimally invasive methods to estimate core temperature. The hypothesis is that the IC will present a minor measurement bilateral difference than the axilla and tympanic membrane methods.

2. Materials and methods

A total of 206 healthy volunteers (104 females and 102 males), see table 1 for sample characterization, were recruited for this study and underwent temperature screening through axillar and tympanic thermometers and frontal facial thermal imaging using an internationally accepted capture protocol (Ring and Ammer 2000, Ammer 2008) and screening guidelines (ISO/TR 13154:2009 ISO/TR 8-600 2017, ISO TC121/SC3-IEC SC62D 2017) in an environmentally controlled examination room (room mean temperature 22.3 °C $\pm$ 1.4 °C and mean relative humidity 50.1% $\pm$ 3.3%). All data were collected in a morning period over 2 weeks in April. For the axilla

Table 1. Sample characterization.

Sex	N	Age	BMI	Systolic BP	Diastolic BP
Males	102	22.7 ± 8.1	23.0 ± 3.0	130.3 ± 13.9	73.5 ± 10.3
Females	104	23.6 ± 9.1	22.2 ± 2.8	121.2 ± 13.7	74.9 ± 10.6
All	206	23.2 ± 8.6	22.6 ± 2.9	125.7 ± 14.5	74.2 ± 10.4

Figure 1. Regions of interest (ROIs) on the IC of the eyes in the IRT images.

temperature assessment, a Beurer FT 09/1 thermometer (measurement accuracy ±0.1 °C and operational range 35.5 °C to 42 °C) was used. The tympanic membrane measurements were obtained with a Hartmann Thermoval (Brenz, Germany) duo-scan thermometer (measurement accuracy ±0.1 °C and operational range 29 °C to 42 °C). The thermal images of the frontal face, taken at 1 m distance and using a 90° angle, in which the IC of the eye ROIs (figure 1) were drawn, each had 35 pixels. The images were taken using a FLIR E60 thermal camera (FLIR Systems, Wilsonville, OR, USA; long-wavelength infrared camera, focal plane array sensor size 320x240, NETD <50 mK at 30 ° C and measurement uncertainty ±2% of the overall reading). Mean temperature values were obtained for the different methods. To study the possible influence of blood pressure (BP) in the measurements, a Beurer BM 28 digital upper arm BP monitor was used and the systolica and diastolic BP were recorded per participant.

Ethical approval was obtained from the University of Porto Ethical Committee and all participants signed their informed consent before taking part in the study.

IRT measurements can be affected by metabolic activity, room conditions, participant medication or condition. All participants were required not to have smoked, drunk alcohol, tea or coffee, or had a heavy meal 2 h before the data collection. There were no oils or ointments in the eye region that could act as a skin thermal insulator. None of the participants reported any topical analgesics or dry eye disease. There was no incident lighting over the subjects in the examination room, and it was protected against thermal reflections with window blinds and having only the required equipment present.

Every time that a bilateral difference higher than 1 °C was found with the thermometer methods, the measurement was repeated, and the smallest difference was taken out of the three assessments.

To assess the reliability of the IC of the eye ROI, the infrared measurements were assessed by three different operators using the FLIR ThermaCAM Researcher Pro 2.10 software package. The agreement between the three operators was assessed, calculating the intraclass correlation coefficient (ICC) and the ROI data consistency by Cronbach's alpha coefficient.

Typically, the data collection was initiated with the tympanic membrane measurement, first on the left and then the right side, and each would take around 1 min; this was followed by the axilla assessment, in the same order, which would take around 90 s each measurement; the BP assessment took another minute on average; by the time the frontal face IRT image was taken, the participant would already be in thermal equilibrium with the room conditions and the image would take less than a second. The manual assessment of the ROIs on the software would take less than 1 min.

To assess the bilateral differences apart from presenting the average reference mean values per site and standard deviations and the side differences, the normality of the data per variable was checked through a

Table 2. Mean temperature measurements by method and side.

Sex	N	Right axilla	Left axilla	Right Tympanic	Left Tympanic	Right IC of eye	Left IC of eye
Males	102	36.3 ± 0.4	36.2 ± 0.5	36.2 ± 0.8	36.3 ± 0.7	36.0 ± 0.4	36.0 ± 0.5
Females	104	36.4 ± 0.4	36.2 ± 0.4	36.5 ± 0.5	36.5 ± 0.5	36.0 ± 0.5	36.0 ± 0.5
All	206	36.3 ± 0.4	36.2 ± 0.5	36.3 ± 0.7	36.4 ± 0.6	36.0 ± 0.5	36.0 ± 0.5

Table 3. Mean temperature measurements by method.

Sex	N	Axilla	Tympanic	IC of eye
Males	102	36.3 ± 0.5	36.2 ± 0.6	36.0 ± 0.4
Females	104	36.3 ± 0.4	36.5 ± 0.4	36.0 ± 0.5
All	206	36.3 ± 0.4	36.4 ± 0.5	36.0 ± 0.5

Table 4. Mean temperature bilateral differences by method.

Sex	N	Axilla	Tympanic	IC of eye
Males	102	0.0 ± 0.3	0.2 ± 0.8	0.0 ± 0.1
Females	104	0.1 ± 0.4	0.0 ± 0.5	0.0 ± 0.1
All	206	0.1 ± 0.4	0.1 ± 0.7	0.0 ± 0.1

Table 5. The data consistency and the intraclass correlation of the IC of eye method.

			ICC 95% c.i.	
ROI	Cronbach's alpha coefficient	ICC	Lower	Upper
Right IC of eye	0.958	0.884	0.857	0.908
Left IC of eye	0.953	0.871	0.840	0.897

Kolmogrov–Smirnov test; in cases where the normal distribution was not followed, a Mann–Whitney U test was used to assess the null hypothesis of the influence of a variable. The ICC was also verified, along with a Friedman's two-way analysis of variance by ranks test, a repeated measures analysis of variance (ANOVA) comparing the mean bilateral differences per method and a Bland–Altman method for assessing the limits of agreement per each method. All statistics were calculated using IBM SPSS v24.

3. Results

Table 2 presents the results per method, site and sex. It can be seen that the temperatures measured by the IC of the eye using the infrared camera were lower to those measured by the axillar and tympanic membrane thermometers.

Table 3 presents the average bilateral values measured per method, in which the IC of the eye using the infrared camera still presented the lowest values.

The mean temperature bilateral differences are displayed in table 4, and the method with the most minor difference is the IC of the eye using the infrared camera.

None of the variables followed a normal distribution, therefore for means of comparison non-parametric methods were used. There was statistical evidence of influence according to sex in the left and right tympanic membrane measurements and in the average of bilateral measurements (Mann–Whitney U, $p < 0.05$).

From the reliability assessment of the IC of the eyes ROI in the IRT images, comparing the results of the three assessors, it can be observed in table 5 that the left and right ROIs have good data consistency and a very good ICC.

The Friedman's two-way analysis of variance by ranks test in table 6 shows that there is a higher variance in the left than in the right side of the methods studied in this research, the IC having the smallest rank.

Table 7 shows the repeated measures ANOVA comparing the mean bilateral differences per method; the only method with statistical evidence of rejecting the null hypothesis of discriminating the measured value per side in repeated measurements is the axilla.

Table 6. Friedman's two-way analysis of variance by ranks test per method.

Side	X^2 (2)	p	Mean rank		
			Axilla	Tympanic	IC of eye
Right	66.285	0.000	2.07	2.36	1.57
Left	77.344	0.000	1.91	2.47	1.62

Table 7. Repeated measures ANOVA comparing the mean bilateral differences per method.

Method	F	p
Axilla	12.098	0.001
Tympanic	2.333	0.128
IC of eye	3.716	0.055

Table 8. The intraclass correlation analysis per method.

ROI	ICC	ICC 95% c.i.	
		Lower	Upper
Axilla	0.695	0.617	0.759
Tympanic	0.451	0.335	0.553
Inner Canthi	0.978	0.971	0.983

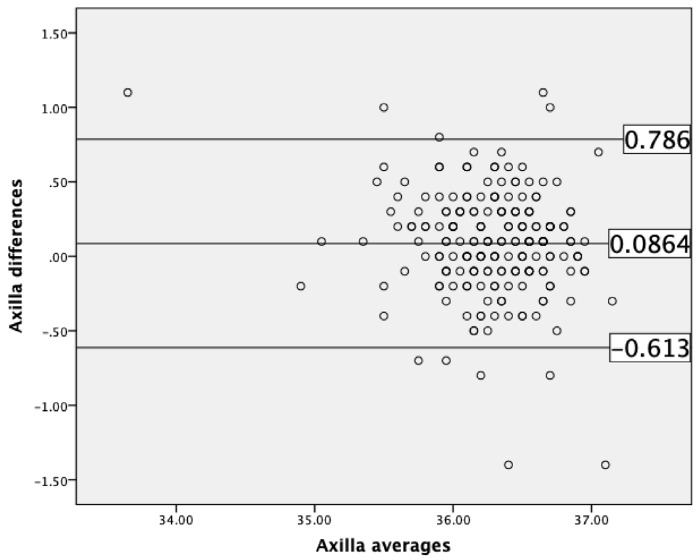

Figure 2. The limits of agreement for the axilla method.

Table 8 presents the ICC between both sides of each method of assessing the body core temperature; the only excellent bilateral association is in the IC using IRT imaging method.

A Bland-Altman analysis was performed to determine the limits of agreement of each body core temperature estimation method, having an axilla value of 0.7 °C (figure 2), tympanic membrane of 0.7 °C (figure 3) and IC of the eye of 0.1 °C (figure 4).

The correlation of the methods per side was also verified and only found statistical evidence between the axilla and the tympanic membrane in the right side and bilateral average ($p < 0.01$) being weak, as can be considered in table 9.

The negative correlations are respective to the order of relationship between the methods, and were found between the axilla and the IC of the eye on both sides and average, and between the tympanic membrane and the IC of the eye at the right side and average.

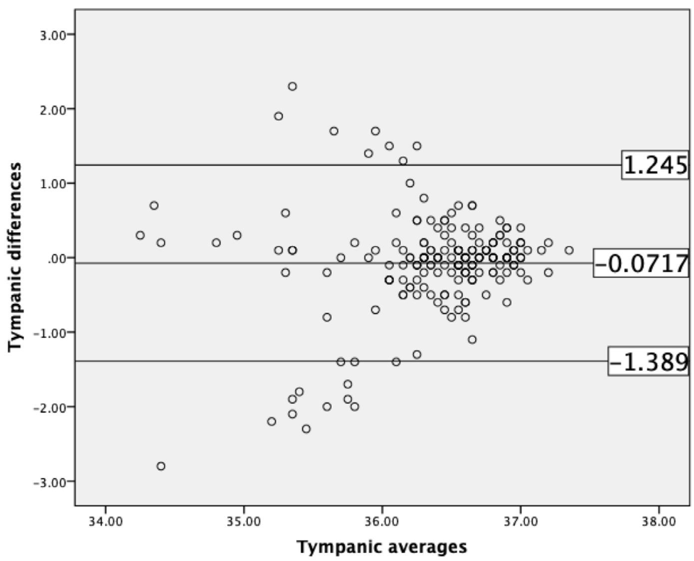

Figure 3. The limits of agreement for the tympanic method.

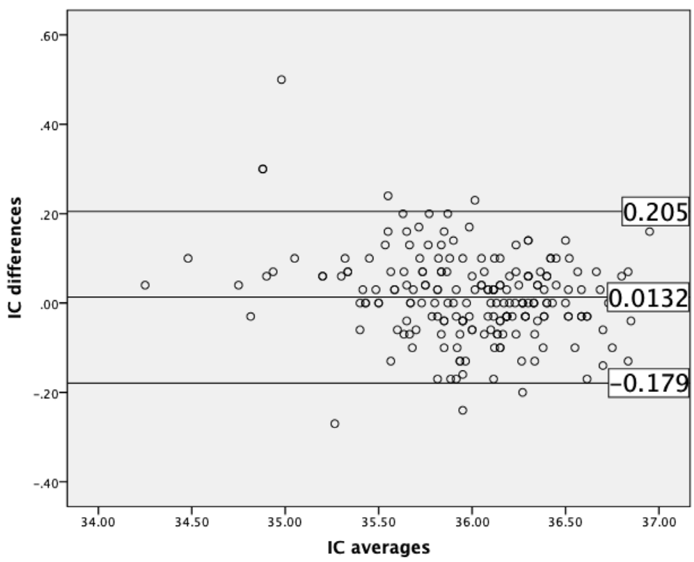

Figure 4. The limits of agreement for the IC of the eye method.

Table 9. Results of the correlations between methods considering the side and average.

Side	Method 1	Method 2	Spearman's rho
Right	Axilla	Tympanic membrane	0.203[a]
	Axilla	IC of the eye	−0.069
	Tympanic membrane	IC of the eye	−0.072
Left	Axilla	Tympanic membrane	0.127
	Axilla	IC of the eye	−0.059
	Tympanic membrane	IC of the eye	0.013
Average	Axilla	Tympanic membrane	0.186[a]
	Axilla	IC of the eye	−0.067
	Tympanic membrane	IC of the eye	−0.062

[a] $p < 0.01$.

4. Discussion

In this study the bilateral differences of mass screening body core temperature methods were assessed; all have been able of estimating an intrinsic error, as demonstrated by previous research (Fernandes *et al* 2016, Towey *et al* 2017). The axilla differences can be explained by the time of exposure as suggested by Perera *et al* (2014); the tympanic membranes are in line with what was demonstrated by Childs *et al* (1999), despite having a larger sample, and can be influenced by the amount of wax in the ear channel. The authors of the current research disagree with the previous study in their recommendation to always use the same site for consecutive assessments; perhaps a second complimentary method is more adequate than relying in this method bias.

From all the statistical results, the method that showed lowest bilateral variation is the IC of the eye through IRT imaging; it is also the most adequate for rapid assessments of masses. The intra-rater in the interpretation of the images showed that this method is reliable and reproducible. It is important to mention that the IC of the eye has the smallest limit of agreement and the highest ICC when comparing bilateral measurements. This can be due to the fact that this method is less susceptible to bias when compared with others, since the international recommended protocols for thermal imaging capture (Ring and Ammer 2000, Ammer 2008) and the standards for temperature assessment (ISO/TR 13154:2009 ISO/TR 8-600 2017, ISO TC121/SC3-IEC SC62D 2017) are followed and respected.

Body core temperature measurement at different sites can present differences due to a lack of a mechanistic relationship related with blood perfusion and local metabolic rates (Taylor *et al* 2014). Despite the IC of the eye measured with IRT being an appropriate method for core temperature estimation in mass screening of fever, it can be affected by exercise and recovery hyperthermia (Teunissen and Daanen 2011) and it must be validated for appropriate fever detection.

Su *et al* (2015) measured ocular surface temperatures with IRT, demonstrating that the method was effective in capturing temperature changes in ocular surface. However, this method is susceptible to being affected by factors such as topical analgesics and dry eye disease; a strict protocol is required to accommodate this.

In terms of speed and practicability, IRT assessment of the IC of the eye beats the other two studied methods: the readings are faster and provide a permanent record in an image, which can be improved through existing methods of eye detection in IRT images (Ng and Acharya 2009, Wang *et al* 2013) facilitating the ROI placement, enforcing repeatability; the outcomes can be also bettered through implementing a decision support system using machine learning (Vardasca *et al* 2018) in the identification of febrile subjects.

IRT offers an excellent means for a qualitative determination of IC of the eye temperature, but there are many difficulties in obtaining an absolute measurement, such as requiring a controlled environment, limiting the IR interference, positioning and initialization of the recording equipment, lack of training of the operators, the presence of artefacts in the subjects (e.g. ointments, masks, glasses, hats, scarfs), the presence of a temperature reference, proprietary camera file formats and complete ignorance of the existing standards at the existing screening locations. All of these can be addressed, but require time, awareness and training.

The correlation showed in the right and average between axilla and tympanic membrane methods is weak and can be casual, a justification as demonstrated by Taylor et al (2014) can be the differences in sites caused by the underlying physiology. Although in terms of ANOVA variability analysis the axilla was the only method with statistical evidence of rejecting the null hypothesis of discriminating the measured value per side in repeated measurements.

Subject sex showed statistical evidence of influence in the tympanic membrane assessments. This is difficult to understand; however, it affected more the left side and apparently the temperatures were higher in females than in males. It is worth mentioning that in this research the menstrual cycle was not taken into consideration and this may be a justification for such oscillations, since the tympanic membrane is a more invasive method than axilla and IC of the eye.

Reference data were produced for the three different methods of mass core temperature screening in a young west European population, filling an existing gap, and which should be considered in further research.

5. Conclusion

Based on the findings of this research, despite all methods being able to estimate body core temperature, it is suggested to use IRT images of the IC of the eye, since it is a fast, reliable and reproducible procedure for mass screening. However, the method requires validation with a reliable method, such as oesophageal or intravenous temperature measurement, and has to be implemented in a system of automatic reading and classification.

Further research is required to understand the higher bilateral variability in using the traditional axilla thermometer and tympanic membrane assessments, since these are the methods currently used within a clinical setup; the same procedure must be applied to fever cases to establish a decision threshold per method.

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