Fluid Losses and Hydration Status of Industrial Workers under Thermal Stress Working Extended Shifts

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Abstract

Objectives

A field investigation to examine the fluid consumption, sweat rates and changes in the hydration state of industrial workers on extended (10, 12 and 12.5 hour) shifts under significant levels of thermal stress (WBGT>32^0 C) was conducted on 39 male underground miners.

The purpose was to assess whether workers under significant thermal stress necessarily dehydrated during their exposure and whether 'involuntary dehydration' was inevitable, as supported by ISO9866 and other authorities. Other objectives were to quantify sweat rates against recommended occupational limits, to develop a dehydration protocol to assist with managing heat exposures and to understand the role of meal breaks on extended shifts in terms of fluid replacement.

Methods

Urinary specific gravity was measured before, during and at the completion of the working shift. Environmental conditions were measured hourly during the shift. Fluid replacement was measured during the working periods and during the meal breaks.

Results

Average environmental conditions were severe (WBGT 30.9^0 C, sd 2.0^0 C, range 25.7-35.2^0 C). Fluid intake averaged 0.8 l/h during exposure (sd 0.3 l/h, range 0.3-1.5 l/h). Average urinary specific gravity at start-, mid- and end of shift was 1.0251, 1.0248 and 1.0254 respectively; the differences between start and mid-shift, mid and end-shift, and start and end-shift were not significant. However, a majority of workers were coming to work in a moderately hypohydrated state (urinary specific gravity avg 1.024, std dev 0.0059).

A combined dehydration and heat illness protocol was developed. Urinary specific gravity limits of 1.022 for start of shift and 1.030 for end of shift were selected; workers exceeding these values were not allowed into the workplace (if the start of shift limit was exceeded) or re-tested prior to their next working shift (if the end of shift limit was exceeded). A target of 1.015 as a euhydrated state for start of shift was adopted for workforce education.

Conclusions

This study found that "involuntary dehydration" did not occur in well-informed workers, which has implications for heat stress standards that do not make provision for full fluid replacement during heat exposure. Fluid replacement during meal breaks was not significantly elevated above fluid replacement rates during work time, with implications for the duration and spacing of meal breaks on long shifts. Testing of urinary specific gravity was found to be a good indication of hydration status and a practical method of improving workforce awareness and understanding of this important risk factor. Approximately 10 000 dehydration tests have been conducted under the dehydration protocol in a workforce of 2 000 persons exposed to thermal stress and has proved practical and reliable.

Key words

fluid replacement, sweat rate, dehydration, hypohydration, heat stress

Summary box:

- A combined dehydration and heat illness protocol has been developed, with recommended limits of urinary specific gravity for the start and end of a working shift.
- A majority of workers started their shift in a hypohydrated state.
- Where workers were well-informed and subject to monitoring, "involuntary dehydration" (if it is defined as a physiologically unavoidable dehydration during exposure to heat) did not occur. Whilst voluntary dehydration (inadequate or delayed thirst response) has been observed regularly in other settings, it is probably a function of poor access to water, workplace practices (particularly

a lack of self-pacing), inadequate education, or insufficient quality or palatability of water, and is neither physiologically nor psychologically inevitable.

- Whilst a meal break is important when working in heat in terms of replacing solutes lost in sweat, its role in fluid replacement for well-educated workers trained in the need for program drinking during the heat exposure may be less than has been previously considered.
- Fluid consumption rates (and hence, in circumstances where workers' hydration status is not changing, sweat rates) of up to 1.5 litres per hour occur in self-paced, acclimatised, industrial workers with typical rates varying between 0.5 and 1.1 litres per hour.

Policy implications

- Education is vital if a workforce that is exposed to significant levels of thermal stress is to come to work euhydrated, and maintain their hydration state during their work shift. Paced fluid replacement (program drinking) rather than responding to the thirst sensation is critical to maintaining hydration levels when working under thermal stress.
- Standards for occupational heat stress should not assume that workers are unable to avoid dehydration when exposed to heat, i.e. involuntary dehydration should not be implicit in heat stress standards.

Introduction

This study reports a field investigation to examine the hydration status and fluid replacement in industrial shiftworkers. All subjects were miners employed in the hottest of four deep, underground mines located within 20 km of each other well inside the tropics in northern Australia. The workers were all on 10, 12 or 12.5 hour shifts. The climatic profile [1] for the city in which these workers live consists of near-maximum summer temperatures of 41.5^0 C dry bulb (DB) and 25^0 C wet bulb (WB). The near-minimum winter temperature is 3.5^0 C DB.

The objectives of the study were:

- To determine whether workers dehydrated during their shift.
- To measure fluid consumption during the working shift.
- To estimate sweat rates during the working shift, and assess these against currently published occupational limits.
- To examine the role of the meal break in overall fluid replacement during the working shift.

The target group within the workforce were those workers most exposed to severe thermal environmental conditions. They are acclimatised and work hardened and are generally well-informed about the importance of drinking water. A personal 4-litre water bottle is a compulsory component of their PPE (personal protective equipment). The employer at this operation provides low-joule cordial essence (flavouring) at no cost, and some workers add this to their drinking water. All subjects in the study were drawn from the target group.

Approximately 2 000 persons work underground at these mines providing a 24-hour, 363-day coverage. As the underground workplaces are widely dispersed, workers are typically visited by their supervisor twice per shift for approximately 10 minutes per visit.

In addition to the heat and humidity in the environment, these workers must cope with poor illumination, dust, noise and broken ground. Compulsory mine workers' uniforms consist of long cotton trousers and short or long sleeved shirts, safety boots, safety helmet, eye protection, heavy safety belt, cap lamp and cap lamp battery. Where the environment is dusty or noisy, a face respirator or noise protection must also be worn. Some activities involve cement grout or other chemical agents, and these require wearing elbow-length impermeable gloves, a rubber apron, and a visor clipped to the safety helmet. However, the workforce is highly mobile, and some work is conducted from within air-conditioned cabins of mobile equipment. Not all work was in extreme conditions or was physically strenuous. Lunch breaks are all taken in air-conditioned underground lunchrooms.

As these workplaces are at a depth of between 1 000 m and 1 800 m below surface, there is no significant change in temperatures in the workplace between day and night due to the thermal damping that occurs in the long intake airways between the surface and the workplace. Furthermore, autocompression (the increase in air temperature as it descends a shaft due solely to conversion of potential energy into heat) adds about 6^0 C DB and 4^0 C WB per 1 000 m of vertical depth.[2] This temperature increase, along with the diminished effects of changing surface seasons due to the distance to the workplace, means that exposures to elevated levels of heat stress occur throughout the year, although they are less frequent and less extreme in winter. An analysis of the incidence of heat illness with respect to surface temperatures at this operation has recently been completed.[3]

Dehydration is known to produce a wide range of physical, mental and psychological decrements in performance,[4-9] and has been implicated in 50% of all heat stroke cases in South African miners.[10] Therefore the ability of industrial workers to replace fluid lost in sweat is crucial when designing protocols for working in heat, and particularly in the design of protocols for extended shifts.

In this regard, there is disagreement in the literature about acceptable sweat rates for industrial workers. Whilst sweat rates of 1.5 to 2.5 l/h have been demonstrated over short periods (with peaks of 3 l/h),[11-12] acceptable figures for a working shift are generally considered to be lower. ISO 7933[13] and Belding and Hatch[14] advocate a limit of 1.04 and 1.0 l/h respectively for acclimatised persons, although ISO 9886[15] curiously states that “There is no limit applicable concerning the maximum sweat rate: the values…adopted in ISO 7933…must be considered not as maximum values but rather as minimal values that can be exceeded by most subjects in good physical conditions”. Nunneley[16] reports that humans can sweat indefinitely at rates of 1.5 to 2.0 l/h, whilst McArdle[17] recommended a limit of 4.5 l over 4 hours. This relatively wide range of acceptable sweat rates is in part related to the wide range of views on acceptable skin wettedness, with ISO 7933 accepting a fully wet skin (1.0 wettedness) for acclimatised workers over extended periods, but Azer[18] recommending a maximum skin wettedness of 0.5 for similar, fully acclimatised persons. A much higher sweat rate is required to maintain a fully-wet skin than a 50% wet skin.[13,19]

Various authors have found that fluid replacement when under thermal stress is only ½ to $^2/_3$ of the fluid loss.[4,10,20] This observation has subsequently been endorsed as an unavoidable water deficit in thermal stress standards such as ISO 7933 (which does not provide for a fluid replacement term in its formulation). It therefore has a major impact on allowable exposure times in hot conditions with high sweat rates.

This fluid deficit has been attributed to two phenomena.

The first is “voluntary dehydration”, in which persons dehydrate while under thermal stress despite having access to plentiful supplies of palatable water. Adolf[4] attributed this to an inadequate thirst response, i.e. the thirst response is delayed and/or insufficient to provide for adequate fluid replacement. Other authors have found that the thirst sensation does not begin until about 1% to 2% of body weight[0] or 2% of total body water[21] has been lost. There is still disagreement as to whether the thirst response is inadequate or merely delayed or both.[21,22]

The second phenomenon is rather confusingly called “involuntary dehydration”. It refers to the fact that during the dehydration process (or once hypohydrated), the rate of fluid retention (or rate of rehydration), even when the fluid intake exceeds the sweat rate, is governed largely by the ability to replace the solutes lost in sweat, principally sodium.[23-26]

Other authors have found and described a condition called “sweat gland fatigue”.[27,19,5,4] Its pathogenesis remains unclear [28]; however, it has been implicated in reductions in sweat rates of up to 50% after continuous exposures of four hours.[29,30] Sweat gland fatigue should not be confused with hidromeiosis, which is a localised reduction in sweat rate; several mechanisms have been proposed for this but the most probable is that localised swelling (hydration) of the stratum corneum results in mechanical obstruction of the sweat duct.[28,31,19]

A further issue for review in this study was to examine the importance of the meal break in maintaining the hydration state. Early authors such as Adolf[4] found that the meal break had an important role in rehydration. He found that the ingestion of food during a meal break stimulated the thirst response and led to the intake of additional fluids, which he found essential to restoring total body water. With the trend towards longer (e.g. 12-hour) shifts, the number of meal breaks and their location within the working shift and duration could be more significant than on traditional 8-hour shifts.

A combined “dehydration and heat illness protocol” (Figure 1) and other management procedures were introduced at this operation immediately prior to and during these studies.[33] Figure 1 superseded an earlier protocol that included a Fantus test.[32] These protocols introduced a new heat stress index[34] and a more pro-active approach to the management of heat stress, heat illness and dehydration in the workplace than had previously been the case. Hydration status was estimated from urinary specific gravity, which is considered to be an important indicator of the absolute hydration status of the body and of relative changes in hydration status over time, although it does not mimic body water loss in a perfectly linear relationship,[35] and may be in error where the subject is experiencing diuresis due to alcohol or caffeine intake, or is taking vitamin supplements or some drugs.

Pure water has a specific gravity of 1.000 (dimensionless), whilst the maximum concentrating capacity of the renal system is about 1.050. In this study, a dehydrated state was considered to be a specific gravity > 1.030, based on the criterion used by the Australian Pathology Association. A euhydrated state was considered to be < 1.015, based on work by Donoghue et al[0] and the fact that 1.015 is one standard deviation below the average start-of-shift value found for workers in this study. However, Armstrong et al[35] reported that a euhydrated state is a specific gravity of 1.004 $\pm$ 0.002, using a carefully controlled protocol to ensure euhydration in 9 male athletes; this is well outside the range of 1.015 to 1.024 considered to be "normal" by Reaburn and Coutts.[36] Armstrong's definition of euhydration as being a fully-hydrated condition (i.e. no nett body water deficit), is different to the more common usage of the term as being a normally-hydrated condition. Further work is needed to fully define euhydration in an occupational setting.

Figure 1 shows that workers under significant levels of thermal stress were tested at the end of shift, and if their specific gravity exceeded 1.030, were required to re-present and have a specific gravity not exceeding 1.022 prior to commencing their next shift. The value of 1.022 was an arbitrary value approximately half-way between a euhydrated (1.015) and dehydrated (1.030) state.

Methods

Subjects

All participants gave their written informed consent to a series of studies that was authorised by management, their Labour unions, and the supervising organisation's ethics committee on human experimentation.

The workers in these mines were all relatively well informed about the issues of working in heat, and in particular about the need for self-pacing and for fluid replacement. Workers were not generally subject to any regular form of medical assessment, apart from a pre-employment health screen. No worker in the study reported heat illness and all workers were engaged in their ordinary work activities.[37]

Sub-maximal $\dot{V}O_{2\max}$ (aerobic capacity) was measured using the Astrand and Rodahl protocol.

Studies

The main study measured the hydration state of 39 male workers most exposed to heat stress before, at the mid-point, and at the end of their shift. The environmental conditions in which they were working and their fluid intake was also measured or estimated regularly during the shift.

For comparison purposes, the specific gravity of a sample of 64 workers prior to commencing their work shift was also measured. No further interaction was had with these workers.

The end-of-shift specific gravity of all workers (n = 546) who were working in such extreme environments that their shift length had been reduced to six-hours duration (locally called a "hot job") was also collected over a period of approximately 12 months. Temperatures in a "hot job" had to exceed a WBGT of approximately 32^0 to 33^0 C; the actual values were based on an adaptation of the Predicted 4-hour sweat rate (P_4SR).[38] If work continued in these conditions for at least two hours, the shift duration was reduced to 6 hours (which includes a meal break). The maximum exposure time to heat stress under a "hot job" would be 4 hours.

Part of the reason for the comparison studies was to ensure that workers who were studied in the main study did not modify their behaviour, compared to workers who were not monitored during their work shift.

Urinary specific gravity

Urinary specific gravity was measured using a handheld, optical refractometer (Atago Uricon-NE) at the start, mid (just before the meal break [called "crib"]) and end of shift.

Environmental conditions

Environmental conditions were measured at each workplace approximately every 60 to 90 minutes using a Heat Stress Meter,[39] which provides digital readouts of ventilated wet bulb temperature (WB), dry bulb temperature (DB), wind speed, globe temperature, calculated mean radiant temperature, barometric pressure and Wet bulb globe temperature (WBGT). Sling (whirling) psychrometers and vane anemometers were also used to obtain redundant measurements of the most important environmental parameters in these workplaces: WB, DB and wind speed. WBGT was evaluated in accordance with ACGIH guidelines.[40] Thermal Work Limit (TWL) values[34] were calculated assuming a barometric pressure of 110 kPa (an approximate average barometric pressure for the workplaces, about 1 000 metres below sea level; TWL is not highly sensitive to small changes in barometric pressure).

Fluid Consumption

Fluid consumption was estimated by allocating a separate 4-litre water bottle to each worker participating in the study. The cup on each water bottle had a capacity of 400 ml. Each worker was visited approximately every 60 to 90 minutes and the water consumption estimated from the cups drunk and checked against water levels in the bottle.

The heat stress exposure hours were obtained by deducting 3.5 hours from a 12- or 12.5-hour shift, and 2.5 hours from a 10-hour shift. This is based on prior internal reviews that showed that for a shift with one meal ("crib") break, workers lose 2.5 hours in travelling underground to their crib room, getting instructions from their supervisor, getting to the job, returning to the crib room for lunch, returning to the workplace after crib, and returning to the hoisting shaft before the end of the shift to get back to the surface by shift end.

For 12-hour shifts, workers take two 30-minute meal breaks per shift, so that exposure time is 3.5 hours less than nominal work duration. Workers on 10-hour shifts have one 30-minute break per shift. Crib breaks may be taken at any time convenient to the workers.

An additional 30 minutes was typically lost at the start and end of each subject's shift, for administrative reasons associated with the test protocol. Therefore fluid consumption rates calculated as litres per hour in this study may be somewhat conservative.

The main study provided pairs of data (before-mid shift, mid-end shift, before-end shift) and the differences were assessed using the paired, two-tailed student's T test assuming equal variances. For the other tests, paired data was not available so the unpaired, one-tailed student's T test assuming equal variances was used.

Results

Subjects

A summary of the anthropometric and body morphology data and $\dot{V}O_{2\max}$ for the subjects in the main study is shown in Table 1.

Environmental conditions

Environmental conditions for the main study were measured at each workplace approximately every 60 to 90 minutes, with 233 sets of readings taken in total. Of these 233 sets, 46 observations were in the cribroom or inside air-conditioned mobile equipment cabins, leaving 187 sets from thermally exposed workplaces (Table 2). The unweighted average of these 187 sets was 28.4^0 C WB, 36.2^0 C DB, 36.3^0 C globe temperature, 1.1 m/s wind speed, 30.9^0 C WBGT and a TWL of 175 W/m^2.

Hydration

The main study

The start, mid and end of shift urinary specific gravity values were measured for 39 workers over 39shifts. 9 of these shifts were 10-hour duration and 30 shifts were 12-hour duration. The results are summarised in Table 3 and Figure 2. There is no significant difference in the means of the paired sets of specific gravity values, either between start and mid shift (p=0.81), between mid and end of shift (p=0.70), or between start and end of shift (p=0.85).

Comparison with other workers at start of shift

The average urinary specific gravity of the separate group of workers (n = 64) prior to going underground was 1.0225 (sd 0.0078, range 1.0020-1.0350). 9% of this group came to work with a specific gravity exceeding 1.0300 and a total of 56% had a specific gravity exceeding 1.0220, these being the allowable end- and start-of-shift limits under the Dehydration protocol.

Comparison with "hot job" workers at end of shift

The average specific gravity at the end of shift for all workers (n = 546) who worked in "hot job" conditions over the previous 12 months was 1.0244 (sd 0.0067, range 1.0020-1.0360). None of these workers reported symptoms of heat illness. For these individuals, specific gravity was checked on the surface rather than underground and this could be between 30 minutes and two hours after the completion of the heat exposure, so that some workers in this study would have rehydrated to some extent prior to providing their urine samples.

The average end-of-shift specific gravity of these workers (n = 546) was significantly higher (p=0.019) than the start-of-shift specific gravity of the group of workers (n = 64) prior to commencing work. However, the absolute increase (1.0220 to 1.0244) was small.

Fluid consumption

The fluid consumed during the working shift was monitored and recorded in detail for 39 workers over 39 shifts with a total nominal shift duration of 444 hours (comprising 23 x 12 hour shifts, 3 x 12.5 hour shifts and 13 x 10 hour shifts). Estimated exposure time was 320 hours (72% of nominal work time). The remaining time was spent getting to and from the workplace, and having meal breaks, etc.

The average fluid consumption per shift was 6.48 litres (over this mix of different shift lengths) with a standard deviation of 2.41 litres and range of 2.40 to 12.50 litres. Moisture content in food was not included in this analysis, but would increase the calculated fluid consumption rates.

The mean full-shift average fluid consumption rate was 0.8 litres per hour (sd 0.27,range 0.32-1.47).

Discussion

Subjects

The average BMI (27.5) of the target group is in the middle of the "overweight" range of 25 to 30 kg/m^2 as designated by the World Health Organisation.[0] The average $\dot{V}O_{2\max}$ (39.0 ml/kg/min) is at the lower limit of the normal range (39-48 ml/kg/min) for non-athletes aged 30 to 39 years.[42] The target group was typical of industrial workers at this operation. A test of 469 contract employees joining the organisation for project work under similar levels of heat stress during this period had a measured $\dot{V}O_{2\max}$ of 39.0 ml/kg/min (std dev 7.8 ml/kg/min) and a BMI of 25.9 (std dev 5.4).

Environmental conditions

54% of workplace readings were above 30^0 WBGT and 83% were above 26.7^0 WBGT. Note that WBGT values of 30^0 and 26.7^0 are the ACGIH[40] recommended limits for continuous work for acclimatised workers at light work and moderate work respectively. On average, therefore, workers in this study were in very thermally stressful conditions. Workers in "hot jobs" (>32^0 C WBGT) were in even more extreme conditions.

Over ten million manshifts have been worked at this operation over the past 30 years in conditions exceeding 28^0 C WB without any recorded incidence of heat stroke.[43] As work in this operation includes both light and moderate rates, with periods of hard work, and work continues in conditions well above the ACGIH recommended values, it could be concluded that the probability of developing a life-threatening heat illness (stroke) under the ACGIH guidelines is very low for self-paced, acclimatised workers.

Hydration Changes

As there is no statistical change in the mean specific gravity before, during or at the end of the working shift, it can be concluded that workers sweating under these substantial levels of thermal stress do have the ability to maintain their hydration state. Note that these results do not support voluntary or involuntary dehydration. This varying conclusion is supported by Donoghue et al[3] who found that serum sodium levels were within the normal range both for workers at this operation who developed heat illness and for those who did not. The explanation for this contrary findings is almost certainly the strong emphasis at this operation on workforce education, self-pacing and programmed drinking during the working shift.

Note also that over 60% of the workers in this study were commencing their shift insufficiently hydrated to be fit for work in hot conditions, using the definition at this workplace of a specific gravity exceeding 1.0220.[33] However, whilst these workers were hypohydrated at the start of their shift, they were non-dehydrating during their shift.

Comparison with other workers at start of shift

The average specific gravity of this group prior to commencing their shift was 1.0225 (sd 0.0078, range 1.002-1.035) which confirmed that workers are substantially hypohydrated prior to starting work.

Comparison with "hot job" workers at end of shift

Those workers who worked in the most severe thermal stress (WBGT>32^0 C) did dehydrate during their shift, compared to workers at the start of their shift. The absolute increase is small (from 1.0225 to 1.0246); however, this could be affected by the time delay between exposure and measurement

The main differences between the groups of workers in the main study (Table 1) and the comparison studies, is that the workers in the main study were monitored regularly during their shift as to how much water they were drinking, and can therefore be assumed to be much more focussed on replacing fluids, compared to the comparison studies, where no fluid monitoring was conducted. This data does therefore tend to support the conclusion that there is some altered behaviour when workers' fluid consumption is being monitored.

Fluid consumption

These average and maximum fluid consumption rates are well in excess of values reported for workers in more temperate climates,[12] and the maximum values are well above those considered advisory by some sources.[13]

Virtually all the rehydration beverage was water, with relatively minor quantities of coffee, tea, cola soft drinks and sports drinks consumed. No carbonated drinks are able to be purchased in the workplace or lunch rooms and few workers bring soft drinks as part of their lunch. Some workers used the low-joule cordial flavouring provided by the employer.

Over the 39 shifts, fluid consumption during meal breaks amounted to 31 litres, or 14% of the total fluid consumed. Duration of meal breaks (60 mins) as a proportion of exposure time was approximately 12%. The role of the meal breaks is therefore less important in maintaining fluid intake in these workers than has been found previously. Given the conclusion above that these workers are, on average, not dehydrating during their working shift, the probable reasons for the relatively low consumption of fluids during the meal break are:

- The ad libitum availability of water "on the job" in personal water bottles,
- Water is cold and moderately palatable, with free access to cordial flavouring,
- Workers are educated about the need to drink small amounts frequently (the recommended value during their induction and annual refresher training is 250 ml every 15 minutes).

The findings of Adolf[4] and others about the importance of the meal break in maintaining adequate fluid intake could possibly be explained by the above. In addition, Adolf's subjects (soldiers) were dehydrating during their exposures, whereas these workers, on average, were not. It is important to recognise that whilst the meal break may not be crucial to the fluid intake of workers who are disciplined about program drinking during their heat exposure, it is crucial to their replacement of sodium and other osmols.[44]

Given that there was no net change in the hydration state of these workers over their shift, average sweat rates would not be significantly different to average fluid consumption rates. On this basis, five out of 39 workers (13%) exceeded a sweat rate of 1.04 l/hr. This implies that the allowable sweat rates recommended under standards such as ISO7933 (1.04 litres per hour for acclimatised persons) are reasonable, although this rate can and will be safely exceeded by some workers, which is in accordance with the comments in ISO 9886.

Conclusions and Recommendations

The conclusions from these studies are as follows:

- Urinary specific gravity is a good screening test for hypohydration, the most serious risk factor for developing heat exhaustion in self-paced workers.
- A combined dehydration and heat illness protocol has been developed, with recommended limits of urinary specific gravity for the start and end of a working shift.
- A majority of workers started their shift in a hypohydrated state.
- Education is vital if a workforce that is exposed to significant levels of thermal stress is to come to work euhydrated, and maintain their hydration state during their work shift. Paced fluid replacement (program drinking) rather than responding to the thirst sensation is critical to maintaining hydration levels when working under thermal stress.

- Where fluid rates were not monitored, workers in very stressful conditions (WBGT>32.0^0 C) dehydrated over the course of their shift, although the actual increase in urinary specific gravity was small (1.0225 to 1.0244).
- Where workers were well-informed and subject to monitoring, "involuntary dehydration" (if it is defined as a physiologically unavoidable dehydration during exposure to heat) did not occur. Whilst voluntary dehydration (inadequate or delayed thirst response) has been observed regularly in other settings, it is probably a function of poor access to water, workplace practices (particularly a lack of self-pacing), inadequate education, or insufficient quality or palatability of water, and is neither physiologically nor psychologically inevitable.
- Standards for heat stress should not assume that workers are unable to avoid dehydration when exposed to heat, i.e. involuntary dehydration should not be implicit in heat stress standards.
- Whilst a meal break is important when working in heat, in terms of replacing solutes lost in sweat, its role in fluid replacement for well-educated workers trained in the need for program drinking during the heat exposure may be less than has been previously considered.
- Fluid consumption rates (and hence, in circumstances where workers' hydration status is not changing, sweat rates) of up to 1.5 litres per hour occur in self-paced, acclimatised, industrial workers with typical rates varying between 0.5 and 1.1 litres per hour.

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Table 1, Anthropometric and body morphology for the 39 workers in the main study

Name	Age, yrs	Height, cm	Weight, kg	BMI	$\dot{V}O_{2\,\max}$, ml/kg/min
n	39	38	38	37	18
Avg	35	178	88	27.9	39.1
Std dev	8	9	16	4.0	7.7
Range	21-52	147-196	65-125	22.1-38.2	28.0-56.3

Table 2 Environmental conditions for the workers in the main study

	WB	DB	GT	Wind	WBGT	TWL
	0 C	0 C	0 C	m/s	0 C	W/m2
n	187	187	187	187	187	187
Avg	28.4	36.2	36.3	1.1	30.9	175
Std dev	2.2	2.6	2.8	1.6	2.0	42
Range	24.2-33.7	23.7-41.3	23.8-41.3	0.1-7.0	25.7-35.2	83-268

Table 3 Urinary specific gravity data from the main study

	S.G. Start of shift	S.G. Mid-shift	S.G. End of shift
n	39	39	39
Avg	1.0252	1.0248	1.0254
Std dev	0.00533	0.00533	0.00686
Range	1.012-1.035	1.009-1.035	1.006-1.035
p value	Start to mid=0.85	Mid to end=0.70	Start to end=0.85

Figure 1 Dehydration and Heat Illness Protocol used in workplace. “S.G.” is urinary specific gravity measured using hand refractometer.

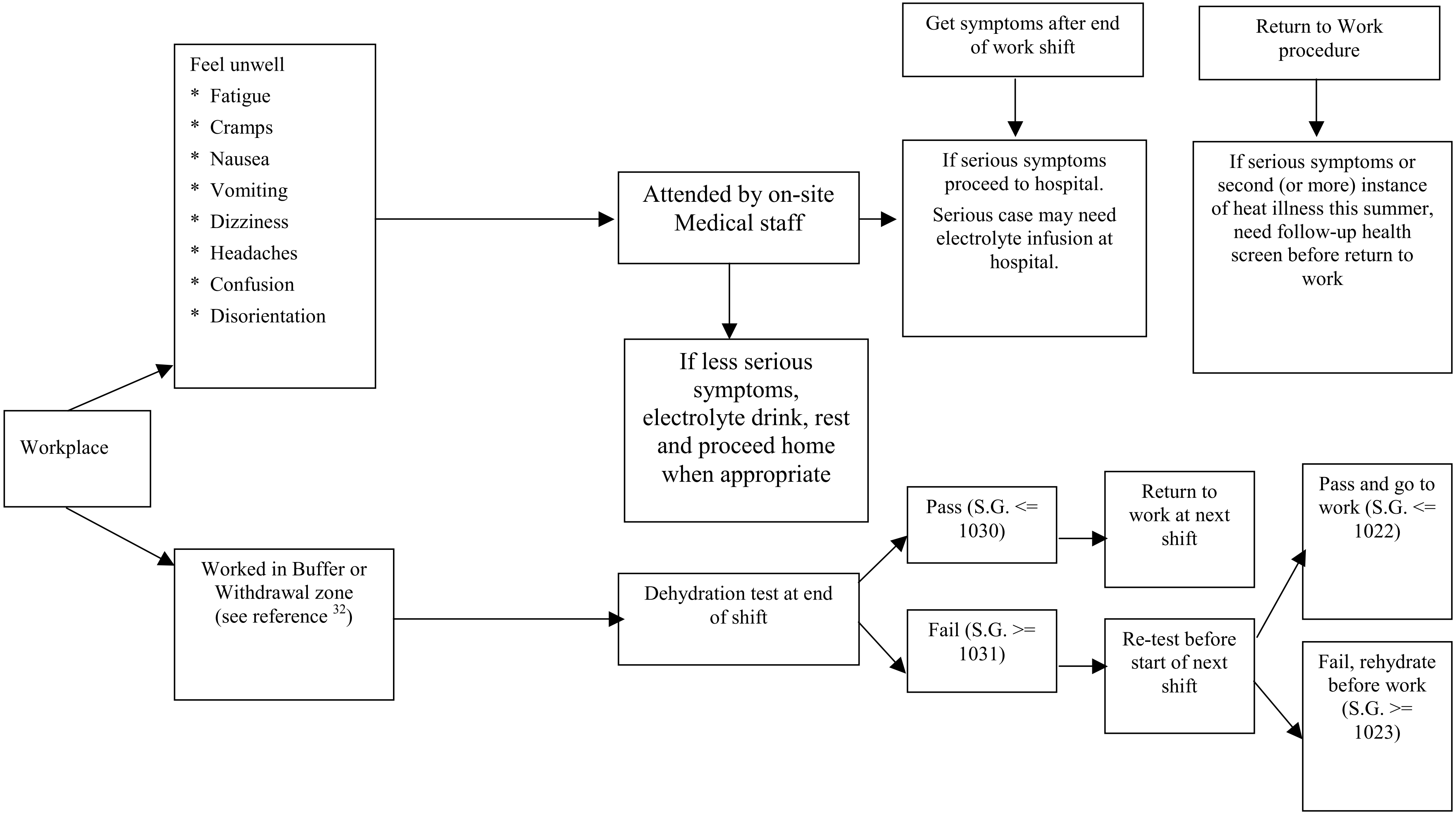

Figure 2 Urinary specific gravity of 39 workers working in very thermally stress conditions at start, middle and end of shift