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**Original Article**

# Relationships between micronutrient losses in sweat and blood pressure among heat-exposed steelworkers

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**Abstract: We aimed to examine the effect of micronutrient losses through sweat on blood pressure (BP) among heat-exposed steelworkers. A total of 224 heat-exposed male steelworkers from an ironworks facility were evaluated in July 2012. We measured the Wet Bulb Globe Temperature Index to evaluate the level of heat stress in the workplace. We collected sweat from the workers during an eight-hour work, and then we measured the micronutrients in the sweat. We also measured the BP of each worker. The results revealed that vitamin C, potassium, and calcium losses in sweat were positively correlated with systolic (SBP) and diastolic (DBP) blood pressure (all $P<0.05$). A linear stepwise regression analysis revealed that potassium, and calcium losses in sweat adversely affected SBP and DBP (all $P<0.05$). An analysis of covariance showed that SBP increased when potassium or calcium losses in sweat were >900 mg, or >100 mg, respectively. Further, DBP increased when potassium or calcium losses in sweat were >600 mg or >130 mg, respectively. Therefore, vitamin C, potassium, and calcium losses in sweat may adversely effect BP. To help steelworkers maintain healthy BP, facilities with high temperatures should try to lower environmental temperatures to reduce vitamin C, potassium, and calcium losses in sweat. Additionally, heat-exposed steelworkers may need to increase their dietary intakes of vitamin C, potassium, and calcium. Further research is needed to confirm these findings and support these recommendations.**

**Key words:** Heat-exposed workers, Sweat micronutrient losses, Blood pressure, Vitamins, Minerals

## Introduction

Hypertension is a multifactorial disease and is a major independent risk factor for cardiovascular diseases[1, 2]. Numerous studies have reported that the prevalence of hypertension among heat-exposed workers is significantly higher than that of workers with exposure to normal temperatures[3]. The difference is likely due to the fact that workers exposed to high temperatures must regulate their body temperatures through sweating[4]. Heat-exposed work can lead to the production of large amounts of sweat, and water-soluble vitamins and minerals can be excreted in the sweat[5–8]. These excretions affect micronutrient levels in vivo and increase the vitamin and mineral requirements for workers who may be exposed to high temperatures[9]. Micronutrient levels are closely related to blood pressure

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(BP). Many papers have reported that dietary sodium intake is positively correlated with BP[10, 11] and dietary intakes of vitamin C, potassium, magnesium, and calcium are inversely correlated with BP[11−16]. Furthermore, serum vitamin C[17−19], serum potassium[19], and serum magnesium[20] levels are inversely correlated with BP. The body cannot produce micronutrients on its own and, therefore, micronutrients must be supplied through dietary intake (Vitamin D is the only exception, since it can be produced by exposure to sunlight)[21, 22]. Therefore, insufficient micronutrient consumption can lead to deficiencies, especially for heat-exposed workers. However, relationships between micronutrient losses in sweat and BP among heat-exposed steelworkers have not been reported. Vitamin C is an antioxidant that inhibits the inflammatory response, reduces oxidative stress[23] and enhances endothelial function through effects on nitric oxide (NO) production[24]. Numerous oxidative and inflammatory mechanisms appear to be involved in the pathogenesis of high BP[25, 26]. Inflammation, oxidative stress and endothelial function are all associated with hypertension[27]. A randomized trial showed that vitamin C supplementation significantly reduced levels of F2-isoprostane, an oxidative stress biomarker[28]. Potassium may lower BP through more than one mechanism: potassium can lead to vasodilatation[29] and may decrease the need for antihypertensive medication[30]. Moreover, potassium lowers BP by regulating the dynamic balance between sodium and potassium, especially for salt-sensitive patients with hypertension[31]. Calcium may regulate hormones, electrolyte interactions, and the sympathetic nervous system to modify BP[30], magnesium can affect cardiac electrical activity, myocardial contractility, and vascular tone. Epidemiologic and laboratory studies have also suggested that vitamin $B_1$[32], $B_2$[33], iron[34], zinc[35], copper[35] and selenium[36] may have beneficial effects on BP, but the mechanisms are not clear.

Heat-exposed steelworkers comprise a distinctive population and evaluations of the relationships between micronutrient losses in sweat and BP in this group are warranted. For this study, we measured the concentrations of water soluble vitamins (vitamins C, $B_1$, and $B_2$) and minerals (potassium, sodium, calcium, magnesium, iron, zinc, copper, and selenium) in the sweat of heat-exposed steelworkers. We analyzed the associations between micronutrient losses in sweat and BP in order to support BP control and improve health promotion.

## Subjects and Methods

*Subjects*

Heat exposure limits for heat-exposed steelworkers are defined in GBZ 2.2-2007: "Occupational Exposure Limits for Hazardous Agents in the Workplace Part 2: Physical Agents," which was implemented on November 1, 2007. For our study, we evaluated 243 heat-exposed male steelworkers aged 22 to 50 years old with lengths of service in the steel industry ranging from 1 to 30 years. The subjects were selected from the converter and rolling workshop of an ironworks facility in July 2012. We excluded participants who had taken micronutrient supplements or antihypertensive drugs within one month of the study and participants with incomplete data. A total of 224 participants were included in the final analysis. All participants voluntarily took part in this study and provided informed consent prior to its start. The study was approved by the Ethics Committee of Hebei United University (currently: North China University of Science and Technology).

*General information*

We used a questionnaire to collect general information about each worker, including age, length of service, type of work, smoking status (a non-smoker was classified as: someone who had never smoked or had smoked less than 100 cigarettes in a lifetime; an ex-smoker was someone who smoked more than 100 cigarettes in the past but was not smoking at the time of the questionnaire; a smoker was someone who had smoked more than 100 cigarettes and was still smoking at the time of the questionnaire)[37], alcohol drinking habits, history of salt in the diet, exercise, family history and so on. To describe alcohol drinking habits, a non-drinker was defined as someone who drank less than once per month and a drinker was someone who had the habit at the time of interview or stopped the habit within one year before interview[37]. Dietary sodium intake was divided into three groups: low (<2.3 g/day [<5.85 g/day salt]), moderate (2.3–4.6 g/day [5.85–11.7 g/day salt]), and high (>4.6 g/day [>11.7 g/day salt])[38, 39]. Dietary sodium intake was assessed by a combination of a 24-h dietary recall[40] and weighing method[41]. The weighing method was used to evaluate working lunch in the factory canteen. We measured the weight and height of each participant and calculated the Body Mass Index (BMI).

*Environmental conditions*

According to the GB/T 4200-2008 Classified Standard of Working in the Hot Environment, a hot environment is defined as a workplace whose average Wet Bulb Globe Temperature (WBGT) is higher than 25°C during working hours. WBGT was directly measured three times on the same day in heat-exposed workplaces using a WBGT index measuring instrument (Questemp36, USA). We measured temperatures in various work environments according to different types of work, including steelmaking, sampling, measuring temperature, rolling mill, finishing, crown block, and heating furnace. We recorded WBGT readings for three days and calculated the Effective Time Weighted Average WBGT Index to define the hot environments. Workers were divided into groups of heat exposure according to the Effective Time Weighted Average WBGT Index: 30–35°C, 35–40°C, and 40–43°C.

*Sample selection and determination*

We collected sweat from the forehead, back, and chest of each participant by scraping the skin with a small beaker or 15-ml centrifuge tube during the rest time in the break room or at the work site immediately after exposure to high temperatures. Sweat was collected twice in the morning and twice again in the afternoon. We transferred the sweat samples into brown bottles and added oxalic acid. The samples were maintained in a bubble-wrapped fridge. And at least 5 ml of sweat was collected from each participant. All collection containers were soaked in 10% nitric acid solution overnight, washed with ultrapure water, and then dried. The total amount of perspiration excreted during an eight-hour work shift was calculated by the weight difference method (sweat excretion = weight before work − weight after work + liquids and food consumption − the weight of defecation and urine − respiratory water losses during work)[42] We carefully measured the weight of each participant before and after work, and before and after drinking, eating, defecating, and urinating during the work shift. The precision of the scale was 10 g. We estimated respiratory water losses (500 to 600 g) of each participant according to labor intensity and heat-exposure time, which were approximated to be 5 h for heavy physical activity and 6.5 h for moderate to heavy physical activity. For comparison, studies have reported that respiratory water loss during exercise to be approximately 88 ± 10 g/h or 0.12 g/kcal[43, 44]. We considered that micronutrient losses in sweat were equal to the product of the concentration of the micronutrient and the amount of sweat[42, 43].

In the field, vitamin C concentrations in sweat were estimated with 2, 6-dichlorphenol indophenol immediately after collection[45]. The sweat samples were then transported to the laboratory in a bubble-wrapped fridge. On the same day that the samples were obtained, vitamin $B_1$ and $B_2$ concentrations were estimated with fluorospectrophotometry (RF-5301PC, Shimadzu Corporation, Japan)[46]. The remaining samples were stored at −20°C until further analysis. After all samples were collected, the concentrations of potassium, sodium, calcium, magnesium, iron, zinc, copper, and selenium in sweat were determined by inductively-coupled plasma-atomic emission spectrometry (ICP-MS, Agilent-7500A, USA)[47]. The concentrations of the standard curves were 0.1 $\mu$g/L, 0.5 $\mu$g/L, 1 $\mu$g/L, 5 $\mu$g/L, 10 $\mu$g/L, 20 $\mu$g/L, 25 $\mu$g/L, and 50 $\mu$g/L. The sweat samples were diluted 10 times by 1% nitric acid (chromatographically pure). Water used in the experiments was deionized water, and glassware was soaked with 10% nitric acid (analytically pure). The relative standard deviations were all less than 5% and the precision of the method was acceptable.

*BP measurements*

We measured SBP and DBP after participants had been out of the high-temperature work environment for at least 12 hours. The participants rested for at least five minutes before BP measurements. A trained investigator used a mercury sphygmomanometer (Jiangsu Yuwell, China) to measure BP before workers began work in the morning. Three consecutive readings were recorded by measuring the same arm and the mean SBP and DBP values were calculated. Hypertension is defined as a SBP above 140 mm Hg or a DBP above 90 mm Hg[48].

*Statistical analysis*

Data were double-entered by Epidata 3.0 and statistical analyses were performed using SPSS 17.0 for Windows. Continuous variables are expressed as means ± standard deviation and count data are expressed as percentages. The t-test was applied to compare the differences between the groups and a one-way analysis of variance was applied to compare multiple groups. Multiple stepwise regression analysis was performed to evaluate the effect of micronutrient losses in sweat on BP among heat-exposed steelworkers. A p-value $< 0.05$ was considered statistically significant.

## Results

Descriptive statistics for the demographic information of participants are listed in Table 1. The subjects had an average age of 36.9 ± 5.9 years old and an average length of service 13.6 ± 6.4 years. All workers worked in three shifts.

**Table 1. Demographic characteristics of heat-exposed steelworkers (n=224)**

| Characteristic | *n* | % |
|---|---|---|
| Age (years) | | |
| 22–29 | 47 | 21.0 |
| 30–39 | 133 | 59.4 |
| 40–50 | 44 | 19.6 |
| Length of service (years) | | |
| 1–9 | 56 | 25.0 |
| 10–19 | 122 | 54.5 |
| 20–30 | 46 | 20.5 |
| Average WBGT value (°C) | | |
| 30–35 | 102 | 45.5 |
| 35–40 | 85 | 38.0 |
| 40–43 | 37 | 16.5 |
| BMI (kg/m$^2$) | | |
| <18.5 | 3 | 1.3 |
| 18.5–23.9 | 85 | 38.0 |
| 24.0–27.9 | 74 | 33.0 |
| ≥28.0 | 62 | 27.7 |
| Physical activity level | | |
| Medium | 89 | 39.7 |
| Heavy | 135 | 60.3 |
| Education level | | |
| Junior middle school or below | 23 | 10.3 |
| High school or technical secondary school | 132 | 58.9 |
| College degree or above | 69 | 30.8 |
| Dietary salt intake | | |
| Low | 32 | 14.3 |
| Moderate | 67 | 29.9 |
| High | 125 | 55.8 |
| Smoking status | | |
| Current smokers | 123 | 50.9 |
| Ex-smokers | 19 | 8.5 |
| Non-smokers | 82 | 36.6 |
| Alcohol intake | | |
| Yes | 140 | 62.5 |
| No | 84 | 37.5 |
| Regular exercise | | |
| Yes | 92 | 41.1 |
| No | 132 | 58.9 |

WBGT: Wet Bulb Globe Temperature

The average BMI of the participants was 25.4±3.9 kg/m$^2$ (range 16.0–36.4 kg/m$^2$). Most of the participants (n=125; 55.8%) had a high dietary salt intake and 67 (29.9%) subjects had a moderate dietary salt intake.

The excretions of water soluble vitamins in sweat during an eight-hour work shift among heat-exposed steelworkers are outlined in Table 2. The average sweat excretion of 224 heat-exposed steelworkers was 3,181±781 ml (range 1,513–7,695 ml). Sweat losses increased with increasing temperature of the work environment (all $P<0.01$). The average concentrations of vitamin C, vitamin $B_1$, and vitamin $B_2$ in sweat were 4.84 ± 1.9 mg/L, 71.3±20.1 $\mu$g/L, and 61.4±22.3 $\mu$g/L, respectively (ranges 0.9–8.2 mg/L, 41–146 $\mu$g/L, and 46.8–114 $\mu$g/L, respectively). The excretions of vitamin C, vitamin $B_1$, and vitamin $B_2$ in sweat in the 35–40°C and 40–43°C groups were significantly higher than those in the 30–35°C group (all $P<0.01$). The excretions of vitamin C, vitamin $B_1$, and vitamin $B_2$ in sweat in the 40–43°C group were significantly higher than those in the 35–40°C group (all $P<0.01$).

The excretions of minerals in sweat during an eight-hour work shift among heat-exposed steelworkers are outlined in Table 3. The average concentrations of potassium, sodium, calcium, magnesium, iron, zinc, copper, and selenium in sweat among heat-exposed steelworkers were 161.2 mg/L, 1,173.1 mg/L, 32.1 mg/L, 5.7 mg/L, 290.3 $\mu$g/L, 274.9 $\mu$g/L, 28.5 $\mu$g/L, and 5.9 $\mu$g/L, respectively (ranges 76.4–193.2 mg/L, 976–3,210 mg/L, 16.4–44.5 mg/L, 5.4–6.4 $\mu$g/L, 243.1–390.4 $\mu$g/L, 231.5–510.3 $\mu$g/L, 21.6–34.8 $\mu$g/L, and 3.9–8.2 $\mu$g/L respectively). The losses of all eight minerals in sweat in the 35–40°C and 40–43°C groups were significantly higher than those in the 30–35°C group (all $P<0.01$). The mineral losses in the 40–43°C group were significantly higher than those in the 30–35°C and 35–40°C groups (all $P<0.01$).

BP levels of heat-exposed steelworkers are listed in Table 4. The average SBP was 128.5 ± 15.0 mm Hg (range 100–175 mm Hg) and the average DBP was 80.8 ± 10.4 mm Hg (range 60–112 mm Hg). The prevalence of hypertension was 29.5% (n=66). We observed significant differences among the three groups of workers in terms of SBP ($F=3.193$, $P<0.05$). DBP in the 40–43°C group was significantly higher than that in the 30–35°C group ($P<0.05$). No significant differences in DBP were observed among the three groups ($F=1.665$, $P=0.192$).

The relationships between micronutrient losses in sweat during an eight-hour work shift and BP among heat-exposed steelworkers are listed in Table 5. A linear correlation analysis revealed that vitamin C, potassium, and calcium losses in sweat were positively correlated with SBP ($r=0.268$, $r=0.299$, and $r=0.303$, respectively; $P<0.01$) and DBP ($r=0.216$, $r=0.233$, and $r=0.303$, respectively; $P<0.05$). No correlations were noted between losses of vitamin $B_1$, vitamin $B_2$, sodium, magnesium, iron, zinc, copper, or selenium in sweat and BP.

The effects of micronutrient losses in sweat during an eight-hour work shift on BP among heat-exposed steelworkers are shown in Tables 6 and 7. We performed separate linear stepwise regression analyses with SBP or DBP as the dependent variable and age; length of work; BMI;

**Table 2. Excretions of water soluble vitamins in sweat during an eight-hour work shift**

| WBGT (°C) | N | Sweat losses (ml) | Water soluble vitamin losses in sweat | | |
|---|---|---|---|---|---|
| | | | Vitamin C (mg) | Vitamin $B_1$ ($\mu$g) | Vitamin $B_2$ ($\mu$g) |
| 30–35 | 102 | 2,742.2±411.4 | 10.7±3.9 | 183.5±60.4 | 160.6±53.8 |
| 35–40 | 85 | 3,272.5±407.2$^{a**}$ | 18.7±6.8$^{a**}$ | 247.7±66.2$^{a**}$ | 209.3±58.5$^{a**}$ |
| 40–43 | 37 | 4,180.6±360.1$^{a**b**}$ | 22.5±8.4 $^{a**b**}$ | 305.6±80.4$^{a**b**}$ | 263.2±87.8$^{a**b**}$ |
| Total | 224 | 3,181.4±781.1 | 15.7±7.8 | 228.0±81.9 | 196.0±78.3 |

Results are presented as means±SD for continuous variables; N=number of workers.
$^{*}P<0.05$, $^{**}P<0.01$; [a] compared to the 30–35°C group, [b] compared to the 35–40°C group.

**Table 3. Excretions of minerals in sweat during an eight-hour work shift**

| WBGT (°C) | N | Sweat losses (ml) | Mineral losses in sweat | | | |
|---|---|---|---|---|---|---|
| | | | Potassium (mg) | Sodium (mg) | Calcium (mg) | Magnesium (mg) |
| 30–35 | 102 | 2,742.2±411.4 | 439.9±174.0 | 2,971.5±289.8 | 82.8±24.4 | 13.8±2.0 |
| 35–40 | 85 | 3,272.5±407.2$^{a**}$ | 523.9±225.8$^{a**}$ | 4,255.9±749.6$^{a**}$ | 113.5±25.3$^{a**}$ | 21.5±2.2$^{a**}$ |
| 40–43 | 37 | 4,180.6±360.1$^{a**b**}$ | 693.5±225.9$^{a**b**}$ | 4,708.8±525.0$^{a**b**}$ | 131.3±18.6$^{a**b**}$ | 23.7±3.2$^{a**b**}$ |
| Total | 224 | 3,181.4±781.1 | 513.6±227.4 | 3,725±845.0 | 102.4±24.1 | 18.4±4.2 |
| WBGT (°C) | N | Sweat losses (ml) | Mineral losses in sweat | | | |
| | | | Iron ($\mu$g) | Zinc ($\mu$g) | Copper ($\mu$g) | Selenium ($\mu$g) |
| 30–35 | 102 | 2,742.2±411.4 | 776.9±97.6 | 681.7±174.4 | 72.2±11.9 | 13.7±3.4 |
| 35–40 | 85 | 3,272.5±407.2$^{a**}$ | 987.3±94.7$^{a**}$ | 974.8±114.6$^{a**}$ | 99.2±10.5$^{a**}$ | 22.5±3.6$^{a**}$ |
| 40–43 | 37 | 4,180.6±360.1$^{a**b**}$ | 1,190.7±259.2$^{a**b**}$ | 1,230.4±274.3$^{a**b**}$ | 127.3±30.4$^{a**b**}$ | 26.3±4.2$^{a**b**}$ |
| Total | 224 | 3,181.4±781.1 | 925.1±189.6 | 883.6±168.4 | 91.6±25.9 | 19.1±5.4 |

Results are presented as means±SD for the continuous variables; N=number of workers.
$^{*}P<0.05$, $^{**}P<0.01$; [a] compared to the 30–35°C group, [b] compared to the 35–40°C group.

**Table 4. BP of heat-exposed steelworkers**

| WBGT (°C) | n | SBP (mm Hg) | DBP (mm Hg) |
|---|---|---|---|
| 30–35 | 102 | 126.2±14.3 | 79.9±9.7 |
| 35–40 | 85 | 129.5±16.5 | 80.6±10.0 |
| 40–43 | 37 | 133.1±12.1$^{a*}$ | 83.6±11.9 |

Results are presented as means±SD for the continuous variables; N=number of workers.
$^{*}P<0.05$; [a] compared to the 30–35°C group, [b] compared to the 35–40°C group.

**Table 5. Relationships between micronutrient losses in sweat during an eight-hour work shift and BP among heat-exposed steelworkers**

| Micronutrient losses in sweat | SBP | | DBP | |
|---|---|---|---|---|
| | *r* | *P*-value | *r* | *P*-value |
| Vitamin C | 0.268 | 0.003 | 0.216 | 0.019 |
| Vitamin $B_1$ | −0.022 | 0.599 | 0.096 | 0.338 |
| Vitamin $B_2$ | −0.053 | 0.599 | −0.052 | 0.605 |
| Potassium | 0.299 | 0.001 | 0.233 | 0.012 |
| Sodium | 0.077 | 0.483 | −0.032 | 0.772 |
| Calcium | 0.303 | 0.005 | 0.347 | 0.001 |
| Magnesium | 0.030 | 0.786 | 0.031 | 0.776 |
| Iron | 0.150 | 0.170 | 0.042 | 0.701 |
| Zinc | 0.102 | 0.359 | −0.071 | 0.521 |
| Copper | 0.180 | 0.099 | 0.075 | 0.495 |
| Selenium | 0.075 | 0.592 | 0.085 | 0.540 |

WBGT; vitamin C, potassium, and calcium losses in sweat; smoking habits; drinking habits; and physical activity level as independent variables. The analyses revealed that, potassium and calcium losses in sweat adversely affected SBP and DBP. BMI was positively correlated with SBP, and alcohol intake was positively correlated with DBP (Table 6).

An analysis of covariance revealed that SBP was significantly higher in workers with potassium losses of ≥900 mg than in workers with potassium losses of <300 and 300–600 mg (all $P<0.05$). DBP was significantly higher in workers with potassium losses of 600–900 mg and ≥900 mg than in workers with potassium losses of <300 mg (all $P<0.05$). SBP was significantly higher in workers with calcium losses of 100–130 mg and ≥130 mg than in workers with calcium losses of <70 mg and 70–100 mg (all $P<0.05$). DBP was significantly higher in workers with calcium losses of ≥130 mg than in workers with calcium losses of <70 mg and 70–100 mg (all $P<0.01$). SBP was

**Table 6. Effects of vitamin C, potassium, and calcium losses in sweat during an eight-hour work shift on BP**

| Factors | B | SE | $\beta$ | $t$ | $P$ |
|---|---|---|---|---|---|
| SBP | | | | | |
| Constant | 56.571 | 8.996 | | 6.288 | <0.001 |
| Age | 0.392 | 0.212 | 0.154 | 1.849 | 0.066 |
| BMI | 1.300 | 0.262 | 0.330 | 4.971 | <0.001 |
| Vitamin C loss in sweat | 0.184 | 0.179 | 0.088 | 1.028 | 0.305 |
| Potassium loss in sweat | 0.015 | 0.005 | 0.219 | 3.264 | 0.001 |
| Calcium loss in sweat | 0.141 | 0.045 | 0.282 | 3.119 | 0.002 |
| DBP | | | | | |
| Constant | 33.883 | 6.161 | | 5.500 | <0.001 |
| BMI | 0.549 | 0.179 | 0.207 | 3.067 | 0.003 |
| Age | 0.435 | 0.145 | 0.253 | 2.999 | 0.003 |
| Alcohol intake | 3.223 | 1.348 | 0.151 | 2.390 | 0.018 |
| Potassium loss in sweat | 0.007 | 0.003 | 0.144 | 2.114 | 0.026 |
| Calcium loss in sweat | 0.094 | 0.022 | 0.318 | 5.054 | <0.001 |

$R^2$=0.402 (Model SBP); $R^2$=0.415 (Model DBP).
B indicates the unstandardized coefficients and $\beta$ indicates the standardized coefficients.

**Table 7. Analysis of covariance of the effects of vitamin C, potassium, and calcium losses in sweat on BP**

| Micronutrient losses in sweat | N | SBP (mm Hg) (M±SE) | DBP (mm Hg) (M±SE) |
|---|---|---|---|
| Potassium (mg) | | | |
| <300 | 61 | 126.82±1.62 | 79.20±1.19 |
| 300–600 | 100 | 126.90±1.25 | 80.14±0.93 |
| 600–900 | 40 | 130.88±1.99 | 81.62±1.49[a**] |
| ≥900 | 23 | 136.28±2.65[a**b**] | 86.25±1.96[a**] |
| Calcium (mg) | | | |
| <70 | 33 | 123.43±2.51 | 77.93±1.71 |
| 70–100 | 83 | 126.26±1.61 | 79.31±1.09 |
| 100–130 | 64 | 131.65±1.79[a**b*] | 81.33±1.23 |
| ≥130 | 44 | 132.23±2.24[a*b*] | 84.99±1.52[a**b**] |

M±SE=Standard Error; N=number of workers.
*$P$<0.05, **$P$<0.01; [a] compared to the first group, [b] compared to the second group.

higher with vitamin C, potassium, or calcium losses of >12 mg, >900 mg, or >100 mg, respectively. DBP was higher with potassium or calcium losses in sweat of >600 mg and >130 mg, respectively (Table 7).

## Discussion

High BP is a major public health concern and it is an important risk factor for cardiovascular disease[1, 2]. Many studies have revealed that the prevalence of high BP among heat-exposed workers is significantly higher than among workers with exposure to normal temperatures[3, 49]. In our study, the average BP among heat-exposed steelworkers was 128.5/80.8 mm Hg and the prevalence of hypertension was 29.5%, which is slightly higher than that reported by Rui-Fang Li[49]. BP increased with increasing levels of heat stress, which was in accordance with results reported by Hong-Yan Yang[50]. Control and prevention strategies for elevated BP are needed in order to improve workers' health.

Heat-exposed steelworkers lose large amounts of water-soluble vitamins and minerals through sweat. In our study, the average losses of vitamin C, vitamin $B_1$, vitamin $B_2$, potassium, and calcium in sweat were 16.3 mg, 240 $\mu$g, 201 $\mu$g, 513.6 mg, 102.4 mg, respectively, which were higher than previous reports; the average losses of sodium, magnesium, iron, zinc, copper, and selenium in sweat were 3,725 mg, 18.4 mg, 925.1 $\mu$g, 883.6 $\mu$g, 91.6 $\mu$g, and 19.1 $\mu$g, respectively, which were similar to previous reports[51]. Further, we did not find accurate reference ranges or standards of vitamin and mineral concentrations in sweat. Clarkson *et al.* reported that concentrations of vitamins C, $B_1$ and $B_2$ lost in sweat were 0–50 $\mu$g, 0–15 $\mu$g, 0.5–12 $\mu$g respectively, per 100 ml[52]. Consolazio *et al.* reported that concentrations of potassium, sodium, magnesium, and iron lost in sweat were 25–28 mg, 113–420 mg, 0.61–0.64 mg, 25–39 ug respectively, per 100 ml[53]. Other studies reported that concentrations of calcium[54], zinc[55], and copper[56] lost in sweat were 54–501 mg, 0.56–0.90 mg, 30–1,440 ug, respectively, per 1 L. Consolazio *et al.* reported an average loss of 340 ug of selenium in sweat over an eight-hour period in men exposed to a temperature of 37.8°C, which was higher than our study[57]. The differences may be due to the variations in instruments or measuring methods and work environments.

Many studies have reported that serum vitamin C, potassium, and magnesium levels are negatively correlated with BP[17–19]. Micronutrient deficiencies in long-term heat-exposed steelworkers are likely due to the large amounts of micronutrients that are lost with sweating, as well as decreased micronutrient consumption associated with a reduce appetite. Most analyses of thermoregulation phasize that eating is the major contributing factor for maintaince of body heat[58]. However, food intake should decrease and, therefore, nutrient intake will be restricted at high temperatures, when heat loss is difficult, so that the body does not acquire more heat than it can. Prolonged strenuous exercise and heat-exposed work can result in marked changes in chromium, copper, iron, magnesium, zinc and ascorbic acid metabolism[59, 60]. Possibly, the transient loss of micronutrients results in hypertension without changes in blood levels of the micronutrients because of hemoconcentration. Our findings are based on long-term occupational exposure to high temperatures.

A linear stepwise regression analysis revealed that is adversely affected by potassium, and calcium losses in sweat, BMI, age, and alcohol intake. Correction of micronutrient deficiencies with targeted nutrition supplementation according to excretion conditions of micronutrients in sweat may be indicated for BP control. Further, it is necessary to control weight and reduce alcohol consumption to maintain healthy BP.

An analysis of covariance revealed that SBP increased when potassium, or calcium losses in sweat were >900 mg, or >100 mg, respectively. Similarly, DBP increased when potassium or calcium losses in sweat were >600 mg or >130 mg, respectively. Therefore, to control BP, heat-exposed workers may consider increasing potassium intake at least 900 mg of potassium and 130 mg of calcium intake to compensate for the losses of potassium and calcium in sweat. There are several possible mechanisms for the effects of potassium and calcium on BP. Potassium can lead to vasodilatation[29)] and decrease the need for antihypertensive medication[30)]. Moreover, potassium lowers BP by regulating the dynamic balance between sodium and potassium, especially for salt-sensitive patients with hypertension[29, 31)]. In our study, we found that most workers (55.8%) had a high dietary salt intake and the mean sodium loss in sweat among heat-exposed steelworkers was 3,725 mg (equivalent to 9.5 g salt), which indicates that a high dietary salt intake is necessary. Calcium may regulate hormones, electrolyte interactions, and the sympathetic nervous system to modify BP[61)]. Therefore, special attention should be given to the effects of potassium, and calcium losses in sweat on BP among heat-exposed steelworkers, More research is necessary to confirm our findings.

## Conclusions

In conclusion, the losses of potassium, and calcium in sweat among heat-exposed steelworkers during an eight-hour work shift adversely affected BP. To control BP, workshops with high temperature environments should try to lower environmental temperatures to reduce potassium, and calcium losses in sweat. Heat-exposed steelworkers may also need to increase their dietary intakes of vitamin C, potassium, and calcium.

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