

Reliable industrial measurement of body temperature

The use of infrared thermometry of tympanic temperature to determine core body temperature in industrial conditions

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Abstract

This study explored the potential use of infrared (IR) thermometry, measuring the temperature within the ear canal, as a relatively non-invasive indicator of the risk of heat stress in industrial applications. Measurements of body temperature using this technique, benchmarked against the intragastric (IG) temperature pill, were obtained from workplaces in the glass manufacturing and refractories sectors. Analysis of the more than 250 data pairs obtained showed that the variability in the IR temperature readings was too great for such measurements to be used to predict actual core temperature (as indicated by IG temperature). Further analysis initially suggested that it could be used as a monitoring or screening tool to ensure that core temperature was not exceeding a critical level. However, when the outcome was adjusted to reflect the inter-subject variability, the variance in the data set was too large to permit the core temperature to be predicted with sufficient confidence to allow it to be used, even as an initial measure to flag a need for more accurate measurement. There are indications from the literature that the make of measuring instrument used and the technique adopted in their use are important sources of variation. It remains to be seen whether refinements to the technique used, either in the manner of use or the circumstances of use, reduce this variance to a more satisfactory level.

Executive summary

Heat stress is recognised as a potential problem in many industries. Existing control measures rely heavily on the use of thermal indices to assess the risk imposed, although it is recognised that these indices are conservative and often restrict work unnecessarily, and that the range of thermal environments over which they have been validated is limited, frequently not extending to the impact of wearing protective clothing and other forms of personal protective equipment (PPE). Even where they provide reliable estimates and risk reduction measures are introduced, good working practice advocates that it should not be assumed that such measures are effective. Measurement of physiological parameters, particularly body temperature, is often seen therefore either as an adjunct to the use of such indices or as an alternative.

Rectal temperature has widely been regarded as the 'gold standard' for indicating core body temperature. However, changing social attitudes mean that this is now rarely regarded as socially acceptable for industrial monitoring.

In recent years, intragastric (IG) temperature (measured using a temperature-sensitive radio-pill) has increasingly replaced the use of rectal temperature as a measure of core body temperature. Evidence from the scientific literature is presented to support this view. However, practical and cost issues mean that it is not a viable method for routine monitoring.

Technological advances mean that new measures, such as the use of infrared (IR) sensors to measure tympanic temperature, theoretically provide a solution for industrial monitoring. Opinions vary as to the reliability of this approach, especially outside the clinical environment. Evidence from the scientific literature is mixed, although there is sufficient positive evidence to suggest that it could provide an adequate monitoring measurement.

Against this background, a study was conducted to investigate the use of IG temperature (as measured by a temperature-sensitive radio-pill) as a 'gold standard' to validate the routine use of the measurement of tympanic temperature using a hand-held IR device in industrial settings.

Repeated, timed measurements were obtained of IG and IR temperatures on workers operating in high temperatures. Volunteer workers swallowed the disposable IG temperature pills and their core temperatures, as reflected by this device, were subsequently logged. Periodically, timed measurements were also obtained by IR sensors. Data were also collected relating to environmental temperature exposures and work activities.

These data were used to generate statistically robust predictions of the levels of the accuracy and reliability obtainable with IR measurement of body temperature.

The results showed that IR temperature recordings were not sufficiently consistent to allow them to be used to directly predict core (IG) body temperature with a satisfactory degree of accuracy. Supplementary analyses showed that additional data, such as environmental temperatures and levels of physical activity, did not allow any greater degree of reliability in such predictions.

Further modelling was used to establish a predictive relationship which would allow a limiting criterion to be established and measured. However, when a more complete regression was determined, using complex modelling to allow for the interrelationship between sets of data obtained from the same subject, the confidence intervals widened and the predictive value diminished to the point at which IR temperature measurements would not appear to be sufficiently reliable or accurate to serve as a viable screening measure.

Therefore, it is suggested that this measurement should not be used as a screening tool to determine the possible presence (or otherwise) of a significant risk of heat stress. Several factors have been identified which potentially contribute to this variability. It remains to be seen whether, with better control of selected factors, the accuracy and reliability of the measurement approach can be improved to a level where its use could be endorsed.

Several caveats must be placed on this approach. It is clear that the technique used to obtain IR measurements is important and that certain safeguards must be adhered to relating to how and where measurements are obtained. A related issue is the possibility that interindividual differences in technique might contribute to the overall accuracy (or inaccuracy) of the technique. Furthermore,

there is evidence that different makes of instrument result in different temperatures being recorded. At present, therefore, this conclusion is strictly only valid for the make of instrument used in this study.

As well as presenting the results from this work, the report also includes more general guidance on the management and prevention of the risk of heat stress and on the nature of heat-related illness.

1 Background

Heat stress is recognised as a potential problem in many industries, including brickmaking (kiln work), metalworking (steel and precious metals), asbestos clearance and glassmaking. Existing control measures rely heavily on the use of thermal indices to assess the risk imposed, although it is recognised that these indices are conservative and often restrict work unnecessarily as a result. In addition, the range of thermal environments over which they have been validated is limited (and frequently does not extend to the impact of wearing protective clothing and other forms of personal protective equipment (PPE)). Even where they provide reliable estimates and risk reduction measures are introduced, good working practice advocates that it should not be assumed that such measures are effective. Measurement of physiological parameters, particularly body temperature, is often seen therefore either as an adjunct to the use of such indices or as an alternative.

Over the last 50 or so years, many approaches have been advocated for the measurement of core body temperature. Many of the 'benchmark' studies used rectal temperature, seen for years as the 'gold standard' to compare other measures against. However, changing social attitudes mean that rectal temperature is rarely regarded as an acceptable measure in experimental, let alone occupational, spheres. Alternatives, such as predictions based on skin temperature, or ear canal (aural) measurements, have their proponents but have been shown to be unreliable and not always practicable.

For example, recent, as yet unpublished research for the emergency services has suggested that a form of skin temperature monitor might provide a viable approach. However, there are clear suggestions that its viability might be restricted to circumstances where the wearer is using totally enclosed clothing (eg a gas-tight suit) and the measurement procedure currently falls well short of a robust industrially useable tool.

In recent years, intragastric (IG) temperature (measured through the use of a temperature-sensitive radio-pill) has increasingly replaced the use of rectal temperature as the definitive measure of core body temperature. However, practical issues mean that it is not a viable method for routine monitoring. For example, detailed studies of the use of IG temperature pills have shown that they must be ingested the evening before the exposure to be measured if accurate temperature readings, unaffected by ingested food and drink, are to be obtained. The technique also has significant cost implications, with the capital cost of equipment (as well as the disposable pills) possibly rendering it unsuitable for routine industrial use.

Technological advances mean that new measures, such as the use of infra-red (IR) sensors to measure tympanic temperature, theoretically provide a solution for industrial monitoring. (It is recognised that this measurement may not provide a specific tympanic temperature. However, for convenience it will be referred to as such in this report.) Opinions vary as to the reliability of this approach, especially outside the clinical environment. However, prior experience has suggested that many of these problems can be overcome by careful attention to technique and that it might therefore offer a viable, robust measure. For example, previous (unpublished) studies by the Institute of Occupational Medicine (IOM) have found the measuring equipment itself to be susceptible to changes in temperature, giving inaccurate readings if taken in a different thermal environment. However, it appears that this can largely be overcome by allowing the equipment to equilibrate to the new environment, after which it will provide more reliable values. Similarly, it is clear that correct placement or alignment of the sensing probe is important but again, adopting and adhering to a consistent technique can overcome these problems.

2 Aims and objectives

Against this background, it was proposed to carry out a study to investigate the use of IG temperature (as measured by a temperature-sensitive radio-pill) as a 'gold standard' to validate the routine use of the measurement of tympanic temperature using a hand-held IR device in industrial settings. It was intended that repeated, timed measurements would be obtained of IG and IR temperatures on workers operating in high temperatures to allow statistically robust predictions of the levels of accuracy and reliability obtainable with IR measurement of body temperature. These were to be used to establish a viable, practicable procedure for the routine monitoring of levels of heat strain among industrial workers.

The overall objective of the proposed research was thus to devise a predictive relationship between IR and IG temperatures to enable the reliable use of IR temperature to monitor core body temperature in industrial environments.

Specifically, the research sought to meet the following aims:

- to collect and collate paired body temperature data using IG and IR measurements in the gut and ear canal respectively
- to use these data sets to establish the accuracy and reliability with which IR temperature can be used as a predictor of IG temperature
- to use time-series data for IG temperatures to determine the influence on the relationship of any temporal slip between IR and IG temperatures
- to use environmental (climate) data to examine the potential distortion of any relationship by demanding thermal environments such as localised radiant heating
- from this, to document and publish a robust procedure for the industrial measurement of IR temperature as a reliable indicator of IG (core) temperature – or to document and publish the reasons why it should not be used.

3 Overview of the literature

3.1 General

It has long been recognised that core temperature measurements from different locations in the body differ from each other. For example, Edwards¹ illustrated both the absolute difference and temporal differences between measurements such as rectal temperature and oesophageal temperature. BS EN ISO 9886² (*Evaluation of thermal strain by physiological measurements*) lists seven different approaches:

- oesophageal
- rectal
- gastro-intestinal or intra-abdominal
- oral (sublingual)
- tympanic
- auditory canal
- urine.

Others, such as that obtained via a catheter in the pulmonary artery, are only viable in clinical settings.

Although the ease of obtaining measurements has evolved since the widespread use of classical mercury-in-glass thermometers, a number of these are of doubtful acceptability to an industrial workforce. Thus oesophageal temperature, in which a transducer is threaded down the throat, is rarely measured, and rectal temperature measurement, while considerably less invasive, is usually regarded as socially unacceptable. Urine temperature is measured in a collecting device (not through catheterisation) and, as BS EN ISO 9886 states, is dependent on the quantity of urine in the bladder. Consequently, while it may be acceptable for one-off measurements, it is unlikely to provide a suitable avenue for regular, repeat measurements (even less so for continuous monitoring).

As a general rule, measurement at deeper or more stable sites yields more reliable (and generally higher) temperatures, hence the benefits of using a measurement such as rectal temperature where the high tissue mass acts as a buffer against brief fluctuations and isolates the measurement site from external influences. However, these characteristics can also have adverse consequences. For example, Leithhead & Lind³ draw attention to the relatively sluggish response of rectal temperature in conditions of high heat stress, indicating that, in such circumstances, incapacitation due to the heat could occur before rectal temperature indicated its imminence.

The challenge, therefore, is to find a measurement approach which is acceptable and practicable as a monitoring method in industrial settings, sufficiently labile to respond appropriately to increases in body heat storage, and sufficiently stable not to be excessively modified by external temperatures.

3.2 Selection of possible measurement sites

3.2.1 Benchmark

From the medical and scientific literature, it seems that pulmonary artery (PA) temperature is widely regarded as the 'gold standard' for body temperature measurement (eg Fulbrook⁴). However, the insertion of an arterial catheter is clearly highly invasive and, even in a clinical setting, is only used where the patient's clinical needs demand it.⁵

O'Brien *et al.*⁶ reported on a comparison between the use of the ingestible IG temperature pill and rectal and oesophageal temperatures. Both hot and cold conditions were studied using the somewhat unusual exposure medium of cold (18 °C) or warm (36 °C) water, combined with rest or exercise. The latter was used intermittently to generate an oscillating temperature load.

Oesophageal and IG measurements gave the closest agreement with rest in cold water but none of the other experimental conditions identified any significant differences between measurement sites, although it was noted that IG temperature tended to be intermediate to those from the other two sites. This was not unexpected given their anatomical relationship to each other.

It was clear from graphical plots, however, that the IG pill temperatures closely mirrored those from the oesophageal sensor. In cold conditions, rectal temperature diverged from the other two, displaying progressively lower temperatures with a widening differential.

Lee *et al.*⁷ reported on a comparison between oesophageal, rectal and intestinal temperatures using physical exercise as a means of generating an applied heat load (metabolic heat). Initial resting temperatures were not significantly different, but in keeping with expectations, oesophageal and intestinal measurements increased more rapidly and to a higher level than rectal temperature.

Similarly, following exercise, oesophageal temperature in particular dropped more rapidly. Intestinal temperatures displayed lower variance, suggesting relative stability. The authors concluded that intestinal temperature could be used as a viable alternative to oesophageal temperature.

On the basis of these two studies, therefore, it seems that IG temperature, measured using an ingestible pill, provides a good basis for a putative benchmark for the proposed study. It appears to be relatively unobtrusive and socially acceptable while potentially providing a valid, reasonably accurate measure of core body temperature.

Most authorities seem to accept that the concept of a single, uniform core temperature throughout the body is misleading. A temperature gradient between the peripheral tissues and the inner structures can be expected and, as referred to above, areas of greater tissue density, such as the rectum, are likely to display a degree of thermal lag. Unlike most core temperature measurement sites, that for IG temperature is not fixed. The locus of the measurement clearly changes as the ingestible sensor pill traverses the gastro-intestinal tract until it is eventually expelled. Clearly some variation in measured temperature and/or responsiveness can be anticipated during this journey. In addition, the sensor pill remains in the stomach for some time and is therefore subject to the temperature of any food or drink ingested during this period. As early as 1962, Fox *et al.*⁸ reported that the departure of the pill from the stomach can be established by observing the effect of a small amount of cold water.

Brake & Bates⁹ illustrate dramatic falls in IG temperature caused by drinking cold water, apparently soon after ingesting the sensor pills (the time of ingestion is not given), although temperatures appear to have been restored almost equally rapidly after a relatively short time.

Wilkinson *et al.*¹⁰ studied this phenomenon systemically. Subjects each swallowed two sensor pills (transmitting on different frequencies). One was swallowed the evening before the study (following the commonly recommended practice), approximately 11½ hours before the measurement period. In a subsample of volunteers, rectal temperature was also measured as a further comparator.

Results from this subgroup showed that IG temperature closely mirrored rectal temperature, although it was on average 0.15 °C higher. Graphical presentations of comparisons between rectal temperature and the temperature recorded by the first sensor pill showed no apparent influence of water ingestion 12½ or more hours after the pill was swallowed.

In contrast, graphical displays of comparisons between this pill and that swallowed at the onset of measurement show a clear, systematic influence. Although the impact diminished progressively with each hourly water ingestion (such that those at five or six hours after onset showed no effect), the effect returned in a small group of individuals thereafter, with one subject displaying a 6 °C reduction in measured temperature after ingesting 250 mL of water at 5–8 °C eight hours after the initial ingestion. The authors hypothesise that, by this time, the pill is no longer residing in the stomach but has passed into the small intestine, where the close proximity of loops of intestine to the stomach allows for the conduction of cooling through the stomach and intestinal walls. Thus, although six to eight hours is usually enough to enable the IG pill to be used reliably, it is nevertheless possible that the temperature of ingested drinks (or food) can continue to exert an influence periodically thereafter.

Subject to simple precautions, it seems that IG temperature, measured using an ingestible sensor pill, provides an acceptable, reliable and reasonably accurate measure of core temperature. This view was also reached by Byrne *et al.*,¹¹ who recently reviewed 12 different studies comparing IG temperature against core temperature measured in the oesophagus or rectum. The authors concluded that this approach gave a valid measure of core temperature that was suitable for 'ambulatory field-based applications'. It was therefore selected as the benchmark comparator for this study.

3.2.2 Simple measurement

None of the other measures listed by BS EN ISO 9886² are without their problems.

Oral (sublingual)

The transducer is placed underneath the tongue. When the mouth is open heat exchange between the mouth and the external environment will influence the internal temperature. For this reason it is advocated in the standard that the sensor should be in place for some 5–8 minutes before a temperature is taken, and that there should be no drinking, eating or smoking for 15 minutes beforehand. Even with the mouth closed, BS EN ISO 9886 states that the temperature can still be influenced by external factors such as strong radiant heat.

Tympanic

Tympanic temperature is strictly that of the tympanic membrane (ear drum) rather than that of the ear canal. As the standard indicates, physical contact between any sensor and this membrane is painful and so previous practice has been to position the sensor as close as possible without actually touching. Given individual variation in the length of the auditory canal, this is not always easy to achieve with any consistency.

As an alternative, the standard refers to the use of IR measuring devices although it advocates caution in their use, listing a series of ‘complicating factors’.

Auditory canal

As an alternative to tympanic temperature, measurement of temperature in the auditory canal has been suggested and the standard lists this as a further option. A key issue here is the temperature gradient between the external opening and the inner recesses approaching the ear drum. The usual procedure is therefore to insulate the opening, inserting the sensor through some form of plug such as hearing protectors or purpose-made mouldings. This more or less seals the ear canal and, after an initial period, internal temperature can stabilise to what potentially provides a reasonable approximation to ear canal temperature. However, as with tympanic temperature, this measurement remains susceptible to external conditions where the surroundings are more than 10 °C different from body temperature (BS EN ISO 9886).

3.2.3 Comparison of measurement sites

Given the plethora of measurement sites, it is perhaps not surprising that a number of studies have been published comparing temperatures from these different locations, either against each other, or against a notional benchmark such as rectal temperature. These studies give somewhat confusing results.

Chronologically, the first study of particular interest is that of Jakobssen *et al.*¹² These authors did not compare IR tympanic against other measurement sites but explored the differences between four different makes of tympanic thermometers (although some comparisons were also made with oesophageal and rectal temperature). Although the results are based upon a large number of repeat measurements, they should be regarded with a degree of caution as they were in fact only obtained from a very limited number of individuals. There were some differences in temperatures measured using the four different instruments. There was a difference of 1.1 °C in mean temperature between the highest measuring (‘First’) and the lowest (‘Genius’). As a result, the ‘FirstTemp’ tended to display higher temperatures than the benchmark oesophageal (mean +0.5 °C), while the others tended to display lower temperatures. Although results from some tympanic–oesophageal comparisons are displayed graphically, actual values are not tabulated and statistical comparisons limited to correlation coefficients. Although these data appear reasonable, it is not, therefore, possible to draw any firm conclusions regarding the absolute accuracy of this technique although the systematic differences between measuring instruments must be noted.

The next paper of interest is that by Yetman *et al.*¹³ These authors carried out a comparison between IR tympanic temperature measurement and values obtained using mercury-in-glass thermometers in the axillae (armpits) or rectum. This is the first of a number of papers which focused on infants, in this case newborn babies. The IR thermometer could be used in either oral or rectal mode. In each case, electronics in the instrument applied a correction factor to the measured value, ostensibly to allow for an established difference between temperatures measured in the ears and those measured at these other sites. This resulted in higher oral temperatures than rectal temperatures for the same reading.

The authors found that, even with this correction, the IR rectal gave significantly lower temperatures than the actual rectal, with a mean difference slightly greater than 0.3 °C. Unfortunately, although the variability in the data is presented graphically, no formal analysis of this is presented, although it is

apparent by measurement of the graphs that 75 per cent of the data points fell within $+0.2^{\circ}\text{C}$ of the measured mean. However, one comment by the authors gives a pointer to a possible problem with this study. The authors comment on difficulties in using the sensor, with the large thermometer probe tending to slip from the aural opening. Although, as the authors indicate, this was not sufficient to prevent temperature measurement in any infant, it must raise the question of how accurately and reliably the probe was directed at the ear drum itself and how often temperatures were obtained from the (cooler) wall of the ear canal.

Roth *et al.*¹⁴ reported the findings from a study comparing rectal and tympanic temperatures in marathon runners. Thirty-seven runners requiring rectal temperature measurement were recruited. These were all presumably suspected as suffering from heat-related disorders. Their mean rectal temperature was 38.4°C , which was significantly higher than the mean tympanic temperature (rectal equivalent setting) of 37.81°C . There was a highly significant linear correlation coefficient between the two sets of measurements. However, an analysis of agreement, calculated in accordance with the widely accepted statistical procedure described by Bland & Altman,¹⁵ revealed a 95 per cent confidence interval of $+1.67^{\circ}\text{C}$ to -2.95°C .

Almost two thirds (62 per cent) of tympanic readings were within 1°C of their rectal counterparts. The authors note that previous studies had suggested better agreement but conclude, on the basis of their findings, that they 'cannot endorse' the use of tympanic temperature in the setting of an endurance event. They explore possible explanations for this, suggesting that some studies have questioned the reliability of tympanic temperatures outdoors or with active cooling.

Stavem *et al.*⁵ compared tympanic (IR) temperature with pulmonary artery temperature in adult clinical patients. Interestingly, they found a difference between measurements obtained in the left ear and the right ear, although the mean difference was not large. The mean tympanic temperature was 0.45°C higher than pulmonary artery temperature in 65 readings from 16 intensive care patients and only 0.07°C higher than rectal temperature in 611 readings from 103 other clinical patients. This markedly smaller difference compared to the previous study (0.59°C) is probably testimony to the more stable environment in the latter research. In intensive care patients a standard deviation of $\pm 0.38^{\circ}\text{C}$ yielded a 95 per cent confidence interval of $\pm 0.76^{\circ}\text{C}$ which, with the offset, gave a range of -0.31°C to $+1.21^{\circ}\text{C}$. In the larger study of non-intensive care clinical patients the equivalent range was -0.67°C to $+0.81^{\circ}\text{C}$. Although not comparing well with other, more invasive, measures, in the intensive care setting (rectal and oesophageal) the authors concluded that tympanic temperature was acceptable for routine clinical purposes.

In contrast Fulbrook,⁴ again studying intensive care patients, found a confidence interval of -1.3°C to $+1.2^{\circ}\text{C}$ compared to pulmonary artery temperature (noticeably wider than the intensive care element in the previous study). The author identified another factor contributing to disparate readings, which was that higher temperatures were obtained where a patient had been lying against a pillow. The authors concluded that the difference was clinically unacceptable.

One issue influencing the measurement of temperatures from different sites is that of differential temperature gradients and responsivity. Robinson *et al.*¹⁶ examined this specific issue in a study involving deliberate body cooling (and then rewarming) in association with cardiac surgery. Benchmarked against pulmonary artery temperature, tympanic temperature gave a closer agreement (and less variability) than either axillary or rectal temperature (although oesophageal was better still). Over 200 readings with two different makes of device yielded mean differences of -0.3°C and -0.4°C with a standard deviation in each case of $\pm 0.5^{\circ}\text{C}$, yielding 95 per cent confidence intervals of -1.3°C to $+0.7^{\circ}\text{C}$ and -1.4°C to $+0.6^{\circ}\text{C}$. The authors suggest that the use of corrections for rectal or oral temperature may in fact be introducing an error as the relationship between the different modes of measurement are not constant.

Giuliano *et al.*¹⁷ examined the use of tympanic temperature, again in a clinical setting. The authors found tympanic (in 'core' mode) to differ from pulmonary artery temperature by an average of -0.11°C (standard deviation $\pm 0.57^{\circ}\text{C}$), yielding a 95 per cent confidence interval of -1.25°C to $+1.03^{\circ}\text{C}$.

Valle *et al.*¹⁸ compared tympanic against rectal temperatures in the clinical setting. The authors found a median difference between the two of -0.5°C , with a larger difference (-1.4°C) in those with higher ($>38^{\circ}\text{C}$) temperatures. Calculated 95 per cent limits of agreement were -0.7°C to -0.4°C and -1.9°C to -0.9°C respectively. One possibly significant feature of this study is that temperature

readings were obtained by a wide variety of staff who would have been very familiar with obtaining rectal temperatures but who had only limited training and experience with tympanic temperature.

Jensen *et al.*¹⁹ compared three different tympanic temperature instruments against a variety of other temperature readings including, as the benchmark, rectal temperature measured using a mercury-in-glass thermometer. Each of the tympanic sensors was found, on average, to yield lower core temperature readings than those from the rectum, with mean differences of 0.24 °C, 0.27 °C and 0.4 °C in those with a temperature greater than 37.5 °C. Standard deviations about these mean differences yielded 95 per cent confidence intervals of approximately -1.4 °C to +0.12 °C, -1.25 °C to +0.71 °C and -1.16 °C to +0.68 °C.

Craig *et al.*²⁰ reported a systematic review of the literature on the accuracy of IR ear thermometry compared to rectal thermometry. Pooled data yielded a 95 per cent confidence interval of -0.74 °C to +1.32 °C, with a mean difference of +0.29 °C. However, the restriction of this review to studies with children limits its usefulness because the smaller sized ear canal in children has been shown to introduce sources of error such as problems in inserting the probe and the relatively short distance from the external air to the ear drum.

Hooper & Andrews²¹ collated the published findings of 20 studies comparing tympanic thermometry with a reasonable benchmark. The findings were unclear. Superficially, 10 of the papers were seen as supporting the use of tympanic thermometry and eight were not. In each subgroup, four were rated as reasonable in terms of research quality. However, the authors applied their own more detailed evaluation of quality, from which they concluded that the negative evidence was more reliable. However, it should be noted that two of the three high quality studies cited in support of this were based on substantially the same data and cannot therefore be accorded equal weight. It should be noted that a number of the shortcomings cited, such as the failure to document specific features, introduce an element of uncertainty but do not necessarily negate the findings. Unfortunately, data from the individual studies is not tabulated, nor are confidence intervals generally reported, so it is difficult to develop any independent view from this paper.

Casa *et al.*²² compared temperature readings using a variety of different body sites and instruments in athletes taking part in various sporting activities. Other than the IG pill, IR aural temperature performed best, with a bias of -1.0 °C and 95 per cent limits of agreements of ± 1.14 °C, yielding a range of -2.14 °C to +0.14 °C.

The authors conclude that, because of the offset of 1.0 °C, tympanic temperature was not a suitable surrogate for rectal. However, if consistent, this could be accounted for in establishing an operational limit. Of more concern was the fact that the relationship appeared to change. According to graphical plots, tympanic temperature overestimated rectal temperatures at lower values and underestimated them at higher values.

Moran *et al.*²³ compared IR tympanic temperature with pulmonary artery temperature in a sample of clinical patients. The average temperature difference was 0.358 °C, with a 95 per cent confidence interval around this ranging from -0.560 °C to +1.276 °C.

Reid *et al.*²⁴ reviewed the published literature on IR tympanic thermometers for use in children (as distinct from neonates). The authors did not tabulate numerical or statistical summaries from the papers identified but concluded that tympanic rather than axillary temperature provided more accurate values. All papers included in the study were required to have used some form of benchmark standard such as pulmonary artery or rectal temperature, but details are not presented of the differences identified.

Terndrup & Rajk²⁵ examined the effect of gross changes in measurement technique on the IR temperature obtained. The authors found that insertion of the probe without using an 'ear tug' (to straighten the ear canal) yielded significantly lower (and less variable) temperatures, demonstrating the importance of technique in obtaining a reliable reading.

Sund-Levander *et al.*²⁶ reported on the results of a study which included some assessment of individual reliability. The technique used by the three subjects who took readings on themselves was not formally studied or documented. The fact that one of these subjects achieved systematically better (less variable) readings and was an experienced nurse was nevertheless taken to indicate the benefits of better technique.

Another paper which reported differences due to technique was that of Robinson *et al.*¹⁶ In this instance, the authors compared temperature readings obtained by trained nurses to those obtained by parents. The latter group were given no training or instruction other than the leaflet supplied with the instrument, so it is perhaps not surprising that they were generally less reliable than the nurses. In fact, given the design of the study it is surprising that their readings were remarkably similar to the nurses on the majority of occasions.

It is important not to confuse experience with expertise. Evans & Kenkre²⁷ carried out a study of nurses and their use of IR thermometers. They found that although the vast majority used such instruments and took temperatures every day, most had not received any formal training in their use (13 per cent had received formal training). Although the authors did not assess practical technique in any way, the implication was that considerable variation in skill could be expected.

Daanen²⁸ reported on a study of the effect of ear canal morphology on the accuracy of IR ear canal temperature measurements, compared to oesophageal temperature. It was reported that the extent of the ear canal visible and the amount of ear wax (cerumen) and ear canal hair were all factors which influenced the apparent accuracy. However, the technique used to obtain the readings is not given and the visibility of the ear drum appears to have been determined without any reference to the use of an ear pull so it difficult to determine the significance of this finding. In addition, ear canal hair was only rated 1 or 2 in all 10 subjects (each ear) on a scale of 1–4 and ear wax mostly rated 1 or 2 (only two ears had a rating of 3) on a scale of 1–5 and so the opportunity for systematic assessment was very limited.

In summary, it is clear that IR tympanic temperature measurement is less accurate and more variable than more invasive measurement methods such as rectal temperature and even more invasive sites such as the pulmonary artery. Opinions vary as to its reliability and utility, which appears in part to depend upon the target population (whether adults, children or neonates) and the circumstances in which the temperatures are to be obtained. Thus, the inaccuracy involved renders it unsuitable for precise clinical assessment but its inherent advantages of being relatively quick to obtain, comparatively unobtrusive and more responsive than some sites means that it finds favour in situations where less accuracy is acceptable.

It is clear from the literature that there is a need to exercise a degree of care in obtaining measurements, and several authors have commented on the higher degree of training required compared to some other approaches. It is also clear that, in some circumstances, measurements may be unduly influenced by other factors, such as recent exposure to local heating or cooling. However, these potential disadvantages are outweighed by the potential benefits of a quick, relatively unobtrusive approach to measurement of body temperature as part of safety procedures for work in hot conditions.

4 Methods

4.1 Outline

It was originally planned that the work would be carried out among maintenance workers during the process of glass manufacture. However, in order to widen the applicability of the work and to provide a larger data pool, the scope was widened to include other glass industry workers (eg bottle manufacture) and workers in the refractories (metalworking) sector, where the melting and casting of metals results in potentially similar exposures to radiant heat sources. Ethical approval was obtained for the work.

Informed volunteers were asked to swallow calibrated temperature-sensitive radio-pills (measuring IG temperature) the evening before the measurements were to be taken. Pilot studies had previously confirmed that the technology worked successfully in the glassworks environment.

At suitable stages during the daily work of the volunteers, measurements of tympanic temperature were obtained using a hand-held IR tympanic thermometer. These temperatures were recorded, along with the time of the measurement, for subsequent analysis.

During study days, experimenters observed the volunteer workers, recording levels of activity (to allow workload to be assessed as a possible covariable) and standard environmental temperature parameters at the working locations.

The results were analysed by IOM statisticians to establish the degree of correlation between the two forms of temperature measurement. In addition to comparisons between measurements obtained at the same time, the temporal covariation of the IG temperature with environmental exposures was explored. It was expected that the 'deeper' measurement of IG temperature would respond more slowly, lagging behind IR temperature when external temperature was rising or falling rapidly. Additionally, IR temperature readings may have been distorted by very recent localised heating – for example through radiant heat exposure.

The results were used to establish the predictive value of IR thermometry to monitor deep-body temperature and to determine a safe working body temperature on the basis of the established error limits of the technique.

4.2 Detailed methods

4.2.1 Recruitment of subjects

All participants were full-time employees of companies that agreed to provide access to their premises and workforce. Participation in the study was entirely voluntary and there was no coercion or inducement offered other than feedback on their individual core temperature results. All participants were fit for their normal work and were not asked to carry out any tasks other than normal work. A medical questionnaire was prepared for all potential subjects. All potential participants were fully informed of the nature of the study and of the requirements for physiological monitoring (see below), and their informed consent was obtained.

4.2.2 Body temperature measurement

Measurement of body temperature was performed using two procedures: an IG temperature system (Cortemp, HQ Inc., USA) and an IR tympanic temperature measuring device (Braun, Germany).

Intragastric temperature

The IG temperature system uses previously calibrated temperature-sensitive radio-pills which are swallowed by the participating subjects. These pills contain a battery, a temperature-sensitive crystal and a low-range radio transmitter (along with a magnetically operated switch so that the fully encapsulated device can be activated before use). The pills travel naturally through the gastro-intestinal tract and subsequently pass to waste. Trials have shown that ingesting the pills the previous evening ensures that they have passed far enough through the tract usually to be unaffected by the ingestion of hot or cold food or drinks.¹⁰ With more recent ingestion, subsequent ingestion of foods or liquids can result in erroneous readings. The pills transmit a radio-frequency signal proportional to the temperature to which they are exposed. This is received by a small body-borne logger which can subsequently be interrogated and the logged temperatures downloaded using purpose-written software.

Pills were issued to participants, usually the day before the measurement day, together with written instructions (see Appendix 1). These instructions reminded employees that participation was voluntary and that they did not have to swallow the pill if they no longer wished to take part. Before issue, a record was made of the reference number and individual calibration number for that pill. As a secondary check, subjects returned the wrapper (and magnetic keeper) and details on the wrapper were cross-checked with the record. The requirement to return the keeper also provided a check that this had been removed before the pill had been swallowed.

On measurement days, individual pill details (reference number and calibration number) were entered into the logger and the pill signal checked. Assuming a signal was detected, the logger was then inserted into a protective pouch and fitted to a belt which was then fitted to the subject. Occasionally, presumably because of a defect in the pill, no signal could be received. In this case, because of the established interference between recently swallowed pills and any other ingested substance or liquid,¹⁰ no second pill was issued and the subject did not participate in the study for that day. This was because it was considered inappropriate to restrict fluid intake in particular to allow measurements to be obtained.

Infrared tympanic temperature

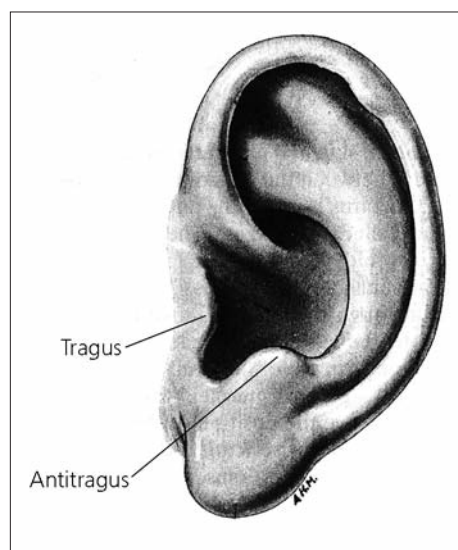
The Braun Thermoscan™ thermometer is sold commercially for use in clinical or domestic settings. It consists of a hand-held unit incorporating a device which measures the IR radiation emitted by the ear drum and surrounding tissues and transforms this signal into the displayed temperature.

According to the manufacturer, the unit performs this eight times within a second and displays the highest value obtained. A single-use disposable cover over the sensing unit ensures hygiene between subjects. Initial data collection was carried out using a model IRT 3520. However, in later surveys this was replaced with the IRT 4520, which incorporates a pre-heated tip. According to the manufacturers, this reduces any errors attributable to cooling of the ear tissues through the insertion of a cold device. However, omitting the IRT 3520 data (a total of 18 data points from five subjects) had no significant impact on the outcome of the statistical modelling, suggesting no systematic difference between the two devices.

The manufacturers of the IR thermometer recommend that the aural canal be free from obstructions or excessive ear wax build-up to obtain accurate readings. For the routine industrial use of such measurements, cleaning the ear canal is unlikely to be practical and this practice was not therefore adopted. However, in order to take this issue into account, the ear was visually inspected using a standard otoscope before taking measurements, and the degree of waxing was recorded.

In taking a measurement, the external ear (pinna) of the subject was grasped and pulled backwards parallel to the head ('ear tug'). This helps to straighten the ear canal and provide a clearer line of sight to the drum itself. The sensing tip of the measuring unit was gently but firmly inserted into the ear canal (prior tests showed this to be important in reducing the risk of an erroneous reading) and the casing aligned between the tragus and antitragus (Figure 1). Previous trials have shown this position to give the most reliable readings.

Figure 1
Illustration of the
external ear (pinna)
(Source: Beagley
H A. Audiology
and audiological
medicine. Oxford:
OUP, 1981)



This procedure was repeated three times in quick succession (with the tip being withdrawn between readings) and the highest value obtained taken as the correct value. This was chosen on the basis that there would be nothing hotter than the ear drum in the ear canal. Although experience has shown that this can give erroneously high readings if there has been significant local radiant heating immediately before measurements are taken, few subjects in this study worked directly exposed to sizeable areas of radiant (red-hot) heat. In the few cases where this did occur, a brief break minimised the risk of such errors occurring.

4.2.3 Climatic measurements

Standard climate parameters of dry bulb temperature, wet bulb temperature, mean radiant (globe) temperature and air velocity were obtained at or as close as possible to the working locations. Exact placement depended upon the layout of the working area, with care being taken to ensure that instrumentation was not placed where it could cause any form of obstruction or safety hazard. Data were manually recorded. The thermal tree was placed in or close to the working area for a minimum of 15 minutes before readings were obtained, although, as outlined below, this was sometimes supplemented by 'spot' measurements of dry bulb temperature.

Dry bulb temperature

This was usually obtained using a thermocouple sensor (K type) shielded in a purpose-built housing on a 'thermal tree'. However, because of the sometimes congested working area or the peripatetic nature of the work being performed, this was not always possible. In such cases, a simple, quick-response hand-held thermocouple sensor was used to provide dry bulb temperature only.

Natural wet bulb temperature

This was obtained using a thermocouple sensor (K type) on a purpose built mount, again fitted to a thermal tree. A standard thermometer wick was used to cover the sensor and the other end of the sensor was immersed in a reservoir of distilled water suspended vertically below the sensor.

Globe temperature

This was obtained using a thermocouple sensor inserted through a purpose-built mount which held the sensor tip in the centre of a 150 mm copper sphere painted matt black. As with the dry bulb and wet bulb units, the sphere was attached to the thermal tree.

Air velocity

Air velocity was recorded using a hand-held hot wire anemometer. In most working areas, little air movement was discernible. However, to accommodate any directional effects, preliminary tests were carried out with the device held in different orientations to identify any directionality.

4.2.4 Data collection

The work was carried out among three groups of workers:

- maintenance workers at the premises of a major manufacturer of float glass, offering access to a workforce exposed to high temperatures during the process of primary glass production and the manufacture of float glass
- production workers at the premises of two manufacturers of glass bottles, exposed to red-hot molten glass during the process of primary glass production and the manufacture of glass bottles
- workers in the refractories sector working with molten ferrous or non-ferrous metals, exposed to the molten metal during casting processes.

Appendix 1 shows the information sheet, medical screening questionnaire and consent form prepared for the project, together with the instruction sheet for taking the gastro-intestinal temperature pill.

The subjects were all regularly working in the conditions in which they were to be monitored. They were instructed to carry out their normal duties and were asked not to deviate from these (other than occasional interruptions for IR temperature measurement or to check IG temperature signal). For this reason it was not considered necessary to apply any additional screening for fitness for work in the heat. However, as will be seen from Appendix 1, they were advised of the nature of the study as part of the informed consent process and of possible specific contra-indications for swallowing the IG pill (as advised by the pill manufacturers). On one occasion, one potential subject sought further advice on this and, despite his enthusiasm to take part, was advised by an IOM researcher that this would be inappropriate. It is not known how many other potential participants withdrew themselves for this reason, as no record was made of reasons for eventual non-participation among those who had initially indicated an interest.

At the start of a measurement day, an initial IR temperature was obtained and recorded, along with the time of the reading. In addition to the logged IG data, a visual check on IG temperature was carried out using a separate hand-held logger (set to the appropriate pill details) and the value manually recorded. Each subject was then asked to proceed with their normal work for that day.

It was considered important that the subjects should be allowed to work as much as possible without interruption. Sampling of IR temperatures was therefore carried out on a convenience basis, with a researcher observing the process and taking readings during naturally occurring breaks or pauses in the work. This usually meant that readings were obtained on a sporadic, irregular basis. On all occasions, however, the time of the recording was noted to allow it to be related to the logged IG data. No drinking was allowed before an IR temperature measurement to avoid any risk of distorting the IG readings for the appropriate time. As readings were obtained in the workplace, this did not cause any problems.

IR temperature measurements were obtained in the workplace but, for safety reasons, not in the immediate working area. The use of natural breaks meant that, when readings were obtained, subjects had moved away from their workstation, allowing time for any immediate local radiant heating of the skin to have dissipated (although in practice, contrary to what might be expected, most workstations do not involve direct exposure to significant areas of radiant (red-hot) sources). Prior experience has shown that core temperature does not change rapidly enough for this brief break to have any impact on the resultant values obtained. The fact that the higher IR temperature readings tended to be lower than the equivalent IG readings (see Figure 2 on page 22) suggests that this procedure was effective in avoiding any systematic distortion of the results by local heating.

During study days, the observing researcher recorded the task being performed, to allow the level of physical work to be assessed as a possible covariable activity (based upon the standard categorisations presented in BS EN ISO 8996²). In addition, standard climate parameters of dry bulb temperature, wet bulb temperature, mean radiant (globe) temperature and air velocity were obtained at or as close as possible to the working locations.

4.2.5 Data processing and data security

Handwritten records of IR temperature, IG temperature, environmental measures and activity were transcribed onto computer datasheets. Logs of IG temperature were downloaded to a computer at the end of each data collection day using commercial purpose-written software.

Data validation included checks on the completeness of the data available for each subject, and checks on valid values and valid ranges in the recorded data. IG data outside physiological ranges were excluded from analysis. In addition, logged data were scanned visually for recorded 'spikes' which were physiologically invalid and these data also excluded (eg an isolated value increasing by 1.0 °C in a 20-second interval and then returning to previous levels thereafter).

All data were archived on back-up media and transferred to secure hard disk data storage systems on the IOM's computer network. The IOM's data management standard includes full daily backup procedures, offsite storage of backup tapes, active protection from the threat of computer virus infection and prevention of unauthorised access to any study data. The project was carried out in full compliance with the Data Protection Act.

4.2.6 Statistical methods

The data were examined in a series of tables and graphs, during which small numbers of implausible IG temperatures were identified and corrected or omitted as appropriate. These occur as a result of transmission noise on the radio signal received and can readily be distinguished on a plot or tabulation of the data. IG temperatures are logged for each individual at 20-second intervals and consequently rapid 'spikes' due to transmission noise are readily discernible from physiological shifts in temperature.

Aural temperatures were matched to the core temperature, measured using the IG pill temperature taken closest in time to the aural measurement. Consecutive changes in IR temperature do not change by more than 0.01 °C in 20 seconds and so no merit was seen in computing an average of the three readings for that minute. Scatterplots of aural and core temperature were produced to examine visually the relationship between the measures. To facilitate comparisons with other studies examining the use of IR thermometry, the difference between aural and core temperatures were also plotted against the average of the two measures in a Bland-Altman plot for assessing agreement.

between two measurement methods.¹⁵ Hopkins²⁹ describes in some detail a possible source of error in using the Bland-Altman analysis in which the analysis can create an apparent bias where none exists. In the example given, this artefact arose where one instrument was calibrated against another, which was subsequently used to validate the former. For this reason, Hopkins advocated the use of regression analyses.

One feature of the Bland-Altman analysis is the use of the average of each pair of values as a comparator, thus attributing equal weight to both measurement procedures.¹⁵ This can be acceptable when, for example, two different measurement techniques are used, neither of which is considered to have any more validity than the other. As an alternative approach, where one technique has the status of a 'gold standard' as in the present study, the regression analysis data can be used to derive a predictive relationship between the two measurement procedures.

For these reasons, it was decided that adopting a framework of regression analyses was the more appropriate procedure, especially as it facilitated the more complex analyses as presented below.

The association between aural and core temperatures was therefore examined using the framework of linear regression. The potential effects of ambient temperature, industry and activity on the relationship between aural and core temperature were also investigated.

The regression model derived for aural and core temperature was then used to calculate estimated values of core temperature for various levels of measured aural temperature. Under the assumption that the distribution of levels around this estimated value followed a normal distribution, with mean equal to the fitted value and standard deviation calculated from the residual mean square of the regression model, it was then possible to estimate the probability that any individual would have a core temperature below any specified value.

Appendix 2 presents a more detailed account of the statistical analyses performed.

5 Results and discussion

A total of 272 pairs of measurements were available for analysis. These represented data from 34 different subjects, 11 of whom were studied on two days. Between 2 and 11 pairs of readings were obtained from each subject on any one day (median 6). IG core temperature values ranged from 36.25 °C to 39.06 °C with the majority towards the lower half of that range (median 37.52 °C).

With the IG temperature as the 'gold standard', a regression analysis was performed with IG temperature as the predictor and IR temperature as the response to calibrate the model. Table 1 shows the results of this regression analysis, showing a highly significant relationship.

Table 1
Summary of
regression analysis
output

Summary of analysis					
Source	df	ss	ms	vr	F pr
Regression	1	22.57	2.5711	105.85	<0.001
Residual	255	54.38	0.2132		
Total	256	76.95	0.3006		
Estimates of the parameters					
Parameter	Estimate	se	t(255)	t pr	
Constant	10.99	2.53	4.34	<0.001	
IG temperature	0.6931	0.0674	10.29	<0.001	

An inverse regression analysis was then used to enable the prediction of an IG temperature for a given IR temperature using this model. A scattergram plot of IG *vs* IR temperature is shown in Figure 2, with the fitted regression line and the confidence interval derived from this analysis shown.

Malchaire *et al.*,³⁰ in describing aspects of the predicted heat strain model (used as the basis for BS EN ISO 7933³¹), adopts a core temperature of 39.2 °C as a safe limit, based on the use of rectal temperature. For the purpose of this present study, a slightly lower limit of an IG temperature of 39.0 °C was adopted.

The use of 39.0 °C rather than the 39.2 °C advocated by Malchaire *et al.* introduces a slightly conservative aspect to this process. However, it is recognised that there is considerable debate regarding an appropriate 'safe' core temperature limit. Malchaire and colleagues for example refer to the World Health Organization (WHO) guideline of 38 °C, arguing that this reflects an average response rather than an individual response. There might also be some debate regarding the use of a 95 per cent safety limit, rather than covering a larger proportion of the workforce.

One important point to note from the data shown is that only one IG (pill) temperature record exceeded this suggested limit of 39.0 °C (with a value of 39.06 °C). It is also worth noting that this temperature was measured shortly after the individual voluntarily withdrew from the heat exposure. The worksites involved in this study were all selected on the basis of a perceived potential heat-related hazard, involving working with molten glass or metal. In all instances, working practices were largely unaltered by the study, with measurements generally being obtained during naturally occurring breaks. At each location strong reliance was placed on self-monitoring and withdrawal as a key element of managing the potential hazard. These data, obtained from six different employers, suggests that existing control measures at these sites appear to be effective.

The review of the literature identified the widespread use (and advocacy) of the Bland-Altman plot as a means of determining the viability of using one measurement as a direct surrogate for the other. To facilitate a comparison of the data from the present study with these earlier papers, Figure 3 (page 24) shows such a plot for the collected pairs of data. The pairs had a mean difference of +0.5422, reflecting the higher values obtained from the IG pill thermometer. The figure shows the limits around this mean, determined by adding and subtracting two standard deviations and yielding limit lines (shown) at -0.4164 °C and +1.5008 °C.

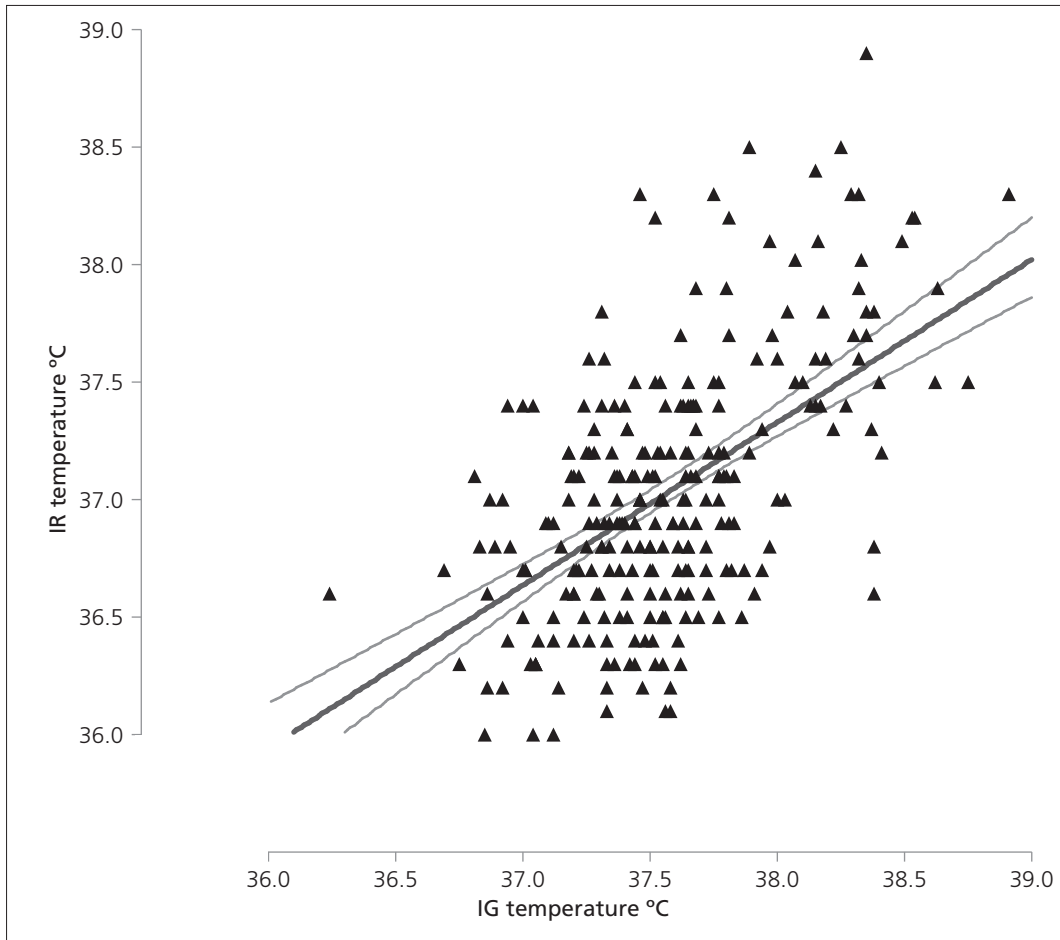


Figure 2
Scattergram plot of IG temperatures against IR temperatures, including the fitted regression line and the confidence interval

Compared to comparisons in the published literature, the Bland-Altman range of approximately 2 °C (1.91 °C) was higher than some (eg Stavem *et al.*,⁵ 1.49 °C) but lower than others (eg Roth *et al.*,¹⁴ 4.62 °C). Nevertheless, it presents too wide a range to allow the IR tympanic temperature readings to be used as a direct surrogate for IG temperature as a measure of core temperature.

However, that is not to say that it cannot be used as an indicator of a limiting criterion. Arguably it is not necessary to know precisely the actual core temperature but to know (with reasonable confidence) that the core temperature is unlikely to have exceeded a safe limit.

From Figure 2, the idea of using the IR temperature to predict the IG temperature looks quite promising. Although the data are spread quite widely, the confidence interval is relatively narrow, as there are many data pairs. Using this interval, to be sure that no more than 5 per cent are above the suggested maximum IG temperature of 39 °C, a maximum IR limit of 37.86 °C would be used.

However, there is a further issue with the data obtained in that all of the pairs of data are not independent from each other. There are a number of pairs of measurements taken from the same person (median 6), indicating that some form of repeated measures analysis would be best. The situation is further complicated statistically because the number of pairs of measurements varied, as did the times at which the measurements were taken. The Bland-Altman approach does not permit such a calculation to be used. To attempt to adjust for a varying number of repeated measurements, therefore, a mixed effects linear regression model was fitted to the data, with the participant as a random effect and the IG temperature as a fixed effect. Table 2 overleaf shows the output obtained when fitting this model. From this it is clear that both participant and IG temperature are significant. One consequence of this is that including participants as a random effect results in additional variation in the model. The confidence interval was therefore adjusted to account for this. The random effect has no influence over the fitted value but does affect the variance; in fact the adjusted variance for the confidence interval can be obtained by adding the residual variance to the variance of the random effect. Figure 4 (page 25) shows the fitted line, after accounting for repeated measures, along with the 90 per cent confidence interval for this line.

Figure 3
Bland-Altman plot
for the collected
pairs of data
showing
differences
between pairs
plotted against the
average of the
pairs of values

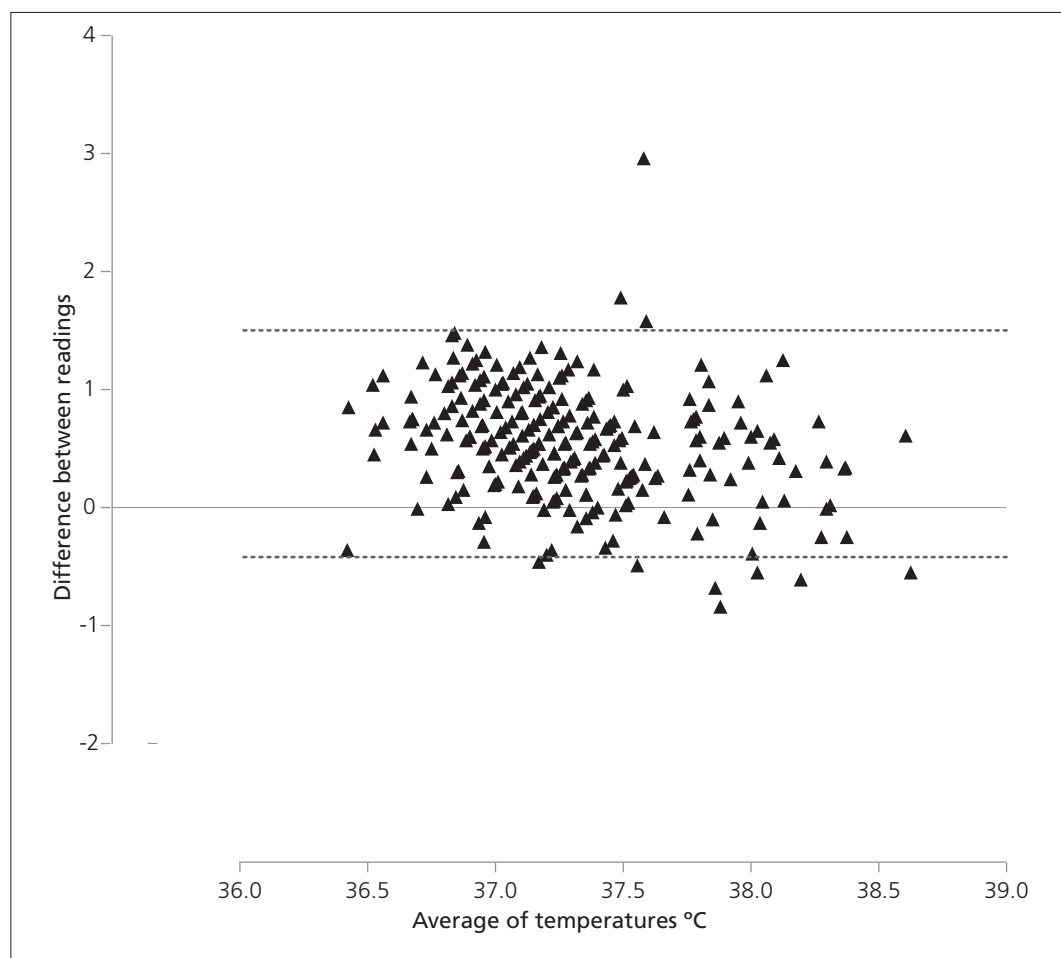


Table 2
Summary of
regression analysis
output, after
accounting for
repeated measures

Estimated variance components				
Random term	Component	se	approx. <i>p</i> -value	
Participant	0.0526	0.0207	<0.001	
Residual variance model				
Factor	Model (order)	Parameter	Estimate	se
Dispersion	Identity	Sigma2	0.169	0.0161
Estimated variance matrix for variance components				
Participant 1	0.0004299			
Dispersion 2	−0.0000494			
	0.0002592			
Parameter estimates				
	Effect	se	Approx. <i>p</i> -value	
Constant	16.24	2.983		
IG temperature	0.5544	0.07929	<0.001	

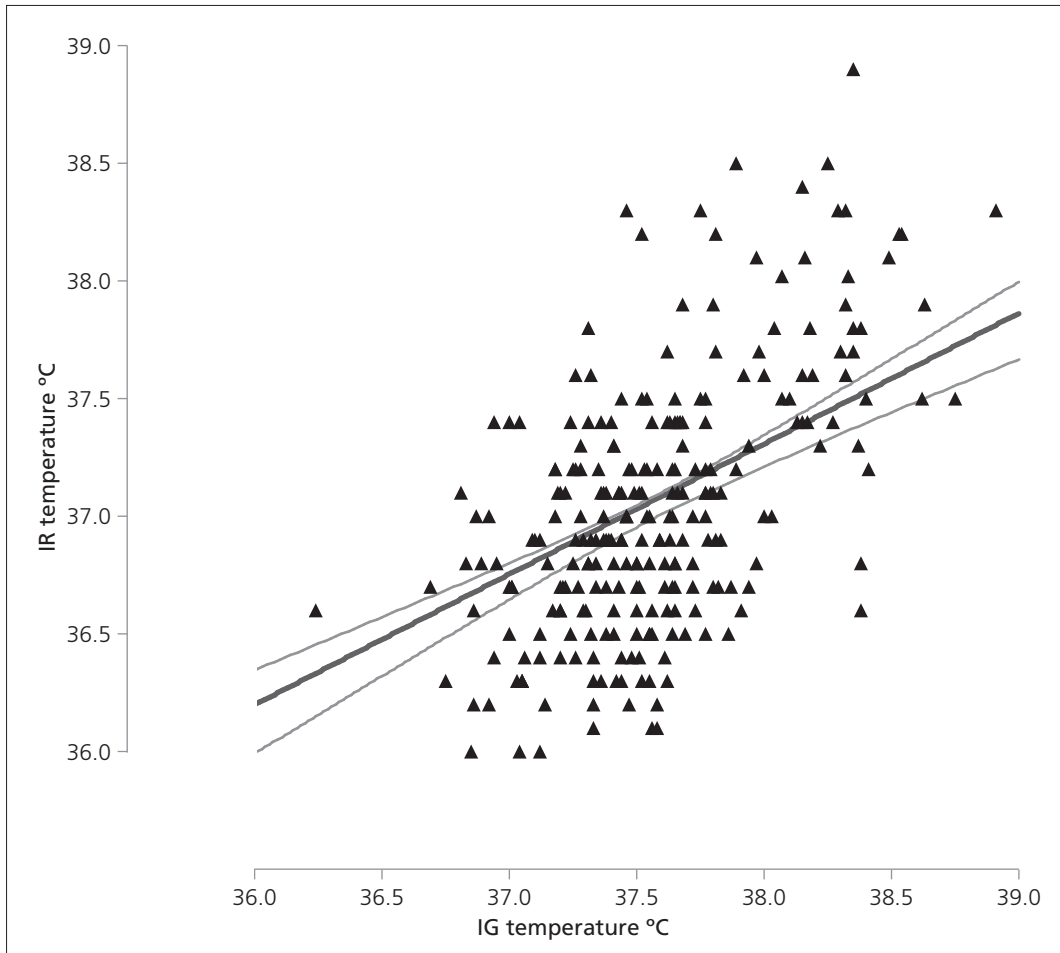


Figure 4
Scattergram plot of IR temperatures against IG temperatures, including the calculated regression line and the 90% confidence interval

Comparing Figures 2 and 4, it will be seen that the latter has slightly wider confidence intervals to either side. Although participants are significant in the model, the extra variation associated with including them is relatively small. Based on this interval, it would now be necessary to set a maximum IR temperature of 37.66 °C, to be reasonably certain that no more than 5 per cent of people had an IG temperature of over 39 °C.

Using confidence intervals in this manner effectively restricts the prediction to the subjects on which the prediction model was based. The confidence interval of a predicted IG temperature from a new IR temperature (known as the prediction interval) is a lot wider, as there is more variance associated with predicting a future value than with fitting an existing value.

Figure 5 overleaf shows the prediction interval associated with the fitted line, after adjusting for random effects. This is very wide and as a result the maximum IR temperature that would ensure no more than 5 per cent of individuals had an IG temperature of over 39 °C is 37.04 °C.

As stated earlier, the median IR temperature from the field work was 37.52 °C. On this basis, if a maximum IR temperature of 37.04 °C was accepted as some form of limit, more than 50 per cent of the employees studied would have at least to be studied in more detail (perhaps with more accurate temperature measurement such as the IG pill). This would place a considerable burden on employers (and other burdens on employees), even though there was no evidence among those taking part in the study of any significant thermal strain.

As a further illustration, Table 3 overleaf presents the confidence intervals (CI) and prediction intervals (PI) for predicting IG temperature from IR temperature for a range of IR temperatures. This clearly shows that, although the confidence intervals of the predicted IG temperature give the impression that IR temperature can be used as a reliable predictor, the prediction intervals are far too wide to enable sensible predictions to be made. Thus, although an IR temperature of 37 °C predicts an IG temperature of 37.45 °C, the range encompassed by that prediction extends from as low as 36.07 °C to as high as 38.92 °C.

Figure 5
Prediction interval
associated with the
fitted line, after
adjusting for
random effects

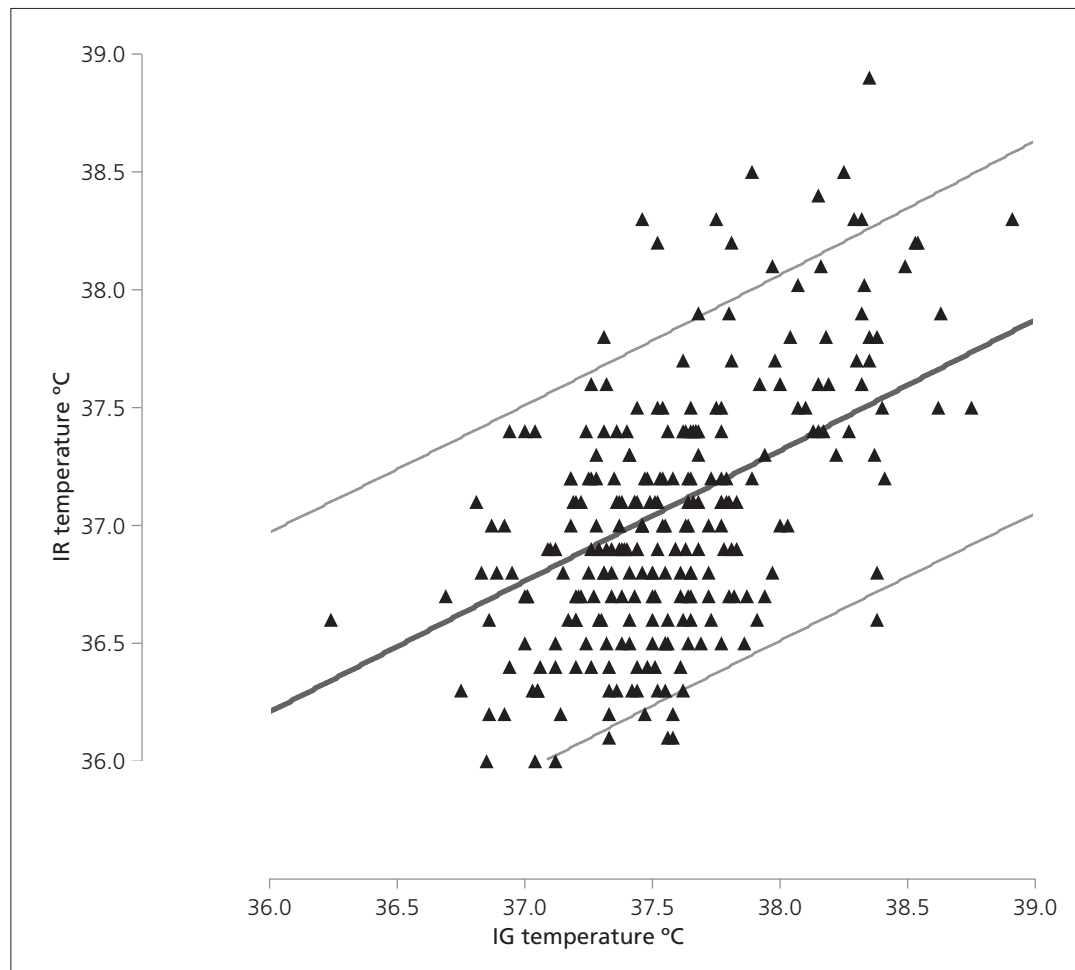


Table 3
Predicted IG
temperatures with
confidence and
prediction intervals
for these, given a
specific IR
temperature

IR temperature (°C)	Predicted IG temperature (°C)	IG 90% CI (°C)	IG 90% PI (°C)
36	35.64	(35.23, 36.13)	(34.15, 37.09)
37	37.45	(37.41, 37.58)	(36.07, 38.92)
38	39.25	(39.01, 39.75)	(37.91, 40.84)
39	41.05	(40.52, 41.99)	(39.65, 42.85)

Clearly, on this basis, IR temperature measurement cannot be used with sufficient reliability to serve as a safety screening tool for potential heat strain. It remains to be seen whether improvements in measurement procedures result in reduced measurement variance and therefore 'tighter' prediction intervals.

There are several caveats to be placed on this finding. Firstly, as indicated by the literature review, there appear to be differences in measured temperatures between different makes of IR tympanic thermometer. The present study was conducted using two models both manufactured by Braun. Although the manufacturers claim improved accuracy for the newer model, excluding data obtained using the older model did not markedly alter the relationship identified.

Secondly, as shown in Figure 6, the regression line is not parallel to the line of identity and actually crosses it at one point. Thus, although on average the tympanic (IR) temperature was 0.54 °C lower than the core (IG) temperature, this average is potentially misleading. As the line shows, at lower body temperatures the tympanic temperature is lower than core temperature, while at higher temperatures the relationship is reversed. This makes it hard to directly determine actual core temperature from IR tympanic temperature (but does not negate the regression prediction given).

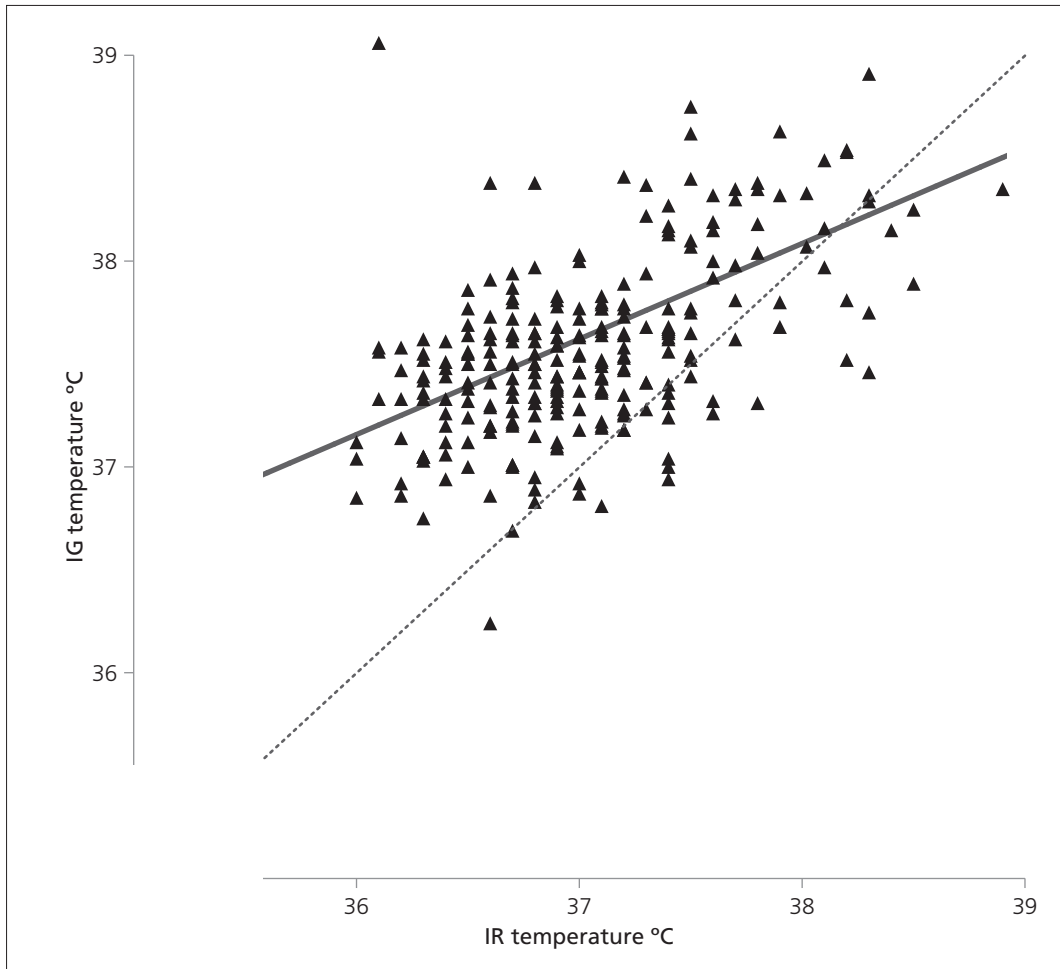


Figure 6
Scattergram plot of IG temperatures against IR temperatures, including the calculated regression line and the line of identity

The data were collected from workplaces which, to some extent, included an element of radiant heating from either molten glass or molten metal. One of the indicated sources of potential error in tympanic temperatures is the possible influence of local heating (or cooling) on the value obtained. This raises the possibility that the altered relationship at higher core temperatures is an anomaly created by radiant heating of the head. It is difficult to exclude this completely. Although, as would be expected, the higher core temperatures tended to be associated with tasks with a significant radiant component (eg fender change in float glass manufacture), this was by no means universal. As a check, a further regression was calculated excluding the fender change data (and others from this location). Although, as would be expected, this altered the precise relationship to some extent, it did not modify the general pattern. Even with these data excluded there was still a tendency for IR tympanic temperature to be below core temperature at lower (core) temperatures and above core temperature at higher values.

An alternative explanation for this observation can be derived from the fact that 'core' temperature is not a unitary value and that temperatures at certain sites (most notably rectal) tend to respond more slowly to changes in temperature. IG temperature tends to occupy an intermediate position (reflecting its anatomical source) between rectal and others such as oesophageal and pulmonary artery temperatures. Given its anatomical location, it is plausible that, under conditions of increased exposure, IR temperature will rise more rapidly than IG temperatures, as a genuine reflection of 'core' temperature rather than an environmentally induced anomaly.

It is difficult to determine this from the field data collected. Operators entering areas of particularly high heat exposure tended to wear insulating clothing. Thus, in the short term at least, most of their body is not actually exposed to the higher temperature of their surroundings. Possibly as a result of this, examination of the activities and the relationships of exposure timings to measurement points and environmental temperatures failed to identify any systematic pattern.

While there does seem to be a reasonable linear relationship between the two measurements, another issue of some concern from a statistical perspective is the comparative absence of data at the higher

end of the measurement range. While this is reassuring from the perspective of the safety of those involved at the various participating sites, it would be helpful to have more measurements at the high end of the range to give more confidence in the accuracy of the prediction.

There is some evidence from the published literature on the use of IR tympanic temperature to suggest that interindividual variability between measurers might be a significant source of variation. For example, Weiss *et al.*³² suggest that one reason for the lower than expected correlation between IR temperature and pulmonary artery temperature in their study could be the 'larger number of operators and the lesser control of operator technique'.

In the present study, data were collected by a small group of experienced researchers. Several papers comment on the importance of correct technique in obtaining accurate IR temperature readings. Although the present report provides the basis for what is believed to be a sound technique, it is clearly important that correct procedures are adopted if this approach is to be advocated for general use.

Finally, the data on which these projections are based were obtained from workers who were exposed to hot environments reasonably regularly. Although this is not sufficient for any physiological acclimatisation to have occurred, the employees will have become accustomed to working in such conditions and probably adapted their working practices accordingly. In addition, although this was not studied systematically, it is likely the workforce was, to some extent, self-selected in that any individual who found it difficult to cope with such conditions might well have sought alternative employment. It is therefore probable that the employees studied did not include the potentially most vulnerable individuals. Particular care should therefore be taken in introducing new employees to such environments, or in exposing existing employees to hot conditions to which they are unaccustomed.

6 Conclusions

The study succeeded in collecting and collating paired data of body temperature measurements, with 272 useable pairs collected.

The data suggest that, at the six sites surveyed, the procedures for managing the risk of heat stress, with a strong reliance on self-monitoring and withdrawal, appeared to be effective, with only one data point (39.06 °C) marginally exceeding the suggested safe working limit of 39.0 °C IG temperature.

An analysis of these pairs, using the Bland-Altman approach, indicated that the relationship between IR (tympanic) and IG (core) temperatures was too variable to allow IR temperature to be used as a direct predictor of IG temperature.

It was not possible to refine and improve this prediction by reflecting any time-slip between the two modes of measurement.

The incorporation of climate or work data did not provide any systematic adjustment to improve this relationship.

As an alternative to using IR temperature as a direct predictor of actual IG temperature, a relationship was established in terms of a limiting IG (core) temperature. This initially appeared to offer some promise with relatively narrow confidence intervals. However, when a more complete regression was determined, using complex modelling to allow for the interrelationship between sets of data obtained from the same subject, the confidence intervals widened and the predictive value diminished to the point at which IR temperature measurements would not appear to be sufficiently reliable or accurate to serve as a viable screening measure.

A number of factors have been identified which potentially contribute to this variability. It remains to be seen whether, with better control of selected factors, the accuracy and reliability of the measurement approach can be improved to a level where its use could be endorsed.

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Appendix 1: Subject information sheet, medical screening questionnaire, consent form and pill instruction sheet

Subject Information Sheet

Reliable industrial measurement of body temperature

The glass industry has commissioned the Institute of Occupational Medicine (IOM) to investigate a method for the reliable industrial measurement of body temperature. The method selected involves the use of a hand-held infra-red device similar to that used by physicians to examine your ears.

The IOM researchers will be comparing this measurement approach with the 'gold standard' method of ingested pill temperature. The measurements will be obtained on glass workers carrying out their normal work.

Before you participate the IOM team will provide you with a full explanation of the study and the extent of your involvement. In order to monitor these temperatures you will be asked to swallow indigestible pills that will monitor your core body temperature while they pass through your digestive system (intra-abdominal temperature). You will pass the pill out within a couple of days when you defecate. The first pill will be ingested approximately 12 hours prior to the first measurements being made. On arrival at the test site you will have a logger attached to you to measure your core body temperature from the pill.

You will then be asked to carry out your normal work with the rest of your colleagues. From time to time while you carry out this work an observer will obtain measurements of the thermal environment in which you are working and observe you at work to estimate the work load involved. At suitable times you will be asked to allow the observer to use the hand-held device to obtain measurements of your ear canal temperature for comparison with those being logged from your digestive system.

It must be emphasised that you personally are not being tested in any way. We want you to carry on working as if you were not being measured and to adhere to all safety procedures. In particular you are not to work any harder or carry on working in the heat any longer than you would usually consider acceptable and you should withdraw from the heat as usual if you feel at all unwell. In addition to usual safety procedures, the use of infra-red measurements means that we will have some indication of your body temperature. We will use those measurements as an additional safeguard and might advise you to withdraw from the heat, at least temporarily, should the values obtained exceed agreed criteria.

You may withdraw yourself from the study at any stage should you choose to do so.

All information gathered will be treated in confidence and will not be used for any purpose other than to meet this study's objective. We hope you decide to take part as the work will be of lasting benefit to the health and safety of you and your colleagues.

Thank you for your co-operation.

Consent form

Reliable industrial measurement of body temperature

- I have been asked to participate in a study to assess the use of infra-red ear canal temperature measurements for possible use with those engaged in work in hot environments.
- I understand that I will not be required to carry out any work other than that which I usually do in the course of my employment.
- I understand that there are no additional hazards associated with performing this work other than those which are involved in my day-to-day work.
- I understand that, while I am carrying out my normal work, measurements will be obtained of my body temperature using a miniature heat-sensitive pill and an infra-red ear canal sensor as demonstrated to me.
- I also understand that, in addition to following usual safety procedures for work in hot conditions, some of the measurements obtained will be monitored and that I will be advised to withdraw from the hot environment if I reach the withdrawal criteria.
- I understand that I may decide not to take part in this study, or to withdraw from the study at any time and that I am under no obligation to participate further.
- I agree to participate in this study and freely give my consent to the specified procedures being performed.

Print name _____

Signature _____

Date _____

Witness name _____

Signature _____

Date _____

Medical screening questionnaire

Surname	Date of birth
First name(s)	Age
Address	
Mobile no.	Postcode
Employer	

Fitness status

	No	Yes
Are you fit for your full operational duties?		
Are you 'in date' for any routine medical examination as required by your employer?		
Are you 'in date' for any special medical examination (eg for hot work) as required by your employer?		

Medical conditions

	No	Yes
Do you suffer from any chest pains or breathlessness at rest or while exercising?		
Are you at increased risk of a cardiac event (eg heart disease, high cholesterol, obesity, high blood pressure, a family history of a serious heart condition in a male relative before the age of 55 or a female relative before the age of 65)?		
Are you at risk of an unexpected acute incapacitating event (eg asthma, diabetes, dizziness or epilepsy)?		
Are you currently taking any prescription medicines?		
Do you have any other medical condition, disease or disability which could affect your ability to participate in the trials?		
Would you like to discuss your fitness to participate in the trials with an occupational health adviser?		
Have you ever suffered heat stroke or severe heat-induced illness requiring first aid or medical intervention?		
Are you planning to have any medical investigations such as MRI scanning within 72 hours of the trials which the swallowing of the radio pill may interfere with?		
Have you had any problems with your gut (eg surgery, diverticulitis, inflammatory bowel disease) that may impair or prevent passage of the radio pill through your intestinal tract?		
Do you have a history of impairment or disorder of the gag reflex?		
Have you had any gastro-intestinal surgery?		

If you have answered No to any of the fitness status questions, or Yes to any of the medical condition questions, you must consult your occupational health service (OHS) to establish whether you can take part in the trials and you must secure written approval from your OHS to participate. This letter of approval should be returned to your Point of Contact. If you have answered Yes to all of the fitness status questions and No to all the medical condition questions, you should return the completed questionnaire, signed and dated, to your Point of Contact.

Signature

Date

CorTemp – core body temperature monitoring system

Subject instructions

Use of the CorTemp core body temperature monitoring system involves you swallowing a temperature sensitive pill. This has been widely used in previous studies and should cause no ill effects in normal use. However, you should not swallow this if any of the following apply to you:

- you weigh less than 36 kg (80 lb)
- you have any form of obstructive disease of the bowel (eg diverticulitis)
- you have any impairment of the gag reflex
- you have had gastrointestinal surgery
- you expect to have an MRI scan whilst the pill is inside you
- you have any form of hypomotility disorder of the gut
- you have a cardiac pacemaker or any other implanted device.

In essence, if you have a swallowing disorder (gag reflex) or some form of serious gastric problem you should not take the pill.

If you have any questions about any of these points please contact Dr Richard Graveling on 0131 449 8039.

The pill is contained in the small plastic bag provided. Please take this pill the evening before the study, as late as possible before going to bed for the night.

You are advised to have a cup of water to hand to assist in swallowing it. Open the bag and remove the pill in its wrapper. When ready to take the pill remove the paper wrapper and the small metal bar included with it (this is a magnet and removing it activates the pill – please do not remove it until you are ready to swallow the pill). **Only swallow the grey plastic capsule.**

Please put the wrapper and bar back into the plastic bag and bring these to work with you the following morning. This allows us to check the serial number and calibration of the pill you have taken against our records.

Can I remind you that your assistance in taking this pill (as with the remainder of the study) is completely voluntary. The pill provides us with the best method of monitoring your body temperature but, if you feel unable to take it for any reason, you do not have to.

Thank you for your help

Dr Richard Graveling F.Erg.S
Head of Human Sciences
Principal Ergonomics Consultant

Appendix 2: Details of confidence and prediction intervals under inverse regression

With the IG temperature as the ‘gold standard’, a regression analysis was performed with IG temperature as the predictor and IR temperature as the response to calibrate the model. This analysis showed a highly significant relationship.

In such a model, the equation of the fitted line is:

$$Y_0 = \alpha + \beta X_0$$

However, this provides a prediction of IR temperature from IG temperature, whereas the reverse (predicting IG temperature from IR temperature) is what is required. To obtain this, an inverse regression is performed, back-transforming the fitted line so that the IR temperature can be used to predict the IG temperature using the equation:

$$X_0 = \frac{Y_0 - \alpha}{\beta}$$

The 90 per cent confidence interval for the initial fitted line is:

$$Y_0 \pm 1.64s \sqrt{\frac{1}{n} + \frac{(X_0 - \bar{X})^2}{S_{XX}}}$$

Back-transformed, this gives:

$$\bar{X} + \frac{\beta(Y_0 - \bar{Y}) \pm 1.64s \sqrt{\frac{(Y_0 - \bar{Y})^2}{S_{YY}} + \frac{\beta^2}{n} - \frac{1.64^2 s^2}{S_{XX}n}}}{\beta^2 - \frac{1.64^2 s^2}{S_{XX}}}$$

From this, the 90 per cent prediction interval is:

$$Y \pm 1.64s \sqrt{1 + \frac{1}{n} + \frac{(X - \bar{X})^2}{S_{XX}}}$$

Back-transformed, this gives:

$$\bar{X} + \frac{\beta(Y_0 - \bar{Y}) \pm 1.64s \sqrt{\frac{(Y_0 - \bar{Y})^2}{S_{YY}} + \frac{\beta^2}{n} - \frac{1.64^2 s^2}{S_{XX}n} + \beta^2 - \frac{1.64^2 s^2}{S_{XX}}}}{\beta^2 - \frac{1.64^2 s^2}{S_{XX}}}$$

Using these formulae we can obtain confidence intervals and prediction intervals of the fitted inverse regression line.

A further characteristic of the data is that some of the pairs were related in that they were obtained from the same individual. It would be expected that such pairs would display some degree of a relationship compared to, for example, the same number of pairs each derived from a different person. To account for these repeated measures, a random effect is introduced to the model, labelled as ‘participant’, where the random effect accounts for the deviation of the average of each participant from the population average.

The random effect has a mean of zero, so it will have no effect on the fitted line, but there is a variance associated with the random effect which will affect the confidence intervals.

To obtain an approximate confidence (and prediction) interval for the fitted line, after taking repeated measures into account, it is necessary to adjust the variance of the interval. This was done by adding the variance of the random effect (r^2) to the residual variance (s^2) in the intervals above, giving:

$$\bar{X} + \frac{\beta(Y_0 - \bar{Y}) \pm 1.64(s+r) \sqrt{\frac{(Y_0 - \bar{Y})^2}{S_{YY}} + \frac{\beta^2}{n} - \frac{1.64^2 (s+r)^2}{S_{XX}n}}}{\beta^2 - \frac{1.64^2 (s+r)^2}{S_{XX}}}$$

And, for the back-transformed equivalent:

$$\bar{X} + \frac{\beta(Y_0 - \bar{Y}) \pm 1.64(s + r) \sqrt{\frac{(Y_0 - \bar{Y})^2}{S_{XX}} + \frac{\beta^2}{n} - \frac{1.64^2(s + r)^2}{S_{XX}n}} + \beta^2 - \frac{1.64^2(s + r)^2}{S_{XX}}}{\beta^2 - \frac{1.64^2(s + r)^2}{S_{XX}}}$$

Appendix 3: Health effects of working in the heat

A3.1 Introduction

There have been many examples of heat illness and death caused by heat stress in different industrial and leisure settings. A key factor in many of these cases is how accustomed those exposed are to hot conditions, both behaviourally and physiologically. In addition to effects on health, working in hot conditions can detrimentally affect task performance, co-ordination and judgment. This has been shown, in some industries, to have an effect on the levels of unsafe behaviour and accidents.

Although these guidelines primarily address the risks of physiological overload (heat fainting, heat exhaustion and heat stroke), other adverse effects can be encountered and these are also outlined here.

A3.2 Heat fainting

This is due to a reduction in blood pressure to the brain. It is more likely to occur in the unacclimatised during early exposure to the heat. Recovery should be rapid if the patient lies down and their legs are raised above their head. However, it can become serious if the patient is held upright or injured in a fall, in which case brain damage or death may occur.

A3.3 Heat exhaustion

Heat exhaustion is a mild response to exposure to hot environments. It results from a combination of thermal and cardiovascular strain. Symptoms include:

- a feeling of being unwell, including tiredness, headaches, dizziness, nausea and vomiting
- breathing difficulties or shallow, rapid respiration
- a rapid pulse which may be bounding or weak
- extreme thirst and mouth dryness
- muscle cramps, particularly affecting the stomach and legs
- poor control over movements, stumbling, weakness
- irritability.

Heat exhaustion is sometimes, but not always, accompanied by a small increase in body temperature (to 38–39 °C). Dehydration or, less commonly, salt deficiency may contribute to the development of heat exhaustion.

Prolonged exposure to the heat can lead to two forms of heat exhaustion: salt depletion and water depletion. Table 4 shows the differences between the two forms. Heat exhaustion usually responds positively to prompt treatment but may predispose the worker to heat stroke.

Selected features	Salt depletion heat exhaustion	Water depletion heat exhaustion
Duration of symptoms	Three to five days	Often much shorter
Thirst	Not prominent	Prominent
Fatigue	Prominent	Less prominent
Giddiness	Prominent	Less prominent
Muscle cramps	In most cases	Absent
Vomiting	In most cases	Usually absent
(Thermal) sweating	Probably unchanged	Diminished
Urine concentration	Moderate	Pronounced

Table 4
Distinction between predominant salt depletion heat exhaustion and predominant water depletion heat exhaustion (Based on Leithead & Lind³)

A3.4 Heat stroke

If the total heat load (environmental conditions and metabolic heat generation) is such that sufficient body heat cannot be lost to the environment, then core temperature will rise. If this continues, the body temperature may exceed its controllable limits. In wet or humid conditions a reduction in

sweating may occur due to swelling and blocking of the sweat glands. Alternatively, sweating may cease because of depletion of body water. The decrease in sweating promotes a further, often rapid, rise in core temperature to beyond around 39 °C, where collapse may occur, to above 41 °C (rectal temperature) where heat stroke may occur.

With heat stroke there is a major disruption of the central nervous function. At body temperatures above about 40 °C the person's mental functions are disturbed and sweating often stops. Normal temperature control mechanisms are lost and a further rapid temperature rise occurs. The symptoms include unconsciousness, convulsions or mental confusion, and failure of the central nervous thermoregulation and sweating. The casualty will be hot, dry and flushed with a high pulse and a core temperature probably above 41 °C. Heat stroke is an acute and potentially fatal condition. It requires immediate medical attention and cooling of the body is essential.

The condition can be of sudden onset with no warning or may be preceded by headache, dizziness, confusion, faintness, restlessness or vomiting (the symptoms of heat exhaustion). The change from normal aches or tiredness to serious symptoms may not be obvious to the casual observer. Therefore exposed individuals and their supervisors must be trained to recognise their onset. The transition from moderately elevated body temperature to heat stroke can be very rapid. For this reason, no person should work alone or unsupervised in potential heat stress conditions. A deterioration in work performance is usually a reliable indication that significant physiological strain has already occurred.

A3.5 Other effects

Heat oedema

This is swelling of the feet and ankles, and it usually occurs among those unacclimatised to the heat in the first week of exposure. It is usually alleviated by rest or by returning to a cooler environment.

Prickly heat (heat rash)

Prickly heat appears in red papules on the skin usually in areas where the clothing is restrictive. It gives rise to a prickling sensation, particularly as sweating increases. It occurs in skin that is persistently wetted by unevaporated sweat, apparently because the sweat ducts become blocked. The papules may become infected unless they are treated.

Heat rash is not dangerous, although it may result in patchy areas of skin that are temporarily unable to produce sweat. This may adversely affect evaporative heat loss and thermoregulation; prickly heat has been shown to decrease tolerance to heat and to reduce work capacity. Sweating capacity has been shown to recover within three or four weeks of prickly heat. A cool shower after exposure to hot conditions can help to reduce the risk of this problem occurring. If heat rash is suspected, the individual should be referred for a medical opinion.

In most cases the rashes disappear when the individual is returned to cool environments.

It is known that prickly heat is related to surface ambient temperature and sometimes to having hot showers.

Heat cramps

Heat cramps (painful muscle spasms) may occur in individuals working in the heat. They are caused by salt deficiency, when salt is lost during severe sweating and large amounts of water are taken without replacing the salt. The condition may have delayed onset and is most likely in people who are unacclimatised to hot work or have a low dietary salt intake. Cramps usually occur in the muscles principally used during work (limbs) or stomach. They can be alleviated by rest, the ingestion of water and the correction of any body fluid electrolyte imbalance, or by putting the affected muscle 'on the stretch' and applying gentle massage to the area. Adequate salt intake with food should prevent this occurring.

A3.6 Illnesses exacerbated by heat

Because work in the heat increases the load on the body, in particular the circulatory system, illnesses affecting this system may well be exacerbated by work in the heat. Some other illnesses may be exacerbated by hot conditions, while not rendering the individual unsuitable for the work. Two examples of this are dermatitis and fungal infections.

Dermatitis

This is a very common skin condition resulting from irritation and inflammation of the skin by external causes (eg abrasive dusts). Sweating softens the outer layer of skin and reduces its effectiveness as a barrier to irritants. PPE and clothing may add to the problems by confining chemical agents against the skin and therefore increasing uptake, or by mechanical abrasion. Avoiding tight clothing, regular replacement of badly soiled clothing and good personal hygiene can all help to reduce the risk of dermatitic conditions developing. Prevention of skin problems requires a focused management programme; refer to the Health and Safety Executive (HSE) guidance documents MS24 (*Medical aspects of occupational skin disease*) and INDG233 (rev1) (*Preventing contact dermatitis at work*).

Fungal infections

Fungal infections are promoted by heat and humidity and tend therefore to occur in areas of the body where such conditions are most pronounced, such as between the toes (athlete's foot) or in the groin or axillae (armpits). Good personal hygiene, possibly enhanced by the use of an antifungal powder, is usually effective in preventing or treating such conditions.

Appendix 4: Managing the risks of heat exposure

A4.1 General

Employers in the UK have an absolute duty to assess risks to health and safety to which their employees may be exposed. The Management of Health and Safety at Work Regulations 1999 require employers to make a suitable and sufficient assessment of risks to health and safety (and to record any significant findings). Regulation 3 of the accompanying Approved Code of Practice lays down a hierarchy of preventive and protective measures to be taken following the risk assessment:

- if possible, avoid a risk altogether
- combat risks at source
- wherever possible, adapt work to the individual
- take advantage of technological and technical progress
- take measures as part of a coherent policy and approach
- give priority to those measures which protect the whole workplace and all those who work there
- ensure workers understand what they need to do
- promote the existence of an active health and safety culture.

As stated above, the first risk control measure is to avoid the risk altogether. Assuming this is not an option, the second stage in the hierarchy of measures is to combat the risk at source. Where heat is an inherent part of the production process (such as in glass manufacture or metal casting), direct reduction at source is unlikely to be feasible (although clearly any enhancement of insulation around the hot process will be beneficial). However, the possibility of indirect reduction through the creation of cooled refuges or similar devices might have a role to play, especially where the habitual role is primarily one of monitoring the process with only periodic needs for physical intervention.

The risk of injury from heat stress, rather than the acute risk of burns, is a cumulative risk determined by, among other things:

- the climatic factors of temperature, humidity and airflow
- the duration of any exposure
- the level of physical activity
- the insulating effects of clothing.

With most occupational health hazards there is a degree of individual variability in susceptibility to injury, and exposure to work in hot conditions is no exception. Studies have suggested that, for a given set of conditions, the core temperatures of a group of individuals could be expected to differ by as much as 2 °C. In addition to interindividual susceptibility, individuals can be expected to vary from day to day in their temperature response. Employers and employees should be alert to this possibility and avoid complacency.

A4.2 Pre-exposure control measures

A4.2.1 Pre-exposure screening

Pre-employment assessments should identify those individuals with permanent or long-standing medical conditions that may render them unsuited for physical work in hot conditions. These are likely to include disorders that may cause someone to be:

- particularly susceptible to heat stress (eg renal problems adversely affecting fluid control)
- more likely to suffer as a result of such exposure (eg cardiac conditions which diminish the capacity to withstand the heightened cardiovascular strain of heat exposure).

Medical assessments are beyond the remit of this document but, in establishing an acceptable level of risk, it is assumed that such health screening has been performed. Advice should be sought from the employer's occupational health providers.

A4.2.2 Health monitoring and self-assessment

Before any period of work involving exposure to hot conditions, employees should be given some form of health check. This should take the form of a self-completed checklist or questionnaire, agreed with the occupational health adviser, which lists symptoms, ailments or medications that may give rise to a temporarily increased susceptibility to the heat. A gastro-intestinal upset, for example, can temporarily disrupt fluid balance, impairing thermal tolerance. Many drugs administered

therapeutically have the potential to impair normal thermoregulation. Individuals should be asked about their use of prescribed medication, ‘over-the-counter’ medicines such as antihistamines, or any other remedies for self-treatment. Table 5 shows some predisposing factors to heat intolerance. This presents conditions most likely to be identified during a pre-employment medical. As such, it is intended as a prompt for a responsible clinician, who will need to exercise clinical judgment as to whether the condition is sufficiently severe to jeopardise heat tolerance. However, other problems may create a short-term susceptibility and these are listed in Table 6. For assistance, this table, together with recommended actions, is presented in Appendix 5 in the form of a checklist. Employees who work in the heat should be instructed to ask their physicians or pharmacists specifically whether drug preparations could adversely affect thermoregulation or heat tolerance. Antihistamines, for example, can suppress sweating.

Obesity (more than 25 per cent over recommended weight for height has been used elsewhere) Skin diseases, eg anhidrosis, psoriasis, miliaria Conditions increasing heat production, eg thyrotoxicosis Low physical fitness (see current Fire Service fitness requirements) Cardiovascular disease Use of certain prescription, over-the-counter or recreational drugs, such as: • anticholinergics, eg atropine, Lomotil • diuretics • phenothiazines • tricyclic antidepressants • antihistamines, cold remedies • anti-Parkinsonian drugs • beta-blockers • amphetamines, ecstasy	Table 5 Long-term predisposing factors to heat intolerance (for consideration by a physician)
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Current upper respiratory infection or fever Recent alcohol consumption Sleep deprivation Dehydrating illness, eg diarrhoea, vomiting Skin diseases, eg anhidrosis, psoriasis, miliaria Use of certain prescription, over-the-counter or recreational drugs, such as: • anticholinergics, eg atropine, Lomotil • diuretics • phenothiazines • tricyclic antidepressants • antihistamines, cold remedies • anti-Parkinsonian drugs • beta-blockers • amphetamines, ecstasy	Table 6 Short-term predisposing factors to heat intolerance
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Where training is extended over more than one day, a brief follow-up check should be included in pre-exposure briefings. It may be advisable for this also to be a written self-administered questionnaire. Instructions should be issued to supervisors on the course of action to be followed if a problem is reported. It must be recognised that an employee may be reluctant to report a problem that excludes them from work, especially if sick pay is limited to basic pay (or is nonexistent). The importance for their own safety, as well as that of their colleagues, must be emphasised and a culture of openness encouraged.

A4.2.3 Information and training

Any system of self-assessment relies on accurate and honest reporting, unless the employee is visibly unwell. It is important, therefore, that employees should be given adequate information and training, not just in recognising the symptoms of heat-related illness but in understanding how their susceptibility may vary and the factors that can contribute to that variation. It is not sufficient, for example, to ask an employee ‘Are you taking any form of medication that might increase your risk of heat-related illness?’ unless the employee has an understanding of which forms of medication could have such effects.

Instruction should cover:

- the risks of working in the heat (covering both the physical (health) effects and the physiological effects on reasoning and decision-making)
- personal factors contributing to such risks (eg medical and lifestyle factors)
- risk control measures before work (eg reporting illness, water intake, avoiding unnecessary physical activity or heat exposure)
- control measures during work (eg avoiding an unnecessarily 'macho' culture, avoiding unnecessary exposure, using safety systems)
- control measures after work (eg fluid replacement, cooling-off procedures)
- avoiding other hazards (eg driving) if affected.

A4.2.4 Precooling measures

Some scientists have advocated artificially precooling workers before they enter a hot climate.

Although the benefits of this have yet to be demonstrated, a degree of water 'preloading' is considered desirable and employees should be encouraged to drink a modest amount (about 250 mL) before starting work (see post-exposure control for more detail).

A4.2.5 Dietary advice

Lack of food can lead to low blood sugar levels, which can increase the likelihood of heat strain.

Workers should be encouraged not to skip breakfast on work days. High carbohydrate foods are preferable. High protein foods place additional demands on water reserves, as some water has to be lost in excreting the nitrogenous waste; and high fat foods take longer to digest, placing a heavier burden on the digestive tract. This places a competing demand on the cardiovascular system, as more blood is required for heat transfer to the skin on exposure to hot conditions.

A4.2.6. Monitoring and control during work

Clothing

In hot climates, evaporation of sweat is usually a key element of reducing the risk of heat-related illness. However, clothing can disrupt this process, particularly where it is occlusive or non-permeable. Ideally, any coveralls should be of a lightweight construction, preferably with an open weave fabric, with reasonable air/vapour permeability. If used, limited-use garments should be chosen with care and non-permeable fabrics avoided. Air exchange can sometimes be improved through the use of two-piece (ie shirt and trousers) rather than one-piece clothing, provided the top is not tucked in. Designs with button or similar closures are preferred to zips as this again aids air exchange. However, metal fastenings should be used with care as they are likely to become heated during exposure to temperatures above around 45 °C and can cause discomfort or burns against bare skin underneath. Where it is necessary for employees to wear protective clothing (perhaps to protect against chemical exposure), expert advice should be sought, as it can significantly increase the risk of heat-related illness.

Environmental monitoring and recording

Monitoring environmental heat exposure should be regarded as an essential feature of any work session. It is unacceptable for employees to be exposed to elevated temperatures creating a risk of injury if those responsible have no knowledge of the temperatures involved and consequent extent of the risk.

Exposure temperature levels should be monitored at all times. It is essential that those responsible for monitoring have a clear understanding of the limits imposed on measurements obtained and of the procedures to be adopted if safe working levels are exceeded.

Records of exposures should be maintained and correlated with physiological monitoring (see below) to confirm the effectiveness of measures taken to control risk and to allow working environments to be modified or criteria refined as appropriate.

Physiological monitoring

Monitoring of the body temperature during work (and rest) provides individualised protection against allowing body temperature to rise to unacceptable levels. Data from various experimental studies have suggested that the core temperature should not exceed 39°C, although measured values will vary with the site and method of measurement. In determining an acceptable working limit, consideration should always be given, among other factors, to:

- the accuracy of the measurement system in use
- the risks associated with collapse in the workplace
- the likely time involved in removing the individual concerned to a cooler location.

If temperatures above 39 °C are recorded, temperature limits and other control measures should be adjusted accordingly.

There are many different methods and measurement sites advocated in the literature for monitoring body temperature. They vary in their invasiveness (from simple heat-sensitive colour-changing patches to rectal thermometers) and accuracy. BS EN ISO 9886 lists many of these. Generally speaking, the more invasive or intrusive measurements tend to be the more accurate. The present study, for example, has shown that the relatively unobtrusive and easily obtained measurement of ear temperature using an infrared sensor is not sufficiently reliable for use, even as an initial screening tool.

Supervisor, buddy and self-monitoring

All those involved in work at elevated temperatures should be aware of the signs and symptoms of the effects of heat so that they can recognise the signs in themselves or detect symptoms in others. Although limiting environmental temperatures and durations of exposure, together with other control measures, should provide adequate control, it should be emphasised to all that voluntary withdrawal from the work area is an option and that no stigma attaches to such an action. Team members should also be encouraged to observe colleagues and to alert supervisors and others to any apparent problems. Such systems on their own are not an adequate risk control measure although they do provide a useful additional measure.

Typical signs include vagueness, impaired memory or reasoning, light-headedness or dizziness, although any abnormal behaviour should be regarded with suspicion.

A4.3 Post-exposure control measures

A4.3.1 Accelerated cooling

After a period of heat exposure, a significant amount of heat will be trapped in the body and clothing of the worker. Their clothing will now act to retain that heat, preventing its dissipation into the environment. The simple expedient of unfastening overalls can help to speed the cooling process. In some circumstances, without this, body temperature can continue to rise inside highly insulating clothing, as heat in working muscles continues to be distributed around the body.

Where natural air movement is low, fans may help with the evaporation of sweat and the dissipation of heat, although care should be taken to avoid the workers becoming chilled. Some studies have shown that immersing hands and wrists in cool water can assist in reducing body temperature. Employees should avoid unnecessary physical activity during cooling-off periods as metabolic heat will reduce the effectiveness of any recovery period.

A4.3.2 Rehydration

Much of the adverse effect of heat exposure stems from the resultant dehydration as the body loses copious quantities of sweat in an attempt to regulate its temperature. Fluid replacement is therefore an important aspect of restoring the thermal and physiological equilibrium of the worker. Studies have shown that by the time individuals feel thirsty, they are already dehydrated. Similarly, although a few mouthfuls may be enough to remove the immediate sensation of thirst, this is not sufficient to restore thermal balance. Cool (10–15 °C) rather than cold drinks are preferable and there is some argument for tepid (30 °C) drinks. The direct cooling effect of any fluid is minimal and, if a drink is too cold, it may cause local vasoconstriction of the blood vessels in the stomach, resulting in a slower rate of absorption. Flavoured drinks are acceptable if preferred but carbonated and alcoholic drinks should be avoided (carbonated drinks cause misleading sensations of fullness). Despite the importance of fluid replacement, workers should be discouraged from drinking copious quantities too rapidly. Rapid absorption of large volumes of water can result in excessive dilution of blood ions (salts) with adverse effects.

It is not usually necessary to provide saline drinks or salt tablets. The salt concentration of sweat is less than that of blood and, although the salts lost through sweating ultimately need to be replaced, dietary salt is normally adequate for this purpose (workers who are on a salt-controlled diet for medical reasons should have been identified earlier).

A4.3.3 Emergency procedures

The measures described above should significantly reduce the risk of serious injury from heat exposure. Nevertheless, it is important that there should be a clear emergency procedure in place to

deal with any such event should it arise. Clinical studies report individuals 'pushing' themselves (eg in an athletics competition) and then collapsing and all staff should be aware of this possibility. In serious cases, if temperature control has failed, core temperature will continue to rise despite withdrawal from the high temperature environment, removal of clothing and so on.

A system should be in place for removing any affected worker from the hot area to a suitable cool location where prompt remedial action can be taken. Here, the ease of exiting from the working area may be an issue. Although a conscious and able casualty may not have a problem with this, the practicality of evacuating an unconscious worker should be considered and some form of plan of action devised, especially from areas with limited access. If necessary, an emergency refuge should be established nearby with cooling fans and other items immediately to hand.

Remedial measures should be in place both for those experiencing minor symptoms (concentrating on rehydration and cooling) and those in a state of collapse, for whom the usual first aid priorities of airways, breathing and circulation should be adopted. In such circumstances, cooling the casualty is important, as clinical experience has shown that complications do not occur if casualties are treated within 15 minutes of collapse and if their temperature is below 38 °C within one hour of starting treatment. A prompt response is clearly vital.

For the conscious casualty who can be cooled (by removing protective clothing, then wetting and fanning the body) and who is able to take water, hospitalisation is not considered necessary, provided there is no impairment of consciousness and no evidence of complications, and provided that core temperature has fallen back below 38 °C within one hour after the start of treatment. It should be noted that, in such cases, evaporation is a much more efficient means of removing heat and wetting and fanning is likely therefore to be a more effective approach than immersion in water or ice packs. Hospitalisation will be required for more serious cases where circulatory collapse may have occurred.

A4.3.4 Information and training

Correct post-exposure behaviour should be included in information and training. All workers should be aware of the importance of cooling and rehydration. Particularly at the end of the day, they should be cautioned against rushing away ('I'll have a drink when I get home' is not acceptable). Those experiencing symptoms such as dizziness should be counselled against travelling (particularly if driving) until symptoms have subsided and adequate cooling and rehydration has taken place. Monitoring the core temperature of such individuals provides further reassurance. Urine colour (small quantities of dark urine suggest continuing dehydration) can also provide an informal check.

Appendix 5: Factors adversely affecting heat tolerance

A number of factors can cause someone to be temporarily less tolerant of heat exposure than normal.

If any of the following apply to you, then you may be at more risk of injury due to heat stress and you should inform your employer. Factors such as significant alcohol consumption or illnesses causing sickness and diarrhoea can result in you becoming temporarily dehydrated. If there is any doubt as to your fitness, seek further advice from an occupational health nurse or physician.

Do any of the following apply to you?	Tick any that apply
Current upper respiratory infection or fever	
Recent significant alcohol consumption (more than the driving limit)	
Significant sleep deprivation (lasting for two or more nights)	
Dehydrating illness, eg diarrhoea, vomiting	
Skin diseases, eg anhidrosis, psoriasis, miliaria	
Use of certain prescription, over-the-counter or recreational drugs, including:	
• anticholinergics, eg atropine, Lomotil	
• diuretics	
• phenothiazines	
• tricyclic antidepressants	
• antihistamines, cold remedies	
• anti-Parkinsonian drugs	
• beta-blockers	
• amphetamines, ecstasy	

Whenever you are given drugs, either on prescription or over the counter, you should make your doctor or pharmacist aware of your profession and check whether the drugs in question could adversely affect heat tolerance.

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