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Original Research

Comparison of Infrared Thermal Detection Systems for mass fever screening in a tropical healthcare setting

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ABSTRACT

Objectives: Fever screening systems, such as Infrared Thermal Detection Systems (ITDS), have been used for rapid identification of potential cases during respiratory disease outbreaks for public health management. ITDS detect a difference between the subject and ambient temperature, making deployment in hot climates more challenging. This study, conducted in Singapore, a tropical city, evaluates the accuracy of three different ITDS for fever detection compared with traditional oral thermometry and self-reporting in a clinical setting.

Study design: This study is a prospective operational evaluation conducted in the Singapore military on all personnel seeking medical care at a high-volume primary healthcare centre over a one week period in February 2014.

Methods: Three ITDS, the STE Infrared Fever Screening System (IFSS), the Omnisense Sentry MKIII and the handheld Quick Shot Infrared Thermoscope HT-F03B, were evaluated. Temperature measurements were taken outside the healthcare centre, under a sheltered walkway and compared to oral temperature. Subjects were asked if they had fever.

Results: There were 430 subjects screened, of whom 34 participants (7.9%) had confirmed fever, determined by oral thermometer measurement. The handheld infrared thermoscope had a very low sensitivity (29.4%), but a high specificity (96.8%). The STE ITDS had a moderate sensitivity (44.1%), but a very high specificity (99.1%). Self-reported fevers showed good sensitivity (88.2%) and specificity (93.9%). The sensitivity of the Omnisense ITDS (89.7%) was the highest among the three methods with good specificity (92.0%).

Conclusion: The new generation Omnisense ITDS displayed a relatively high sensitivity and specificity for fever. Though it has a lower sensitivity, the old generation STE ITDS system showed a very high specificity. Self-reporting of fever was reliable. The handheld thermograph should not be used as a fever-screening tool under tropical conditions.

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Introduction

The global outbreak of severe acute respiratory syndrome (SARS) in 2003 and the influenza A/H1N1 pandemic in 2009 has led to a proliferation of screening measures that aim to identify cases so that they may be isolated, thereby curbing transmission of respiratory diseases. The presence of fever as a diagnostic criterion for influenza-like illnesses has resulted in the widespread use of fever screening systems for rapid identification of potential cases for public health management.[1–6] As a substantial proportion of affected cases during SARS and the 2009 influenza pandemic had fever as their main symptom,[7] screening systems may identify some of the more severe cases that have a higher propensity for transmission.

Compared to traditional thermometry methods, Infrared Thermal Detection Systems (ITDS) have the advantage of being a time-saving, non-invasive and objective method of fever screening. Despite the widespread use of ITDS (e.g., at hospitals and airports), the initial experience of such systems during SARS suggested a low efficacy.[2,8–11] Since then, there have been further reports on mass screening of fever, with conflicting results.[8,12–19] To date, there are few clinical studies evaluating the various fever screening systems available, or the reliability of self-reported history of fever. As ITDS systems detect a difference between the subject and the ambient temperature, the deployment of these systems is more challenging in hot climates, either in tropical or subtropical regions where year round transmission of respiratory pathogens occurs, or in temperate countries during emerging outbreaks in summer months. This study, conducted in Singapore, evaluates the accuracy of three different ITDS for fever detection compared with traditional oral thermometry and self-reporting in a clinical setting.

Methods

Singapore is a tropical city in South-East Asia with diurnal daily temperatures of 23 °C and 34 °C. This study is a prospective operational evaluation conducted in the Singapore military on all personnel seeking medical care at a high-volume primary healthcare centre from 10 to 14 Feb 2014.

Device selection

Three ITDS—the STE Infrared Fever Screening System (IFSS) (Singapore Technologies Electronics, Singapore), the Omnisense Sentry MKIII (Omnisense Systems Ptd Ltd, Singapore) and the handheld Quick Shot Infrared Thermoscope HT-F03B (Shenzhen WTYD Technology Limited, Guangdong, China)—were evaluated. The STE ITDS was the first thermal imager based system in the world designed for mass human temperature screening, developed and deployed during the SARS outbreak of 2003.[20] The basic setup consists of a mounted thermal imager which uses a Thermal Reference Source (TRS) as a reference to display the temperature profile of the subject. Temperature is represented as an illustration of different colours on a real-time monitor, each of which corresponds to a particular temperature, and the user interprets a febrile subject based on the hot spots on the subject's skin surface (see Fig. 1A). The Omnisense Sentry MKIII is similar in setup to the STE IFSS, and has been marketed as a new generation ITDS with real-time calibration to ambient temperature with a claimed 0.1 °C accuracy. It also has a video capture device that is digitally synchronized to the thermal image, with a dual video display which sets off an automated alarm and visual auto-tracking of the target once a febrile subject enters the screening area (see Fig. 1B). It is in widespread use in various commercial buildings and hospitals locally. The Quick Shot Infrared Thermoscope is a handheld thermal scanner which displays the estimated core body temperature after it is directed a few centimetres from a subject's forehead, and is also widely used in the Singapore military, primary healthcare settings and childcare centres due to its portability and non-intrusiveness.

Participants and eligibility

Subjects who sought medical care at a high-volume primary healthcare centre in the military were included. The evaluation was conducted from 8:00 AM to 3:00 PM every day, as the majority of patients consulted in the morning. Eligible

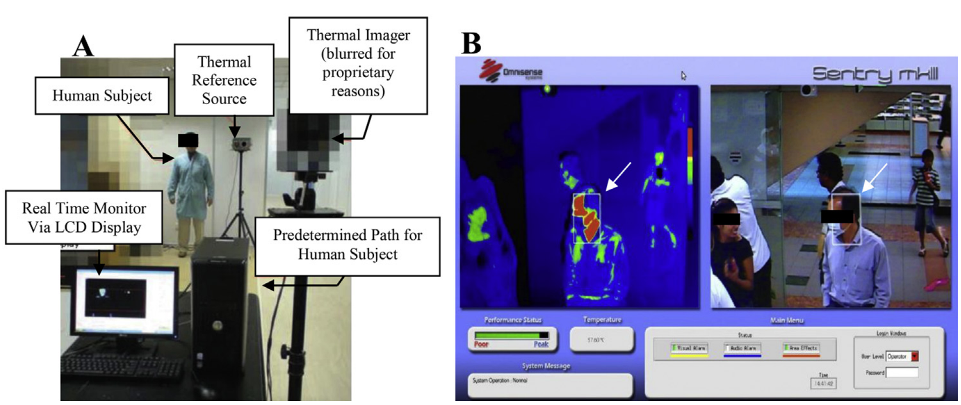


Fig. 1 – Basic ITDS Setup and the Omnisense Dual Video Monitor. (A) shows the STE ITDS, which illustrates the basic setup of the ITDS, with the STE ITDS video monitor in the foreground. (B) shows the Omnisense ITDS video monitor with auto-tracking of febrile subjects (white arrows).

subjects filled a questionnaire which included being asked, ‘Do you think you have a fever/feel feverish now?’ and whether they had taken medication for pain or fever (analgesic or antipyretic drugs) in the previous 24 h. Examples of trade and generic names of common analgesic/antipyretic drugs were provided. Their responses, along with the time and demographic data, were recorded. As the study was performed in a military setting, young males are over-represented relative to the population as a whole.

Temperature measurements

Temperature measurements were taken outside the healthcare centre, under a sheltered walkway. Participants were given at least 30 s rest to allow for adequate cooling down. The three ITDS were positioned at the optimal distance from each participant as recommended by the manufacturer. The camera fields of view for the Omnisense ITDS and STE ITDS were preset to include the subject's face and neck. Participants were asked to remove any headwear and instructed to walk along a predetermined route in single file.

Two independent trained observers were stationed at each of the Omnisense ITDS, STE ITDS and handheld infrared thermoscope ITDS screening stations, and were blinded to the findings from their co-observer and other thermometers. All the ITDS were calibrated to detect core body temperature based on adjusted skin temperatures, with a calibrated set-point of 37.5 °C core body temperature being a positive result.

The gold standard of oral temperature was measured by clinical staff (Digital Thermometer KT-DT4B; Hong Kong Capital International Electronics Co. Ltd, Guangdong, China), as per the healthcare centre's established protocol. ITDS temperature measurements were taken immediately before each oral measurement, and fever was defined as an oral temperature of ≥37.5 °C. Ambient temperatures were recorded hourly via the Wet Bulb Globe Temperature with the Questemp 32 Thermal Environment Monitor (3M, St Paul, Minnesota).

Statistical methods

With an estimated fever prevalence of 10% among a population of subjects presenting to the medical centre and an estimated correlation of more than 0.5 between two thermal scanners, it was proposed that a total sample size of approximately 600 subjects would be needed for this evaluation.

The questionnaire responses, ITDS recorded data and oral temperature measurements were entered into an Excel (Microsoft Corp., Redmond, WA, USA) database and analysed with the R Statistical Software 3.0.3 (R Foundation for Statistical Computing, Vienna, Austria).[21]

Self-reported fever, ITDS and oral temperature measurements were analysed with descriptive statistics. Intra-class correlation and Cohen's Kappa statistics are descriptive statistics to determine inter-observer variability for quantitative and categorical measurements made by different observers respectively. Inter-observer variability for handheld thermoscope (quantitative measurements) and other ITDS (categorical measurements) were therefore assessed via intra-class correlation and Cohen's Kappa statistics respectively. Univariate regression models were conducted to investigate variables (age, sex, recent analgesic/antipyretic use, time of day and ambient temperature) which could be associated with temperature measurements and to identify factors that influenced the difference between oral and ITDS temperature measurements. Linear regression models were used if the outcome variable is a handheld thermoscope measurement and logistic regression models were used if the outcome variable is a self-reported fever or ITDS measurement. Factors that were significant at a significance level of 0.05 were included in the final multivariate linear or logistic regression models. All tests were assessed at a significance level of 0.05.

Sensitivity (the proportion of those with confirmed fever identified as febrile by ITDS/self-report) and specificity (the proportion of those who are confirmed afebrile and were identified as afebrile by ITDS/self-report) were calculated. To examine the difference in sensitivity and specificity, McNemar's test was conducted.

Results

Demographic data and baseline data

There were 430 subjects screened, with a predominantly male population (99.1%), of whom 34 participants (7.9%) had confirmed fever as determined by oral thermometer measurement. Table 1 shows the demographic attributes of the participants. There were 52 participants (12.1%) who reported fever, and the number of fever cases detected by the handheld infrared thermoscope ITDS, STE ITDS and Omnisense ITDS were 29 (6.7%), 21 (4.9%) and 66 (15.3%) respectively. Ambient temperatures ranged from 25.7 °C to 35.7 °C, which were consistent, or slightly warmer, than the range of temperatures experienced in Singapore (23 °C–34 °C).

Table 1 – Baseline characteristics of study population.

Baseline characteristics	*n* (%)
Total	430 (100)
Age (years)	19.8[a]
Race	
Chinese	373 (86.7)
Malay	17 (3.6)
Indian	32 (7.4)
Others	8 (1.9)
Sex	
Male	426 (99.1)
Female	4 (0.9)
Recent analgesic/antipyretic use	53 (12.3)
Fever detected	
Self-reported fever	52 (12.1)
Fever detected by handheld infrared thermoscope ITDS	29 (6.7)
Fever detected by STE ITDS	21 (4.9)
Fever detected by Omnisense ITDS	66 (15.3)

ITDS, Infrared Thermal Detection System.
[a] Mean.

Table 2 – Significant bivariate and multivariate associations[a] of thermometry measurements. Odds ratios for possible readings are reported.

Factors	Handheld infrared thermoscope ITDS		STE ITDS		Omnisense ITDS		Self-reported Fever	
	Gradient (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Significant Bivariate Associations								
Analgesic/antipyretic use	−0.04 (−0.18, 0.10)	0.56	1.03 (0.99, 1.07)	0.21	1.13 (1.06, 1.22)	<0.001	1.13 (1.03, 1.24)	0.01
Ambient temperature (°C)	0.02 (0.00, 0.04)	0.04	1.00 (0.99, 1.00)	0.19	1.00 (1.00, 1.01)	0.34	0.98 (0.97, 0.99)	<0.001
Significant Multivariate Associations								
Analgesic/antipyretic use	–	–	–	–	1.1 (1.03, 1.18)	0.01	1.08 (0.99, 1.19)	0.08
Ambient temperature (°C)	0.02 (−0.01, 0.06)	0.14	–	–	–	–	0.98 (0.96, 1)	0.02

ITDS, Infrared Thermal Detection System; OR, odds ratio; CI, confidence interval.
[a] All analyses (logistic and linear regression) were adjusted for factors that showed significant effects in the univariate regression analysis.

Univariate analysis/multivariate analysis

In univariate analysis (see Table 2, Figs. 3 and 4), fever detected by Omnisense ITDS was positively associated with those taking antipyretics/analgesics, while the handheld infrared thermoscope ITDS readings were found to be negatively associated with higher ambient temperature. Self-reported fever was positively associated with antipyretics/analgesics, and was negatively associated with higher ambient temperature.

In multivariate analysis (Table 2), Omnisense ITDS was positively associated with subjects previously having taken antipyretics/analgesics, while self-reported fever remained negatively associated with high ambient temperatures.

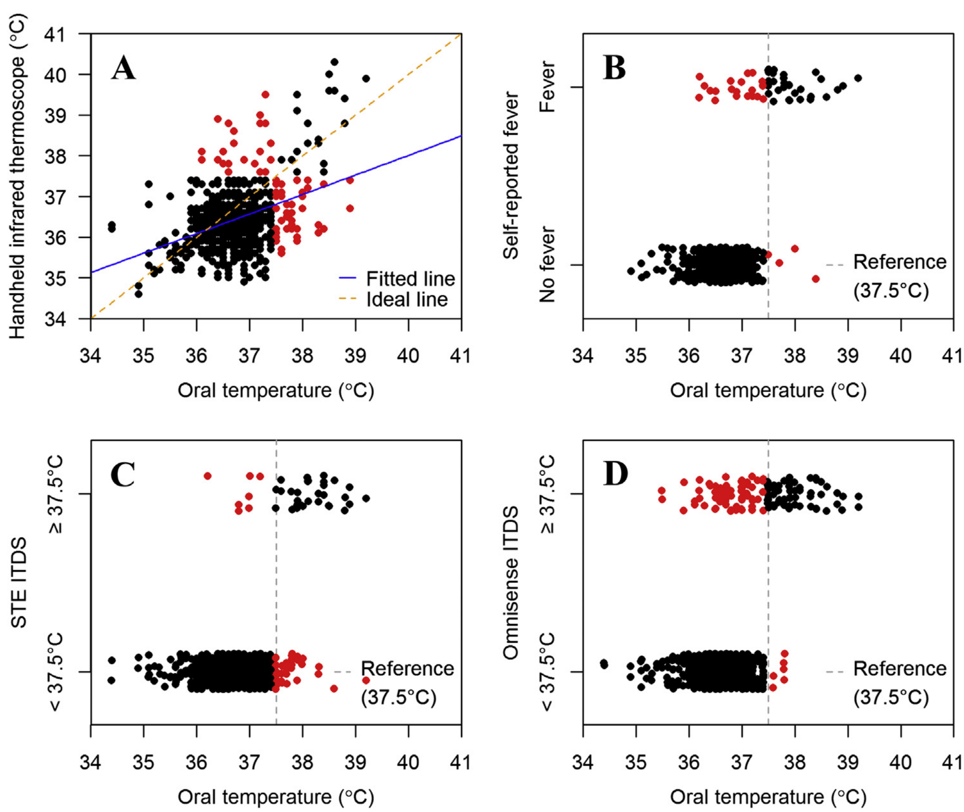
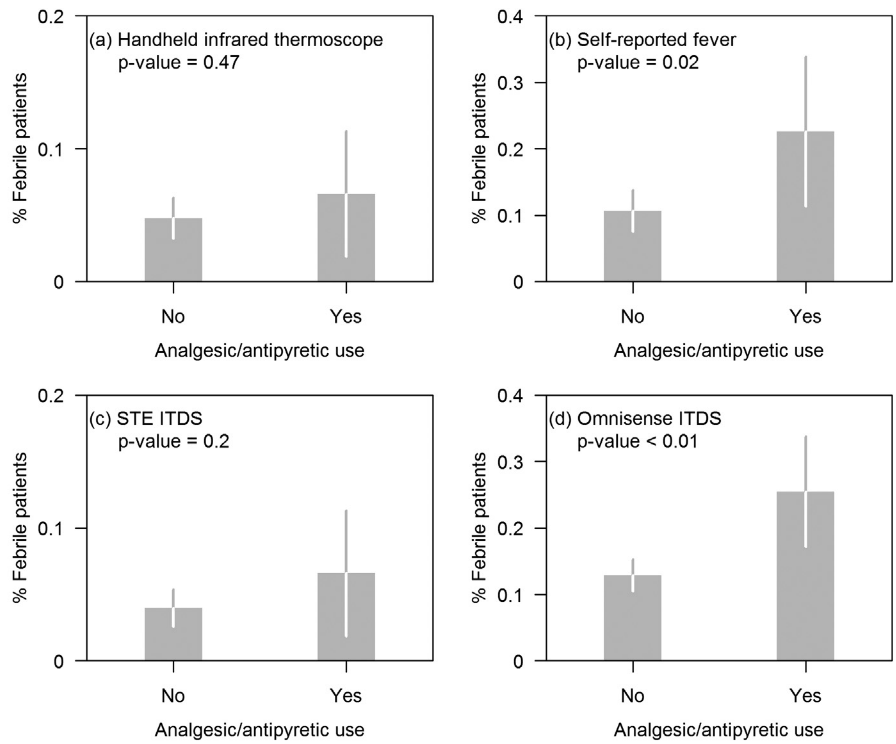


Fig. 2 – Summary of the comparisons between the oral temperature and fever screening methods, (A) handheld infrared thermoscope ITDS, (B) self-reported fever, (C) STE ITDS and (D) Omnisense ITDS. Random jitters are added to separate the overlapping points on all panels. On panel (A), the fitted line is obtained using the univariate regression analysis, while the ideal line features the perfect situation when the temperatures measured by the fever gun exactly match the oral temperatures. Misclassified records measured by any of the four thermal screening methods are coloured in red, while the correctly classified records are in black. ITDS, Infrared Thermal Detection System. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



[a]Bars with whiskers, which show 95% confidence interval, represent empirical means of FRI positives. P-values were calculated using fisher's exact test.

Fig. 3 – Proportion of Febrile Patients Stratified by Analgesic/Antipyretic Use for Each Fever Screening Method.[a]

Inter-observer variability

There was no inter-observer variability for all the three ITDS. The intra-class correlation coefficient was 0.86 (95% CI 0.84–0.89) for the two handheld infrared thermoscope ITDS, which indicated a strong agreement between the two observers. The proportions of agreement above chance were 0.86 and 0.92 for the STE ITDS and the Omnisense ITDS respectively which imply strong agreements.

Sensitivity and specificity

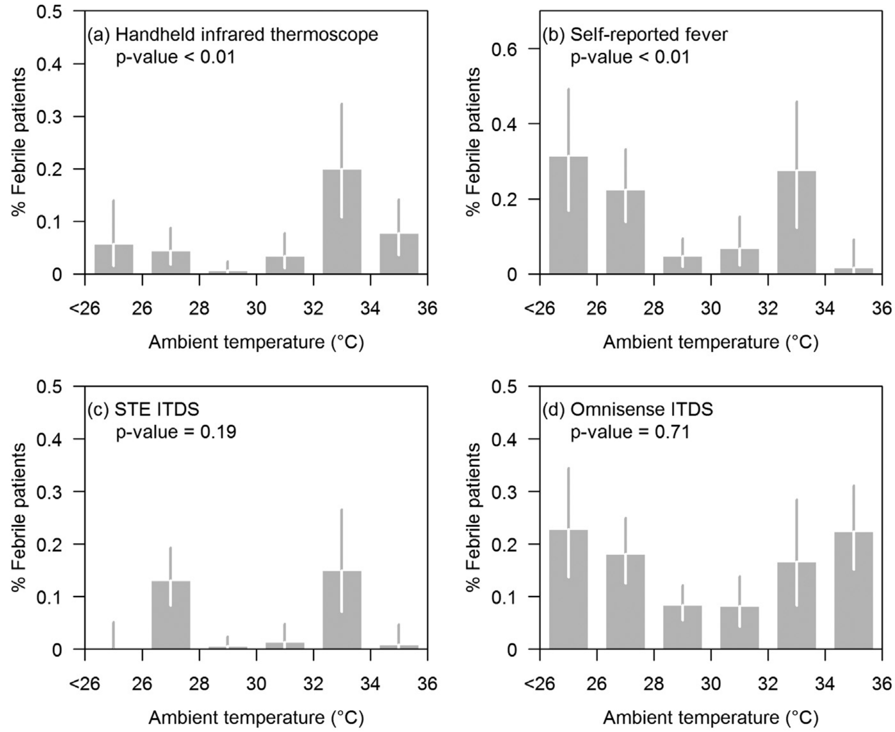
A comparison of the four thermal screening methods is presented in Fig. 2. The older STE ITDS failed to identify almost half of the febrile cases. The Omnisense ITDS was able to pick up about 80% of the febrile cases. However, around 8% of the negative cases were misidentified as positive by the scanner. Self-reported fever also represented a high percentage of fever cases.

The handheld infrared thermoscope ITDS had a very low sensitivity (29.4%), but a high specificity (96.8%, Table 3). The STE ITDS had a moderate sensitivity (44.1%), but a very high specificity (99.1%). Self-reported fevers showed good sensitivity and specificity (88.2% and 93.9%, respectively). The differences in sensitivity and specificity between the STE ITDS and Omnisense ITDS were significant (both $P < 0.01$). The sensitivity of the Omnisense ITDS was the highest among the three methods. Hence, it performed well in terms of ruling out the disease when the true result was negative. It had a slightly lower specificity compared with the STE ITDS and the handheld infrared thermoscope ITDS.

Discussion

Thermography is a non-invasive and rapid screening method for body temperature. It has widespread use in medical imaging and engineering applications,[22] and much focus has been placed on the screening of fever for disease diagnostic purposes. Various studies have examined the role of ITDS for fever screening at airports,[8,23] emergency departments[12,14] and outpatient consultations[15] over a range of age groups.[13,24] Caution has been expressed in the use of ITDS, due to several confounders, including individual factors, the targeted body area and environmental factors.[13,14,25] This evaluation was therefore conducted to evaluate current fever screening technology in the context of high ambient temperature.

There was an overall prevalence of 7.9% fever in our evaluation, which is similar to the prevalence of febrile subjects for an outpatient setting in other studies.[17,26,27] The Omnisense ITDS had a very high sensitivity, comparable or superior to recent studies.[13,26,28,29] Importantly, all of the false negative cases had low grade fever not greater than 37.8 °C, suggesting that false negatives were mainly confined to low grade pyrexia. If the definition for fever in the context of the WHO case



[a]Bars with whiskers, which show 95% confidence intervals, represent empirical means of FRI positives. P-values were calculated using chi-square test for trend.

Fig. 4 – Proportion of Febrile Patients Stratified by Ambient Temperature for Each Fever Screening Method.[a]

definitions for SARS and influenza-like illness were used (≥38.0 °C), an even higher proportion of febrile cases would have been detected in this evaluation. However, this is just a hypothesis, as the use of 38.0 °C as a definition for fever was not tested in our study.

The Omnisense ITDS was also noted to have a relatively high specificity of 92%. Recent advances in infrared thermography, including sophisticated image analysis and processing, automated target recognition and reduced observer dependence are postulated to be responsible for improved detection rates.[22] Feedback from the observers highlighted easier visualization with dual video, automated alarm for febrile cases and clearer delineation of hot spots as factors for the easier identification of febrile cases.

All of the systems trade off sensitivity with specificity. In a setting where secondary evaluation is available or during a pandemic with high illness severity, it is preferable to have false positive cases instead of false negatives to prevent the spread of public health threats. The false positive rate for the next generation ITDS is relatively low at 7.4%. False positive cases can easily undergo a confirmatory oral temperature test with a minimal increase in workload. The converse is not true, as a high negative rate may allow undetected infected cases through.

The STE ITDS showed a low sensitivity in detecting febrile cases, possibly due to inconsistent performance in environments with varying ambient conditions.[20] Moreover, visualization of febrile subjects on the display monitor is labour intensive, requiring the user to distinguish temperature on a low-resolution colour scale from the display monitor. Adequate training of observers on the identification of febrile subjects on the display monitor is also critical, as there is a spread of possible scenarios (such as size and intensity of red patches on the head regions). These factors may have resulted in the STE ITDS failing to detect nearly half of the febrile cases. The observers in this evaluation found that a high degree of attention was required for the STE ITDS, and subjective identification of febrile cases based on the distribution of hot zones made the screening process highly user-dependent. However, although the STE ITDS may be too insensitive to be used as a mass-screening test for fever in environmentally uncontrolled situation, it may be useful as a rule-in test when fever is already suspected, e.g., self-reported fever, due to its high specificity. Based on these findings, the SAF has undertaken an update of its fever screening systems.

Table 3 – Sensitivity and specificity of various fever screening methods.

Methods	Sensitivity	Specificity
	Mean (95% CI)	
Handheld infrared thermoscope ITDS	29.4% (25.1%, 33.7%)	96.8% (95.2%, 98.5%)
STE ITDS	44.1% (39.4%, 48.8%)	99.1% (98.2%, 100%)
Omnisense ITDS	89.7% (86.8%, 92.6%)	92.0% (89.5%, 94.6%)
Self-reported fever	88.2% (85.2%, 91.3%)	93.9% (91.7%, 96.2%)

CI, confidence interval; ITDS, Infrared Thermal Detection System.

The handheld infrared thermoscope ITDS showed a low sensitivity. Various variables for the poor performance of handheld infrared fever screening devices have been previously identified in various studies.[14,17] A chief factor may be that the outdoor temperature had a far larger confounding effect on the handheld thermoscope ITDS compared to the other ITDS, especially when utilized without a dedicated TRS, resulting in a positive association with the ambient temperature on univariate analysis. This may have led to the preset threshold cut off temperatures becoming inaccurate if the environmental condition changes.[14] Though admittedly convenient, mass screening for febrile subjects should not be encouraged with the handheld infrared thermoscope ITDS, due to the high rate of false negative results.

Self-reported fever showed high sensitivity and specificity. While self-reported fever is arguably the easiest screening method, it should be noted that in a pandemic there may be incentives to avoid self-reporting.[30] Our evaluation also found that at a high ambient temperature, participants are less aware of true fever, suggesting that ambient temperature may interfere with one's own sense of core body temperature. The positive association with fever medications is expected given that one would be on fever medications after reporting fever.

Most studies have evaluated fever screening in a controlled air-conditioned environment, be it in the inpatient, emergency department, or airport setting, where minimal fluctuations in ambient temperatures are expected. However, patient numbers may overwhelm existing front line healthcare resources (such as emergency departments, clinics) during a pandemic, and surge capacity in the form of outdoor triage may be required for infection control measures.[31,32] This may present difficulties in the tropical setting, where large fluctuations in the diurnal temperatures in a single day may affect temperature measurements, including that of self-reported fever. Moreover, traditional methods of fever measurement through oral and tympanic thermometers are time-consuming and require close contact with potentially infectious patients. In such situations, the next generation ITDS can be employed for mass fever screening as it has a high throughput capability, with an acceptable sensitivity and specificity found in this study. However, it would require logistical arrangements to be made in that the subjects have to walk past the scanners along a predetermined route in single file within a sheltered (though not air-conditioned) area at a triage station. We feel that this can be easily incorporated as part of the existing workflow in a hospital or clinic setting.

It should also be noted that fever is not a constant phenomenon during an infectious disease episode, and analgesic/antipyretic drugs may have been taken by subjects. ITDS do not identify afebrile cases or exposed individuals during the incubation period, which is a major limitation of screening in preventing importation of disease. However, such screening methods may reduce the magnitude of importation, and during an epidemic reduce disease spread in specific areas. Despite its advantages, caution has been expressed on the solitary use of ITDS for mass screening at points of entry, especially in a non-epidemic setting. Surveillance and contact tracing also play keys roles in the mitigation of a potential pandemic.[15] However, in a pandemic influenza scenario, one may expect a higher prevalence of fever and as a result a higher predictive value of the mass fever screening modalities. In such a setting, the ITDS would play a more prominent role in rapidly identifying potentially infectious cases for public health management.

Limitations

Due to variations in body physiology, technique or measurement, oral thermometry does not always reflect true core body temperature. However, it is a commonly utilized method for fever screening, and is what our military uses on a routine basis, and hence was preferred as the gold standard for this study over tympanometry, which is the preferred gold standard in other settings but which is documented to be less accurate than oral thermometry.[26] The study population, being military servicemen, was predominantly of a young male demographic, and therefore not reflective of the entire population. This may impact the study findings; for example, the elderly may have a lower core temperature during infection, due to an attenuated inflammatory response, and therefore the sensitivity in diagnosing infections of all the screening measures considered may be lower in the population as a whole. Additionally, this study has an under-representation of females, in whom pregnancy, menstruation or hormonal treatments may cause variation in the external skin temperature, thereby influencing our results.[13] This evaluation was only conducted in one healthcare centre over one month. A multicentre study conducted over a longer time period would be useful to assess if the findings could be generalized to a pandemic situation which may be substantially longer than one month, and where fever screening would be utilized in various settings including border control and airports. However, given the lack of seasonality in equatorial Singapore, the weather during the month in which the study was performed is very similar to that throughout the rest of the year, the monsoon season excepting, and therefore we anticipate that the duration of the study will not limit the generality of our findings.

Conclusion

The new ITDS technologies displayed a relatively high sensitivity and specificity for fever. Though it has a very high specificity, the older ITDS system showed a lower sensitivity. Self-reporting of fever was reliable; however the handheld thermograph should not be used as a fever-screening tool based on its very low sensitivity.

Author statements

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Ethical approval

Not required. As this was a non-interventional operational evaluation, under the institutional research guidelines, the

Joint Medical Committee 04/14 granted exemption from review and written informed consent.

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None declared.

Competing interests

None declared.

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