Hydration Status and Kidney Health of Factory Workers Exposed to Heat Stress: A Pilot Feasibility Study

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Abstract

Dehydration associated with heat stress increases the risk of workplace injury or illness, decreases productivity, and may contribute to the chronic kidney disease epidemic identified in outdoor workers from hot climates. There is limited research on the effects of chronic occupational heat stress among indoor workers. We aimed to test the feasibility of measuring markers of hydration and kidney function in foundry factory workers in Southern Brazil, exposed and not exposed to heat stress. Factory workers exposed to heat stress (wet bulb globe temperature ≥ 28.9) and not exposed to heat were identified by management and invited to participate. Clinical and biochemical markers of hydration and kidney function were evaluated before and after a single

8.5 h work shift (lunch time not included). Feasibility outcomes included rates of enrolment, % completion of study protocols, and time to complete data collection. This study was deemed feasible with 80% enrolment and 90% completion of the protocol. Among the preselected workers, the enrolment rate was 91%. All subjects completed the physiological measures and blood collection and 95% completed the urine studies. Mean time to complete data collection pre-shift was 19.1 ± 4.2 min and post-shift: 14.3 ± 4.0 min. Workers exposed to heat stress had a greater decline in estimated glomerular filtration rate compared to controls over the work shift (-13 ± 11 vs. -5 ± 7 mL/min; $p < 0.01$). We demonstrated the feasibility and challenges of conducting future hydration and kidney function research among indoor factory workers. Further study is needed to determine if exposure to indoor heat contributes to a decline in kidney function.

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Introduction

Occupational heat exposure affects millions of workers worldwide and although the effects of heat stress on hydration status and kidney health have been explored in those working in outdoor settings, there is limited research on indoor workers [1]. Occupational heat stress occurs in those working near furnaces, ovens, smelters, and boilers in kitchens; steel plants; foundries; automobile industries; and glass manufacturing units where high temperature is present and robust preventive measures are often not implemented [2].

In industrial settings, extreme temperatures are found even with mild outdoor temperatures [3]. The high temperatures contribute to increased prevalence of kidney stones [4] and signs of dehydration and symptoms of heat-related illness [5, 6]. Besides consequences in physical and psychological well-being, heat stress is also associated with worksite accidents and reduced productivity [7].

Concerns regarding the kidney health of workers exposed to heat stress were recently identified. Chronic kidney disease (CKD) has affected young agricultural workers without evidence of a recognized cause, in hot regions in Central America [8, 9] and Asia [10, 11] and has been recently named and categorized by the International Society of Nephrology as chronic kidney disease of unknown (CKDu) etiology [12].

Although a causal relationship has not been clearly defined, there is growing evidence that extreme occupational heat stress and repeated dehydration is likely one of the contributors to the epidemic of CKDu occurring in these regions [13, 14]. Other factors may also be contributing to CKDu, such as rhabdomyolysis due to extreme physical work, nonsteroidal anti-inflammatory drugs, illegal alcohol, renal-damaging infections, exposure to fructose-containing beverages, pesticides, other agrochemicals, heavy metals, and toxic pollutants [12, 15].

Studying the effect of heat stress among indoor workers has several advantages in the investigation of the relationship between heat stress and kidney health, including a controlled and measured environment, accurate documentation of fluid intake, reduction in confounding variables, and an environment conducive to assessing outcomes.

Our hypothesis is that it is feasible to conduct a study protocol on hydration and kidney health in factory workers. Our study describes the results of a pilot feasibility study that compared hydration and kidney health status in 2 cohorts of workers (a heat-exposed group and a control group not exposed to heat).

Our objectives were:

Primary: To determine the feasibility of factory worker participation in a single-center study examining the effects of work-related heat stress in 2 cohorts (workers exposed and not exposed to high temperatures), measured by rates of enrolment and completion of study protocols. This included measuring the time to complete data collection and impact on the work day.

Secondary: To determine the effect of heat exposure on the physiological, laboratory, and self-reported participant symptoms in workers exposed and not exposed to heat stress measured pre- and post-shifts.

Methods

Ethics

This protocol was approved by the Institutional Ethics Committee at Pontificia Universidade Católica do Paraná, No. 2.310.225. Individuals participating in the study signed an informed consent form.

Study Design and Population

Participants were workers from the foundry division of one large metallurgical industry in Southern Brazil. The study group included male workers who perform their activities near furnaces (wet bulb globe temperature [WBGT] ≥ 28.9) while wearing heavy protective clothing (heat group); the control group was comprised of men that also perform manufacturing activities with similar physical effort, but not near furnaces. Only workers from the morning shift (05:30 h shift start) were invited to participate, and both groups had an 8.5 h/day work shift (lunch time not included), 5 days per week. A variety of jobs/tasks were performed by participants of both groups.

Inclusion criteria: male workers, 18–50 years old, working the same job during the preceding 2 months. Exclusion criteria: current use of diuretics or lithium. Eligible participants were selected and invited by their department manager to participate in the study. The manager of the heat group was instructed to invite all eligible participants. We expected the inclusion of approximately 20 workers from both groups.

Setting

Data collection was performed in the outpatient clinic of the metallurgical factory. Workers were instructed to visit the clinic before starting the working shift and just after finishing it. All measurements and data collection were performed at the clinic. Because most workers use preschedule public transportation, evaluations were performed during part of the working shift.

Protocol

Participants received a questionnaire to document demographics, life habits, general health information, working history, and cooling methods at home. They were instructed to complete this questionnaire and bring it on the study day. Answers were checked by the researcher (F.B.N.) to assure understanding, completeness, and quality.

Pre-shift, workers received a form to document the quality and quantity of beverages consumed during the shift, measured by standard plastic cup volumes. They were instructed to maintain their customary drinking habits. According to managers, workers were instructed to drink beverages according to their thirst. Fluids available for consumption near their worksite included plain water and fluid-replacement beverage. Coffee, tea, soft drinks and others were available during the meals. The fluid-replacement beverage was a recipe of water with a pharmaceutical electrolyte and glucose powder plus a dietetic artificial juice powder. Three samples of this fluid were collected on different days and chemically analyzed for electrolytes and carbohydrate content.

Heat-Related Illness Symptoms

Pre-shift, participants were questioned if they had any symptom of illness during the last week. The heat-related symptoms (headache, fever, excessive sweating, very small or no urine volume, dark urine, exhaustion, nausea, stomach ache, dizziness, heart racing, cramps, vomiting, fainting, and diarrhea) were assessed as described previously in an investigation with agricultural workers [16].

Thirst

Pre- and post-shift, participants were asked “How thirsty do you feel right now?” as calibrated on a visual analog scale. Workers were instructed to place a mark on a 10-cm horizontal line anchored by phrases “not at all” and “very thirsty” at the extremes.

In the post-shift survey, participants were asked the number of urine voids during the working day. The following open questions, as previously published in an occupational heat stress investigation, were used [17]: was today a typical workday for you? If not, why? Were the study visit times acceptable? Were you comfortable with the study? Which measurements did you find to be uncomfortable?

Physiological Measures

Body weight was measured using a certified and calibrated 150 kg electronic platform scale. Before weight measurement, participants were instructed to empty their bladder and remove extra coats and empty their pockets. They were advised to attend the clinic for post-shift evaluation wearing the same items. Height was assessed pre-shift.

Blood pressure (BP) and heart rate were measured in sitting position, after a minimum of 5-minute rest, with certified, calibrated digital equipment (Omron HBP, model 100, Kyoto, Japan). The mean of 3 measures was used as the BP.

Blood and urine specimens collected at the factory clinic pre- and post-shift were promptly delivered to a single laboratory for biochemical analysis. Blood was drawn and measured, complete blood count, plasma glucose, serum urea, uric acid, electrolytes, and creatinine were measured by enzymatic colorimetric test. Glomerular filtration rate was estimated using the formula from the CKD Epidemiology Collaboration [18]. Serum osmolarity (mOsm/L) was calculated using the following formula: $(2 \times \text{Sodium}) + (\text{BUN}/2.8) + (\text{Glucose}/18)$ [19]. Urine samples were used to evaluate electrolytes, urea, albumin/creatinine ratio, and urine specific gravity (USG). Urinary osmolarity (mOsm/L) was calculated by the formula: $(\text{sodium} + \text{potassium}) \times 2 + \text{urea}$ [20]. Euhydration cutoffs for USG (<1.020), serum osmolarity (<290 mmol/L), and urinary osmolarity (<700 mmol/L) were ob-

tained from the Position Stand of the American College of Sports Medicine [21]. Participants were asked if urine collection was the first, second, or another void of the day.

Heat Stress and Environment Assessment

The WBGT indices for each job of the study group participants were provided by the factory's safety engineering department following standards of assessment [22]. Although assessments were not performed in the same days of data collection for each participant, evaluations were performed in the same period of data collection, (November and December of 2017 – spring in Southern Hemisphere).

Outdoor temperature and relative humidity during the 13 data collection days were obtained from the public website <http://ciram.epagri.sc.gov.br>.

Statistical Analyses

Continuous variables are reported as the mean value and SDs when normally distributed, or as the median and interquartile range when not. A *t* test was used to compare groups where variables were normally distributed and the Mann-Whitney U test was used when not. Paired samples *t* test and Wilcoxon signed-rank test were used to compare changes in the same subjects pre- and post-shift, according to the distribution of variables. Chi-square or Fischer exact-test was performed to compare distribution, when appropriate.

Results

Characteristics of participants were similar between groups and are presented in Table 1. In general, they were young (range 19–50 years old), healthy, completed secondary level of education and were at the job <1 year (range 2–192 months). Only one participant did not have a cooling method at home and 64% reported having air-conditioning. Two participants from the control group reported frequent use of nonsteroidal anti-inflammatory drugs (2–3 times a week).

Feasibility

A total of 35 workers worked in a hot environment and 14 were preselected by management to be eligible to participate. All 14 workers consented to participate. The control group department had 70 workers and 17 agreed to participate out of the 20 invited. Two declined due to blood collection discomfort and one alleged religious reasons. The total enrolment rate was 91%. We finished data collection when the heat group manager said that he could not invite any other workers.

Blood collection and the physiological measures had 100% participation. One participant was not able to collect a urine sample pre- and post-shift and another, post-shift. Laboratory results of total blood count from one

Table 1. Descriptive characteristics of participants ($n = 31$)

	Heat ($n = 14$)	Control ($n = 17$)	p value
Age, years ^a	31 (26–39)	24 (20–34)	0.06
Ethnicity white, n (%)	9 (64)	11 (65)	0.88
Education, years ^a	11 (8–11)	11 (11–11)	0.49
Weight, kg ^b	86.1±13.1	82.5±15.8	0.50
BMI, kg/m ² , ^b	28.2±2.9	25.6±4.9	0.10
Active smoker, n (%)	3 (21)	2 (12)	0.63
Low alcohol intake, n (%) [*]	11 (79)	17 (100)	0.08
Hypertension, n (%)	1 (7)	1 (6)	0.71
Diabetes, n (%)	0 (0)	1 (6)	0.55
Nephrolithiasis, n (%) ^{**}	1 (7)	0 (0)	0.45
Months at the same job ^a	5 (3–30)	6 (3.5–9.5)	0.86
Cooling methods at home, n (%)	13 (93)	17 (100)	0.26

^a Median (interquartile ranges).

^b Mean ± SD.

^{*} Never or less than once a week.

^{**} If the episode was while working in a hot environment.

BMI, body mass index.

Fig. 1. Self-reported beverage intake during the shift ($n = 31$).

participant in the control group (pre-shift) were not obtained due to hemolysis. Six post-shift urine evaluations (2 from the heat group) of sodium, potassium, urea, and specific gravity were not measured due to technical problems in the laboratory. All participants completed the heat-related symptoms survey.

Mean time to complete data collection pre-shift was 19.1 ± 4.2 min (range 12–33 min), and the mean post-shift time was 14.3 ± 4.0 min (range 9–25 min). Participants worked 30–50 min less than on a regular day.

In the post-shift survey, 13% reported an atypical workday due to a lighter task than usual. Visit time was considered acceptable, in that 93% and 90% reported being comfortable during the study; 6% were not comfortable during blood collection, and 4% during BP measure. Thirst perception was equivalent at baseline 4.7 (2.4–5.5) in the heat group versus 3.5 (1.4–5.0) in controls and did not change over the shift 2.5 (1.3–4.9) versus 4.7 (2.2–5.5).

Self-reported total beverage intake was twice as high among heat group participants (2.3 [1.7–3.1] vs. 1.2 [0.9–1.4] L in the control group; $p < 0.001$) during the work shift. Plain water was the most consumed fluid, followed by coffee and a fluid-electrolyte replacement beverage (Fig. 1) composed of 34.5 mmol/L of sodium, 5.6 mmol/L of potassium, <7.1 mmol/L of chloride, and <0.8 g/L of carbohydrate. Heat-related symptoms of illness were reported by some participants. Only self-reported excessive sweating was significantly different between groups (29% in heat group and 0% in control group; $p = 0.03$).

Other Results

From 29 participants who collected a urine sample pre-shift, 38% reported it being the first urine of the day (50% of participants from the heat group 27% from the control group). Reported number of urine voids during the shift was not different 2 (2–4) times for the heat group and 2 (1–2) times for the control group ($p = 0.06$).

Table 2. Pre and post-shift comparisons intra and intergroup ($n = 31$; mean $\pm$ SD)

	Heat ($n = 14$)		Control ($n = 17$)	
	pre-shift	post-shift	pre-shift	post-shift
SBP, mm Hg	124.7 $\pm$ 9.0	121.5 $\pm$ 6.3	118.2 $\pm$ 9.4	118.7 $\pm$ 5.0
DBP, mm Hg	73.4 $\pm$ 8.0	69.3 $\pm$ 7.8**	67.3 $\pm$ 8.4 ^a	65.2 $\pm$ 7.3
Heart rate, beats/min	63.7 $\pm$ 6.1	69.9 $\pm$ 8.5**	67.8 $\pm$ 8.4	70.4 $\pm$ 9.0
Weight, kg	86.1 $\pm$ 13.1	85.9 $\pm$ 12.9	83.1 $\pm$ 15.3	83.0 $\pm$ 15.7
Hematocrit, %	44.5 $\pm$ 2.3	43.7 $\pm$ 2.2	44.9 $\pm$ 0.74	43.0 $\pm$ 3.0**
Hemoglobin, g/dL	14.6 $\pm$ 0.8	14.2 $\pm$ 0.8	14.8 $\pm$ 1.0	14.1 $\pm$ 0.9**
Leucocytes, n/mm^3	7,726 $\pm$ 1,745	7,960 $\pm$ 1,459*	7,189 $\pm$ 1,819	7,991 $\pm$ 1,379**
Glucose, mg/dL	90.7 $\pm$ 19.8	84.2 $\pm$ 10.0	88.3 $\pm$ 20.1	83.1 $\pm$ 8.6
Serum creatinine, mg/dL	0.95 $\pm$ 0.09	1.06 $\pm$ 0.1**	0.85 $\pm$ 0.13 ^a	0.92 $\pm$ 0.12**
eGFR, mL/min	106 $\pm$ 13	93 $\pm$ 11**	119 $\pm$ 15 ^a	114 $\pm$ 16**
Serum uric acid, mg/dL	6.41 $\pm$ 1.27	6.62 $\pm$ 1.34*	5.13 $\pm$ 0.68 ^b	5.20 $\pm$ 0.55
>7 mg/dL, %	29	43	0 ^a	0 ^a
Serum sodium, mmol/L	141.3 $\pm$ 1.8	141.2 $\pm$ 1.8	141.6 $\pm$ 1.5	141.1 $\pm$ 2.3
Serum potassium, mmol/L	4.52 $\pm$ 0.31	4.69 $\pm$ 0.42	4.43 $\pm$ 0.26	4.57 $\pm$ 0.80
Serum osmolarity, mmol/L	293.8 $\pm$ 3.9	293.4 $\pm$ 4.1	294.2 $\pm$ 3.6	293.1 $\pm$ 4.8
>290 mmol/L, %	93	100	88	88
Alb/creatinine, mg/g ^c	0.47 (0.34–0.63)	0.44 (0.41–0.65)	0.55 (0.46–0.77)	0.45 (0.4–0.75)
>30 mg/g, %	0	0	0	0
Urinary specific gravity	1.021 $\pm$ 0.005	1.023 $\pm$ 0.004	1.024 $\pm$ 0.005	1.023 $\pm$ 0.007
>1.020, %	71	67	73	58
Urinary osmolarity	817 $\pm$ 197	940 $\pm$ 182	967 $\pm$ 181	1,138 $\pm$ 310*
>700 mmol/L, %	79	92	82	83

* $p < 0.05$ vs. pre-shift.** $p < 0.01$ vs. pre shift.^a $p < 0.05$ vs. heat group.^b $p < 0.001$ vs. heat group.^c Median (interquartile ranges).

SBP, systolic blood pressure; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate.

Evaluation of Hydration and Kidney Health Variables

Clinical and laboratory results pre- and post-shift in both groups are shown in Table 2. Diastolic BP and heart rate decreased in the heat group. Body weight did not vary in either group pre- and post-shift. In relation to lab results, serum sodium was maintained with some significant changes in the blood cell count being observed. Almost all participants had serum osmolarity above 290 mmol/L pre-shift (93% in heat group and 88% in control group) and post-shift (100% in heat group and 88% in control group). USG and osmolarity were also high in both moments and increased significantly in the control group.

The heat group had higher serum creatinine at the beginning of the working day (0.95 ± 0.09 vs. 0.85 ± 0.13 ; $p < 0.05$) and lower estimated glomerular filtration rate (eGFR) compared to the control group (106 ± 13 vs. 119 ± 15 mL/min; $p < 0.05$). Creatinine increased and eGFR decreased after a shift in both groups, but more signifi-

cantly in the heat group, corresponding to a 12% decrease. No participant had a diagnosis of CKD (eGFR < 60 mL/min and/or urinary albumin/creatinine ratio above 30 mg/g). Individual variations are shown in Figure 2.

Serum uric acid was also higher in heat group and increased only among those participants. At the end of the shift, 43% of patients had hyperuricemia (> 7 mg/dL) compared to none in the control group.

Environmental Monitoring

Outdoor temperature and relative humidity during the 13 data collection days were mean minimum/maximum, 20.3 and 27.4°C and mean minimum/maximum relative humidity, 67 and 98%.

WBGT evaluation for the job tasks performed by heat group participants varied from 28.9 in tasks that require a heavy work load to 31.8 in tasks that require a moderate work load.

Fig. 2. eGFR pre- and post-shift in heat group (a) and control group (b). eGFR, estimated glomerular filtration rate.

Discussion

In this in-factory pilot feasibility study, we were unable to fully evaluate recruitment feasibility due to the restricted access to all eligible participants. However, among the workers invited to participate, enrolment rate met our enrolment target of 80%. In addition, we exceeded the target for protocol completion, and the time to complete measurements each day was acceptable to the workers and management.

Enrolling participants in a work environment has been challenging in previous studies for reasons such as high turnover, worksite changes, and constraints imposed by repeated testing within the work shift [23, 24]. Furthermore, the majority of participants answered the post-shift questions positively.

We evaluated hydration status by several techniques, with variable accuracy and applicability since no gold standard is available for such assessment [21, 25, 26]. Acute change in body mass has been postulated as an easy and efficient technique to detect hypohydrated subjects. Body mass loss $>1\%$ can compromise thermoregulation and $>2\%$ is followed by physical and psychological symptoms [21, 26]. In this investigation, mean body mass was assessed by body weight and did not change over the shift, with no worker having weight loss higher than 2%. However, the mass of liquids and of food consumed during the working day, as well as the mass of excreted solids and liquids affected this measurement, making interpretation difficult.

A very high prevalence of workers with serum and urine osmolality above euhydration cutoff were observed in both groups, pre- and post-shift evaluation, showing that they began the workday in a hypohydrated status that was not recovered during the shift. A similar

result was observed in Australian blast crew personal in surface mining, where 80% had a USG ≥ 1.020 upon commencing their shift and remained hypohydrated during and after work [27]. However, reference values for euhydration/hypohydration diagnosis are based on studies in athletes and military subjects to determine the effect of heat stress and its influence on performance [21]. It is currently unknown if it is applicable to the hydration assessment of workers exposed to heat stress on a continual basis, in which euhydration may be an incorrect assumption [28].

As expected, the heat group reported a higher intake of water and total beverages and both groups had a low consumption of fluid replacement beverage (median 0.2 L). According to the American National Institute for Occupational Safety and Health guidelines, during prolonged sweating lasting several hours, it is advisable to consume a beverage that contains balanced electrolytes and carbohydrate to replace losses [7]. It has been shown that a beverage with 10–30 mmol/L of sodium and 4–8% of carbohydrate may induce a greater voluntary intake, aid rehydration, improve work performance, and delay the onset of fatigue [29]. Taking it as a reference, in our investigation, sodium content was adequate but carbohydrate was almost absent.

The frequency of self-reported heat-related symptoms in the previous week was lower compared to investigations with sugarcane workers in Mesoamerica [16, 30]. This might reflect the significant differences in general health, socioeconomic profile, and work conditions between these 2 populations. Furthermore, heat acclimation might have contributed to this finding.

Regarding kidney function, our results indicate that indoor working conditions were associated with a decrease in eGFR more pronounced in the heat group. This

change is in accordance with findings in other study populations exposed to heat stress such as sugarcane workers [31, 32] and athletes in endurance competitions [33], but not under sedentary conditions [34]. Authors considered as potential mechanisms for the kidney function decrease observed in these investigations dehydration, volume depletion, rhabdomyolysis, systemic inflammation, and oxidative stress triggered by environmental heat and the extreme physical activity. It has been postulated that these repeated episodes of injury or illness eventually result in abnormal repair mechanisms and subsequent CKD [14, 35]. In our small sample, the connection between acute episodes and CKD was not possible to explore due to the short follow-up.

A striking difference between groups was in the serum levels of uric acid. In fact, marked hyperuricemia and uricosuria with crystal formation with a rise in both serum and urine uric acid during the workday have been documented in sugarcane workers [32, 36]. Together, these findings contribute to the hypothesis that uric acid associated with high vasopressin expression may be important etiologic factors of CKDu [31].

WBGT threshold limit values indicated that workers should be on work/rest cycles of 50% work + 50% rest or 25% work + 75% rest each hour depending on the task, to reduce the risk of heat illness or injury. In our setting, although there are air-conditioned rooms for cooling near work sites, workers were not on regular work/rest cycles.

Our investigation has some limitations. First, management selected the workers who could be approached for the study due to the factory's personnel department concerns of misinterpretation. This influenced the number of participants and possibly the enrolment rate. Second, serum and urinary osmolality were calculated rather than measured directly. Third, hydration status is better evaluated by first-morning urine, but its values can provide misleading information if obtained during rehydration periods [21], and plasma osmolality does not accurately detect whole-body hydration, especially when total body water, fluid intake, and fluid loss are fluctuating [25]. Fourth, lack of control for body gains and losses affects interpretation of body mass change. Finally, usual beverage intake and urine habits could be influenced by data collection awareness. Our study had favorable management involvement and support and appropriate infrastructure for data collection. These data may not be generalized to other settings due to the favorable environment we observed as the high department manager's involvement and an appropriate infrastructure in

the factory setting for data collection. The present results encourage further investigations of hydration status and kidney health in factories and other settings with similar conditions.

Conclusion

Research in factory workers is challenging and requires buy-in from management. We were able to demonstrate feasibility for enrolment and protocol completion for a preselected group of workers. We demonstrated the negative physiological acute effects on kidney function of indoor heat stress. Further research is needed to study the effects of indoor heat on kidney function both in the short and long term in larger studies.

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