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ASSESSMENT OF CONSTRUCTION WORKERS' HYDRATION STATUS USING URINE SPECIFIC GRAVITY

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Abstract
Objectives: The study objective was to assess hydration status by measuring USG among construction workers in Iran. **Materials and Methods:** The study design was comparative and experimental. Sixty participants were randomly selected from the construction workers from a construction campus with a similar type of work, climate and diet and formed 2 groups (individuals exposed to the sun and non-exposed individuals). TWL and USG were measured in both groups on 2 consequent days, at the beginning, mid and end of the work shift. **Results:** USG test showed that mean USG was 1.0213±0.0054 in the control group and in the exposed group, where it was significantly higher, it amounted to 1.026±0.005. In the exposed group, 38% of workers had a USG level between 1.026–1.030, representing a higher risk of heat illness and impaired performance and 12.72% had a USG level above 1.030 representing a clinically dehydrated status, while this proportion in the control group was 15.2% and 0.58%, respectively. The mean TWL index measure was 215.8±5.2 W/m^2 for the control group and 144±9.8 W/m^2 for the exposed group, where, again, it was significantly higher. The Pearson correlation measure showed a significant correlation between USG and TWL. **Conclusions:** Strong correlation between TWL, as an indicator of thermal stress and USG shows that USG can be considered as a predictor of thermal stress. The difference between USG among the exposed and non-exposed workers and the increase in USG during midday work show the sensitivity of this measure in different thermal and climatic conditions, whereas, the high level of dehydration among workers despite acceptable TWL level, shows that heat stress management without considering the real hydration status of workers, is insufficient.

Keywords:
Thermal stress, Dehydration, USG, TWL

INTRODUCTION

Workers from many various industries, especially those from construction, agriculture and other externally situated occupations, are under thermally stressful work conditions [1].

Heat stress is a well-recognized health hazard to the workers and heat-related illnesses range from heat cramps and heat exhaustion to the rare but fatal condition of heat stroke [1]. In addition, many other diseases or health related statuses like skin problems (e.g. prickly heat), heat

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strain, and chronic heat disorders [2] affect workers' productivity and safety [3]. Impairment of mental functions as well as fatigue increase the risk of occupational accidents and endanger the workplace safety [1]. It was shown that intellectual performance is affected at the level of 2% hypohydration [4]. Heat exhaustion is a result of inability of the circulatory system to simultaneously supply sufficient blood flow to the skin, to the vital organs and to exercise skeletal muscles. People with heat exhaustion may develop fatigue, headache, dizziness, anorexia, nausea, vomiting, shortness of breath, or syncope, while confusion, ataxia, prolonged unconsciousness, or convulsions are strongly suggestive of heat stroke.

Heat cramps, painful involuntary contractions of skeletal muscle are other results of heat stress [5].

Dehydration of 1–2% of body weight in a moderate environment results in a 6–7% reduction in physical work capacity, water loss of 3–4% of body weight in the same environment causes a reduction of 22% of physical work capacity and in a hot environment, 4% of body water loss can cause a physical work capacity reduction of around 50%. In addition, chronic hypohydration leads to the increased risk of renal calculi and bladder cancer [3].

There are different physiological parameters for evaluating heat strain including body core temperature, heart rate, sweat loss and urine specific gravity (USG) [6]. Testing USG has been shown to be a reliable and an important indicator of the body absolute hydration status [7] that can be used as a single measure, which is non-invasive, easy and quick to conduct in the field work [6]. Kavouras in his study on assessing hydration status concluded that in the absence of a 'gold standard' for the assessment of hydration status, USG is one of the most widely used indices that can provide reasonable results, especially when the analysis is based on the first morning urine sample [8]. USG could be used as an educational tool for workers about the required fluid intake before and after heat exposure [5]. However, urinary specific gravity does not show a perfect linear relationship with body water loss, where there is diuresis as a result of alcohol or caffeine intake, vitamin supplements or some drugs.

The maximum concentrating capacity of the renal system is about 1.050, while the pure water has a specific gravity of 1.000 [7]. There is no consensus concerning USG level that would indicate dehydration. Australian Pathology Association criteria defined dehydrated state as a USG > 1.030. USG < 1.020 was the recommended cut-off point for euhydration by Armstrong et al. [9] and Shirreffs and Maughan [10]. Oppliger and Magnes [11] suggested the most accurate cut-off values to be USG of 1.015 and 1.020. Brake and Bates considered USG equal to 1.015 as a euhydrated state [7].

Thermal Work Limit (TWL), a newly developed index, incorporates all needed inputs and generates a single figure specifying a maximum work limit and is claimed to be "simple to use, less prone to interpretive error, reliable and far superior to currently recommended indices an indicator of thermal stress" [3]. All 5 main parameters that define thermal environment, i.e. dry bulb temperature (DB), wet bulb temperature (WB), radiant temperature (Trad), air velocity as well as wind speed (WS) and atmospheric pressure (Patm) have been utilized by TWL to predict a safe maximum metabolic rate for specific conditions. Also, TWL accommodates the clothing factor, which is a reflection of behavioral and physiological factors that affect thermal stress [3].

This study was an attempt to assess hydration status by measuring USG among construction workers in Iran.

MATERIAL AND METHODS

The study design was comparative and experimental. During the hot season 60 participants were selected randomly out of construction workers from a construction campus nearby Teheran. The workers were involved in a similar type of work, worked in a similar environment and had a similar diet. The participants were divided into 2 groups, 30 workers in each group. One group was exposed to the sun heat and the other was not (control group) and worked in shadow, in a roofed over area. Both groups worked under similar conditions, were matched considering the work metabolism rate (65–130 W/m^2), work duration, meal and beverage consumption, work hours, place and duration of rest and type of clothing.

Medical records of the participants were assessed for the genetic or other related diseases like renal diseases, diabetes and skin diseases. Other information like being under any medication, especially diuretic medication, was collected by the help of a healthcare center in the construction campus. Each of the above mentioned conditions was considered as an exclusion criterion. Information regarding age, weight and height of the participants was also collected. In order to control water consumption, all the participants received a water bottle of the same size and similar brand (450 CC/h). The process of distribution and consumption of water was controlled by the HSE officers on site, and if a worker did not follow the water consumption pattern, he was excluded from the study. To control the diuretic effect of tea, the midday tea break was set after the urine sample collection.

The urine samples of both groups were collected 3 times (at the beginning, middle and at the end of the working hours) on 2 consequent days. The urine samples were kept in a box under ice bags and were sent to Noor laboratory, Tehran, Iran. All the samples from the first day were checked for creatinine in order to identify any hidden renal failure and those with abnormal level of creatinine (more than 150 mg/dl) were excluded from the study (one worker was excluded from the control group). In this study USG values above 1.015 indicated varying degrees of hypohydration and a value above 1.030 represented a clinical state of severe dehydration [5].

Based on the study of Miller and Bates, the following categories of hydration status based on USG were used in this study:

1. ≤ 1.015 – optimal level of hydration (euhydrated).
2. 1.016–1.020 – marginally adequate hydration.
3. 1.021–1.025 – hypohydrated.
4. 1.026–1.030 – severely hypohydrated, at increased risk of heat illness and impaired performance. Should not work in hot conditions.
5. > 1.030 – a clinically dehydrated state, based on the criterion used by the Australian Pathology Association.

The atmospheric parameters required for calculating the TWL indicator (DB, WB, Trad, WS, Patm) were measured 3 times a day at the beginning, mid and end of the working hours in the working place of both groups. To ensure accuracy of measurements, all the measures were taken twice on 2 consequent days. Clothing of the workers was a uniform with thermal resistance of 0.71, intrinsic clothing insulation (I_{cl}) and vapour permeation efficiency (Vpe) of 0.45 [12]. TWL was calculated each day for the beginning, middle and end of the working hours on 2 consequent days. In this study, for measuring the atmospheric parameter, the WBGT measuring instrument MTH-1 made in UK was used. The wind speed was measured by the use of a thermal digital anemometer VT50 made in France. In order to facilitate the calculation, calculation equations were programed in Excel software (Microsoft Office 2007) that provided a software package for calculation of TWL based on the method designed by Brake and Bates [7].

The first sheet of excel software was programed for calculation of TWL. The 5 main atmospheric parameters (DB, WB, Trad, WS and Patm) and the clothing parameter (I_{cl}) were used as an input and TWL, central body temperature and the sweating level constituted calculated output.

There were 5 zones with different intervention that was advised based on the TWL level. There was a withdrawal zone in TWL < 115 or DB > 44°C or WB > 32°C, showing that continuation of ordinary work is not allowed in the absence of any intervention to reduce thermal stress. For TWL between 115 and 140, there was a buffer zone showing the required special intervention such as not working alone or increasing wind speed by 0.5 m/s at each worker upper torso, etc. TWL between 140 and 220 was an acclimatization zone and TWL > 220 was an unrestricted zone.

Statistical analysis

The below equation was used for calculating the TWL:

$$M–W = C+R+E+B+S_{sk}+S_c \quad (1)$$

where:

M – metabolism rate (W/m^2);

W – physical work level (W/m^2);

C – heat lost from the skin due to movement (W/m^2) = h_c ($t_{skin}–t_a$) in W/m^{-2}, where h_c is the coefficient of heath transfer due to the movement and is equal to 0.608 $P^{0.6}×V^{0.6}$ (P – atmospheric pressure Kpa and V the wind speed m/s, which in this model was limited to 4 m/s);

R – heat lost from the skin due to radiation (W/m^2) = $h_r f_r$ ($t_{skin}–t_{rad}$) in W/m^{-2}, where f_r is the coefficient of posture equal to 0.73 in standing position and h_r is the coefficient of heat transfer due to radiation (W/m^2 in °C) and is equal to 4.61 $[1+(t_{rad}+t_{skin})/546]^3$ and t_{rad} is the mean radiation temperature in °C and t_{skin} is the skin temperature;

E – heat lost from the skin due to evaporation (sweating) (W/m^2) is E = λ Sr for λ Sr/Emax < 0.46; λ Sr exp[–0.4127×(1.8 λ Sr/Emax – 0.46)1.168] for 0.46 ≤ λ Sr ≤ λ Sr/Emax; E = Emax for λ Sr/Emax > 1.7; t_Σ = 0.1 t_{skin}+0.9 $t_{core,}$ λ = 2430 kJ/kg^{-1} at 30°C, Sr = the real amount of sweating kg/m^2 × h and λ is the latent heat due to evaporation, and t_ε is the regulatory heat signal based on °C;

B – heat lost via respiration due to evaporation or movement = 0.0014 M (34 – dry temperature °C) +0.0173 M (5.87 – the humidity pressure Kpa);

S_{sk} – health stored in the skin (W/m^2);

S_c – health stored in central body (W/m^2).

All analyses were performed using statistical package for social sciences (SPSS) version 19.0 for windows (IBM Corporation, New York, United States). T test and Mann-Whitney U tests were used to compare the TWL and USG levels between the two groups (exposed and non-exposed), ANOVA test was used to compare the USG measures at the beginning of work, mid work and at the end of the working hours in mean measures on the 2 days for both groups.

RESULTS

The mean age of participants was 30.5±5.9 in the control group and 31.1±7.3 in the exposed group. The mean weight and height was 75.6±6.2 kg and 1.75±0.06 m in the control group, respectively and 73.4±7.6 kg and 1.76±0.06 m in the exposed group. There was no significant difference in age ($p = 0.728$), weight ($p = 0.254$) and height ($p = 0.463$) between the 2 groups. Both groups worked under similar conditions, were matched with respect to the work metabolism rate (65–130 W/m^2), work duration, meal and beverage consumption, work hours (8 h a day), place and duration of rest (two 15-minute breaks during morning work time and afternoon work time and one-hour lunch rest) and type of clothing (Clo = 0.71, icl = 0.45). The mean shadow temperature during measurement days was maximum 36.5°C and minimum 23.6°C.

The USG test showed that mean USG was 1.0213±0.0054 in the control group and 1.026±0.005 in the exposed group. The USG level was significantly different between the 2 groups ($p = 0.001$) (Table 1).

Table 2 shows the trend of mean TWL and USG values during the working hours, at the beginning of the shift, at midday and at the end of the shift in the exposed group and in the control group, showing that the maximum USG level and minimum TWL was in the middle of working hours (around noon) (Table 2). Table 2 also shows that the mean USG level for the exposed workers was 0.0263 even at the beginning of the day. The results of ANOVA test showed that there was a significant difference in USG levels in different working hours measurements (beginning, mid and end) in the exposed group ($p = 0.03$) but this difference was not significant in the control group ($p = 0.798$).

Table 1. Thermal work limit (TWL) and urine specific gravity (USG) measures in the exposed and control groups

Indicator	Samples (n)	Range	Mean	Standard deviation	p
TWL					0.000#
exposed group	6	–	144.0	17.0	
control group	6	–	215.8	9.0	
USG					0.001*
exposed group (mean measurements)	52	–	1.0253	0.0032	
control group (mean measurements)	52	–	1.0227	0.0027	

Mann-Whitney U test.
* t test.

Additionally, this table shows that at the beginning of the work shift the mean TWL level was 161.5±4.9 in the exposed group and 224.5±2.1 in the control group, however this difference was not statistically significant ($p = 0.121$).

Table 3 shows the hydration status of workers. In the exposed group, 37% of the individuals had the USG level between 1.021–1.025, representing hypo-hydrated status and 38% had the USG level between 1.026–1.030, representing severely hypo-hydrated status, which shows that these workers were at the increased risk of heat illness and impaired performance and should not work in hot conditions. 12.72% had the USG level above 1.030 representing a clinically dehydrated state. In the control group, 15.2% of the individuals had the USG level between 1.026–1.030, representing severely hypo-hydrated status, and 0.58% had the USG level above 1.030, representing a clinically dehydrated state.

The mean TWL index measure was 215.8±5.2 W/m^2 for the control group and 144±9.8 W/m^2 for the exposed group (Table 1). The trend of the TWL level during the working hours showed that maximum TWL level was in the middle of the work shift. The independent t test showed that the TWL level was significantly different between the 2 study groups ($p = 0.003$) (Table 2).

The Pearson correlation measure showed a significant correlation ($p = 0.001$) of –0.93 between USG and TWL.

Table 2. Thermal work limit (TWL) and urine specific gravity (USG) changes during working hours

Indicator	Measures (M±SD)			p*	p**
	beginning of the work[1]	middle of the work	end of the work		
TWL				0.012	0.135
exposed group	161.5±4.9	127.5±4.9	143.0±7.1		
control group	224.5±2.1	206.5±7.8	216.5±6.4		
USG				0.334	0.135
exposed group	1.0263±0.0051	1.0273±0.0047	1.0252±0.0044		
control group	1.0217±0.0063	0.0212±0.0053	0.0211±0.0044		

[1] Mann Whitney U test comparison of TWL level between exposed group and control groups at the beginning of the shift work (p = 0.121).
* Repeated Measure ANOVA test.
** Friedman test.

Table 3. Urine specific gravity (USG) and hydration status of the study groups

USG level	Hydration status	Urine samples n (%)	
		exposed group (N = 173)	control group (N = 171)
≤ 1.015	euhydrated	7 (4.00)	28 (16.30)
1.016–1.020	marginally adequate hydration	14 (8.10)	34 (19.80)
1.021–1.025	hypohydrated	64 (37.00)	82 (47.90)
1.026–1.030	severely hypohydrated	66 (38.00)	26 (15.20)
> 1.030	clinically dehydrated state	22 (12.70)	1 (0.58)

DISCUSSION

This study was an attempt to assess the dehydration status of construction workers by using USG and to assess the efficiency of USG in thermally stressful situation. Based on the author's knowledge, this is the first study that assesses the dehydration status of workers in Iran by measuring USG values.

This study showed a strong correlation between TWL as an indicator of thermal stress and USG, which shows that USG can be considered as a predictor of thermal stress. Additionally, the difference between USG among the exposed and the non-exposed workers and the increase in USG during midday work show the sensitivity of this measure in different thermal and climatic situations.

This study showed that the average USG value was 1.0213 in the control group and 1.026 in the exposed group. In the study of Hunt on heat strain, hydration status and symptoms of heat illness in surface mine workers the average mean USG was 1.024 and 1.021 for blast crew and drillers respectively. However, over 70% of the drillers and over 80% of the blast crew reported at least one symptom on the basis of the Heat Illness Symptoms Index suggesting that dehydration is the primary issue for surface miners working in the heat [13]. This study also showed that the average specific gravity of the urine in persons within the group exposed to heat stress at the beginning of labor exceeds the value of 1.026, which is interpreted as a severely hypohydrated, at the increased risk of heat illness and impaired performance; and should not work in hot conditions. Many other findings, particularly at the construction sites, showed that poor hydration of workers is abundant in many countries [15]. Some studies in Australia show that 51% to 39% of the urine samples had USG of 1.026 [16].

The result of environmental monitoring using TWL indicator showed that at the beginning of the shift (morning) the TWL level was 161.5±4.9 in the exposed group, which shows the acclimatization level. All the workers in this group were working in exposure to the sun more than one month before the study and therefore, they were acclimatized to the condition [14], while the TWL level in the control group in the morning was 224.5±2.1 which is an unrestricted condition. The TWL in the group exposed to the sun in the middle and at the end of the day were in the range of forcing employers to intervene: "not working alone or increasing wind speed to 0.5 m/s at each of the upper torso worker". The mean total TWL indicator in the control group was an unrestricted condition and in the exposed group it indicated acclimatization. As all the workers were acclimatized to the environment (more than 7 days of work in hot environment) [14], the working conditions were regarded as acceptable considering heat stress. Nevertheless, the values of USG and hydration status of workers show that more than 7% of workers were in a clinically dehydrated status and 27% were severely dehydrated. This finding shows that heat stress management without considering the real hydration status of workers, is insufficient. This finding is in compliance with the study of Bates et al. [15] that showed that heat management based on environmental monitoring but without addressing the hydration issue cannot protect workers from the effects of heat stress. Also Stover et al. in his study on dehydration status among high school football players used USG as the marker of dehydration and showed that pre-training USG values remained consistently high each day (range for daily means: 1.022±0.003 to 1.024±0.005) and implementation of a new drinking strategy was required to maintain hydration [17].

Study of Bates and Schneider [3] on hydration status and physiological workload of UAE construction workers, showed that against very hot climatic conditions, where workers are receiving enough fluids and are well hydrated before the work shift, their hydration status was in the normal range. This study showed that the USG level of workers increased during midday work in both shift groups, which is inconsistent with the study of Miller and Bates [16] and Bates et al. [18]. They show that the USG level does not change greatly over the course of a shift and they conclude that unless there is an active campaign to encourage scheduled drinking, workers will voluntarily drink only sufficient amount of fluid to maintain the level of hydration to which they are habituated and that in many cases this level is inadequate for working in heat. However, in our study, the workers were asked to drink a specific volume of water during their work, but still the USG level increased at midday.

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