

## ORIGINAL ARTICLE

# Efficacy of ice slurry and carbohydrate–electrolyte solutions for firefighters

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## Abstract

**Objectives:** To examine the thermoregulatory and fluid–electrolyte responses of firefighters ingesting ice slurry and carbohydrate–electrolyte solutions before and after firefighting operations.

**Methods:** Twelve volunteer firefighters put on fireproof clothing and ingested 5 g/kg of beverage in an anteroom at 25°C and 50% relative humidity (RH; pre-ingestion), and then performed 30 minutes of exercise on a cycle ergometer (at 125 W for 10 minutes and then 75 W for 20 minutes) in a room at 35°C and 50% RH. The participants then returned to the anteroom, removed their fireproof clothing, ingested 20 g/kg of beverage (post-ingestion), and rested for 90 minutes. Three combinations of pre-ingestion and post-ingestion beverages were provided: a 25°C carbohydrate–electrolyte solution for both (CH condition); 25°C water for both (W condition); and a –1.7°C ice slurry pre-exercise and 25°C carbohydrate–electrolyte solution post-exercise (ICE condition).

**Results:** The elevation of body temperature during exercise was lower in the ICE condition than in the other conditions. The sweat volume during exercise was lower in the ICE condition than in the other conditions. The serum sodium concentration and serum osmolality were lower in the W condition than in the CH condition.

**Conclusions:** The ingestion of ice slurry while firefighters were wearing fireproof clothing before exercise suppressed the elevation of body temperature during exercise. Moreover, the ingestion of carbohydrate–electrolyte solution by firefighters after exercise was useful for recovery from dehydration.

## KEYWORDS

carbohydrate–electrolyte solutions, firefighters, heat-related illness, ice slurry, precooling

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## 1 | INTRODUCTION

Firefighters are obliged to wear fireproof garments for their safety. This clothing provides excellent fire protection and safety<sup>1</sup>; however, because of its high thermal resistance and poor vapor permeability, the clothing leads to the accumulation of heat during physical exertion, and the evaporation of sweat to lower body temperature cannot be expected especially in firefighting environments typically characterized by a high heat load.<sup>2</sup> A rise in core body temperature and dehydration is associated with an increased risk of reduced work efficiency and the development of heat-related illness.<sup>3–5</sup>

It has been widely demonstrated that by lowering the body temperature before exercise, precooling delays the elevation of body temperature during exercise in a hot environment and that precooling is a general strategy that can be used to delay fatigue due to heat and improve athletic performance.<sup>6–11</sup> However, many existing methods face issues relating to their field applicability and practicality.<sup>12–14</sup> In recent years, the ingestion of ice slurry before exercise has attracted attention as a practical precooling method, mainly in the field of sports.<sup>15–19</sup> A mixture of ice and water not only delays the elevation of body temperature due to exposure to heat but also supplies water to compensate for the plasma volume lost through sweating during exercise. The ingestion of ice slurry for precooling suppressed the elevation of body temperature and extended the duration of exercise compared with that following the ingestion of cold water.<sup>20–22</sup> The ingestion of ice slurry before exercise performed while wearing fireproof clothing was reported to suppress the elevation of body temperature.<sup>23,24</sup>

The duration from receiving a call for service to arriving at the scene is short for firefighters and sometimes firefighters go from one scene directly to another without adequate rehydration; therefore, there is a risk of dehydration. Consequently, firefighters need to receive adequate hydration within a limited time. To avoid spontaneous dehydration caused by a decrease in plasma electrolyte levels, it is recommended to supply electrolytes, including sodium, in addition to water.<sup>25</sup> To supply energy and facilitate intestinal water absorption, it is also considered important to supply carbohydrates at the same time.<sup>26,27</sup> Therefore, when sweating, beverages containing electrolytes and carbohydrates (carbohydrate–electrolyte solutions) are used. Prior studies have demonstrated that carbohydrate–electrolyte solutions are more useful than water for recovery from dehydration induced by sweating a lot.<sup>28,29</sup>

The first purpose of the present study was to investigate whether consumption of a beverage before exercise reduces heat strain by having actual firefighters perform exercises simulating an actual firefighting operation in an artificial hot environment and examining their thermoregulatory function. The second purpose was to verify whether certain beverages

facilitate recovery from dehydration after exercise. We hypothesized that the ingestion of ice slurry before exercise would suppress the elevation of body temperature during exercise and that the ingestion of a carbohydrate–electrolyte solution after exercise would effectively restore body fluids.

## 2 | METHODS

### 2.1 | Participants

In total, 12 healthy male volunteer firefighters aged 20–32 years (age:  $24.4 \pm 4.3$  years; height:  $172.3 \pm 3.2$  cm; body weight:  $70.5 \pm 7.4$  kg; body mass index:  $23.7 \pm 1.9$ ) provided written informed consent and participated in the experiments. The participants reported in their answers to questionnaires that they had no particular diseases that required treatment and no history of disease.

### 2.2 | Experimental procedures

All experiments were performed between June and September 2017 in an artificial climate chamber (TBR-8E20W0P2T; Espec, Osaka, Japan) at the University of Occupational and Environmental Health, Japan. On the day before each experiment, all participants were asked to eat the same dinner. Two hours before the start of the experiment, the participants ingested a 400-kcal meal (Calorie Mate Jelly; Otsuka Pharmaceutical, Tokyo, Japan) and 500 mL of water (Crystal Geyser; Crystal Geyser Water Company, Calistoga, CA, USA).

The participants were asked to wear working clothes, which were short-sleeved shirts made from 100% polyester and long pants made mainly from aramid fiber, similar to that worn when they are on duty. After resting for 30 minutes in a room with a dry-bulb temperature of 25°C and relative humidity (RH) of 50%, they put on fireproof clothes (Dual-Fine; Akao, Tokyo, Japan), fireproof helmets (NEO-TS; Akao), fireproof gloves (EGS-29; Akao), and fireproof boots (SG-AO; Akao). Ten minutes later, they ingested 2.5 g/kg body weight of beverage twice within 4 minutes; that is, they ingested 5.0 g/kg of pre-exercise beverage over 8 minutes (pre-ingestion). After they finished ingesting the beverage, they moved to a hot room (35°C and 50% RH) and rode on bicycle ergometers (TKK3070; Takei Scientific Instruments, Niigata, Japan). Ten minutes after they started ingesting the pre-exercise beverage, they performed ergometer exercises at 125 W for 10 minutes, representing rushing to the scene, and then at 75 W for 20 minutes, representing spraying water; as a result, participants performed a total of 30 minutes of exercise at a constant pace of 50 rpm. After completing the exercises, they rested for 5 minutes and then returned to the

room (25°C and 50% RH). The participants then removed their fireproof clothing and changed from their short-sleeved shirts and long pants into fresh clothing. Seventy minutes after they ingested the pre-exercise beverage, the participants started ingesting a post-exercise beverage (post-ingestion). The participants ingested 10 g/kg of beverage over 10 minutes and then 5 g/kg of beverage twice in the following 10 minutes; that is, a total of 20 g/kg of beverage over 30 minutes. The participants rested in the room until 90 minutes after the start of post-ingestion.

A crossover study was conducted applying three sets of conditions in a randomly assigned order: 25°C carbohydrate–electrolyte solution ingested before and after exercise (CH condition), –1.7°C ice slurry made from carbohydrate–electrolyte solution ingested before exercise and 25°C carbohydrate–electrolyte solution ingested after exercise (ICE condition), and 25°C mineral water ingested before and after exercise (W condition). Experiments in the same participant were separated by at least 4 days. The commercially available Pocari Sweat® (Otsuka Pharmaceutical) carbohydrate–electrolyte solution was used, the major components of which were Na<sup>+</sup>, 21 mEq/L; Cl<sup>–</sup>, 16.5 mEq/L; K<sup>+</sup>, 5 mEq/L; citric acid, 10 mEq/L; and carbohydrate, 6.2 g/100 mL. The ice slurry was made from Pocari Sweat® using a frozen drink machine (DM2000; Margaritaville, Boca Raton, FL, USA). The mineral water used was commercially available Crystal Geysers®, which contains Na<sup>+</sup>, 0.49 mEq/L and K<sup>+</sup>, 0.03 mEq/L.

## 2.3 | Measurements

During experiments, the rectal temperature ( $T_{re}$ ) as a representative core temperature was continuously monitored using a copper-constantan thermocouple, 4 mm in diameter, as a rectal temperature probe. A disposable rubber cover (Nikkiso-therm, Tokyo, Japan) was placed on the front part of the probe, and the probe was inserted 12 cm into the anus. Using a device to measure the temperature of the external auditory canal and its surroundings, the development of which we were engaged in (Midori Electric, Nagano, Japan), the core temperature of the participants during experiments was continuously estimated from the auditory canal temperature ( $T'_{ac}$ ) instead of the esophageal temperature, which is a dynamically changing core temperature.<sup>30,31</sup> The intestinal temperature ( $T_{int}$ ) during experiments was measured by having the participants ingest a wireless temperature sensor, 12 hours prior to the start of the experiment (CorTemp HT150002; HQ, Inc, Palmetto, FL, USA), which is a widely used method of measuring the core temperature. Heart rates (HR) were continuously monitored using a heart-rate monitor (BSM-2401; Nihon Kohden, Tokyo, Japan). During exercise, participants were interviewed regarding their self-rating of perceived exertion (RPE), head and whole-body thermal

sensations, and thermal comfort every 5 minutes. The thermal sensations were scored using a 13-point scale ranging from extremely cold (–6) to extremely hot (+6), and thermal was scored comfort using an eight-point scale ranging from comfortable (+1) to extremely uncomfortable (+8) created with reference to ISO 10551:1995.

Before pre-ingestion, after exercise, and 45 and 90 minutes after post-ingestion, blood was drawn, urine was collected, and nude body weight was measured (CHING-150IG-H; Sartorius, Göttingen, Germany, precision 1 g). A 14-mL blood sample was drawn from the median cubital vein each time without cannulation. The hemoglobin (Hb) concentration was analyzed using a sodium lauryl sulfate-Hb method (Hemoglobin B-test Wako; FUJIFILM Wako Pure Chemical Corp., Osaka, Japan:  $r^2 > .999$  [5–30 g/dL], CV% among triplicate <1.46% [15 g/dL]), and the hematocrit value (Hct) was analyzed based on the microhematocrit (Hematocrit capillaries, Na-hep 9100275, Hirschmann Laborgeräte GmbH & Co. KG, Eberstadt, Germany: CV% among triplicate <0.991%). The percentage change in plasma volume (% $\Delta$ PV) was calculated from the Hct and Hb measurements.<sup>32</sup> Blood glucose (Glc) was measured using an enzymatic method (YSI 2300 STAT PLUS Glucose and L-Lactate Analyzer; YSI Inc., Yellow Springs, OH, USA: CV among triplicate <1.86% [10 mmol/L]). We asked SRL, Inc. (Tokyo, Japan) to analyze serum Na<sup>+</sup>, K<sup>+</sup>, and Cl<sup>–</sup> concentrations; serum osmolality (Sosm); serum arginine vasopressin (AVP); urine Na<sup>+</sup>, K<sup>+</sup>, and Cl<sup>–</sup> concentrations; and urine osmolality (Uosm). The urine volume was measured using a scale (ACS200; AS ONE, Osaka, Japan). The sweat volume during exercise was estimated from the change in body weight between, before and after exercise, and its ratio to body weight before exercise was also calculated.

## 2.4 | Statistical analysis

Statistical Analysis System (SAS) version 9.4 (SAS Institute Inc, Cary, NC, USA) software was used to perform statistical analyses. Differences in the means of measurements among the beverage conditions and among different timepoints were analyzed using mixed-effects models for repeated measures to adjust for carryover effects. These models included fixed effects for the condition, time, condition-time interaction, number of repetitions, execution order, and measured values before pre-ingestion, and random effects for participants. When any significant main effect or interaction effect was detected, a multiple comparison test adjusted using the Bonferroni correction was performed for individual time points. For body temperatures and HR, mean values per minute in 5-minute intervals were used in analyses. For all analyses,  $P < .05$  was set as the significance level. All figures are represented as the means  $\pm$  standard error of the mean for

clarity of presentation, and all other data are presented as the means  $\pm$  standard deviations.

### 3 | RESULTS

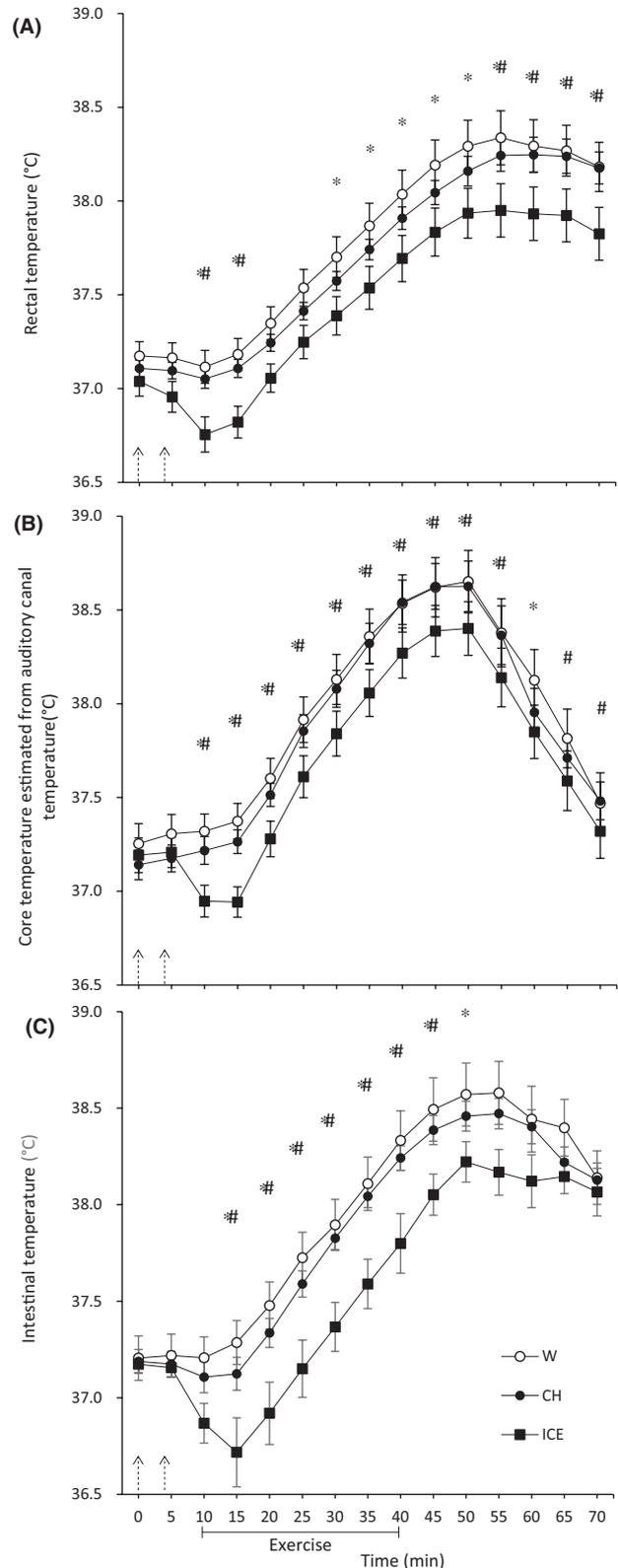
#### 3.1 | Experiment data

All participants completed their assigned exercises. The amount of beverage ingested before exercise was  $348.6 \pm 47.6$  g, while the amount of beverage ingested after exercise was  $1412.9 \pm 142.4$  g. One participant suffered a severe trigeminal headache when ingesting ice slurry and was able to ingest only half of the targeted amount; however, data for this participant were included in the analysis. Among a total of 36 runs,  $T'_{ac}$  data were partially missing for four runs while  $T_{int}$  data were completely missing for five runs and partially missing for three runs. One  $T_{int}$  datum was missing among 12 runs shortly after the end of exercise. Urine at 45 minutes after post-ingestion could not be collected from one participant in the CH and ICE conditions.

#### 3.2 | Pre-ingestion

$T_{re}$ ,  $T'_{ac}$ , and  $T_{int}$  from the start of pre-ingestion to 30 minutes after the end of exercise are shown in Figure 1A–C. In the ICE condition, body temperatures started to fall after the start of beverage ingestion and  $T_{re}$  at 10 minutes after beverage ingestion was significantly lower (W vs CH vs ICE:  $37.12 \pm 0.30^\circ\text{C}$  vs  $37.05 \pm 0.17^\circ\text{C}$  vs  $36.75 \pm 0.33^\circ\text{C}$ ; W vs CH,  $P = 1.000$ ; W vs ICE,  $P = .008$ ; CH vs ICE,  $P = .005$ ). The results were similar for  $T'_{ac}$  and  $T_{int}$ . During exercise,  $T_{re}$  from 30 minutes after beverage ingestion was significantly lower in the ICE condition than in the W condition ( $P < .05$ : W vs ICE conditions). Moreover, in the ICE condition,  $T'_{ac}$  was significantly lower for 45 minutes continuously starting from 10 minutes after beverage ingestion and  $T_{int}$  was significantly lower for 30 minutes continuously starting from 15 minutes after beverage ingestion compared with those in the other two conditions ( $P < .05$ : ICE vs other conditions). After the completion of exercise, body temperatures continued to rise for approximately 10 minutes until the participants removed their fire protection clothing. Throughout the experiment,  $T_{re}$  changed slowly in general even when participants took a rest after removing their fireproof clothing, and it was significantly lower in the ICE condition from 55 minutes after beverage ingestion ( $P < .05$ : ICE vs other conditions).

HR from the start of pre-ingestion to 5 minutes after the end of exercise are shown in Figure 2. HR during exercise gradually increased but seemed to change less in the ICE



**FIGURE 1** Rectal temperature ( $T_{re}$ ; A), core temperature estimated from the auditory canal temperature ( $T'_{ac}$ ; B), and intestinal temperature ( $T_{int}$ ; C) from the start of pre-ingestion to the start of post-ingestion for W, CH, and ICE conditions (means  $\pm$  standard error of the mean). Arrows denote when the drink was ingested. \* $P < .05$  (W vs ICE), # $P < .05$  (CH vs ICE)

condition than in the other two conditions. However, no significant differences were detected at almost any time point during exercise, except at 5 minutes after the start of exercise (W vs CH vs ICE:  $133.9 \pm 14.5$  bpm vs  $134.5 \pm 12.7$  bpm vs  $127.5 \pm 12.1$  bpm; W vs CH,  $P = 1.000$ ; W vs ICE,  $P = .038$ ; CH vs ICE,  $P = .078$ ).

The estimated sweat volume per unit body weight during exercise was significantly less for the ICE condition (W vs CH vs ICE:  $18.61 \pm 4.75$  g/kg vs  $18.26 \pm 4.64$  g/kg vs  $16.29 \pm 4.29$  g/kg; W vs CH,  $P = 1.000$ ; W vs ICE,  $P < .001$ ; CH vs ICE,  $P < .001$ ). The median of the absolute sweat volume during exercise were 1349.3 g in the W condition, 1272.0 g in the CH condition, and 1147.9 g in the ICE condition.

Changes in whole-body and head thermal sensations (Figure 3A,B), thermal comfort (Figure 3C), and RPE (Figure 3D) are shown. Regarding thermal sensations at 10 minutes after beverage ingestion, the subjective feeling of heat was significantly lower in both the head and whole body in the ICE condition ( $P < .05$ : ICE vs other conditions), but no significant differences were found during exercise ( $P > .05$ ). No significant differences were observed in thermal comfort or RPE between beverage conditions throughout the observation period ( $P > .05$ ).

Regarding blood test results, the change of Hct was only significantly different between the W the ICE conditions in the post-exercise tests (W vs CH vs ICE:  $48.31 \pm 2.31\%$  vs  $49.08 \pm 1.93\%$  vs  $48.42 \pm 2.18\%$ ; W vs CH,  $P = .806$ ; W vs ICE,  $P = .015$ ; CH vs ICE,  $P = .204$ ) (Figure 4). Other blood test results and all items in the urinalysis demonstrated no significant difference after exercise ( $P > .05$ ) (Tables 1 and 2).

### 3.3 | Post-ingestion

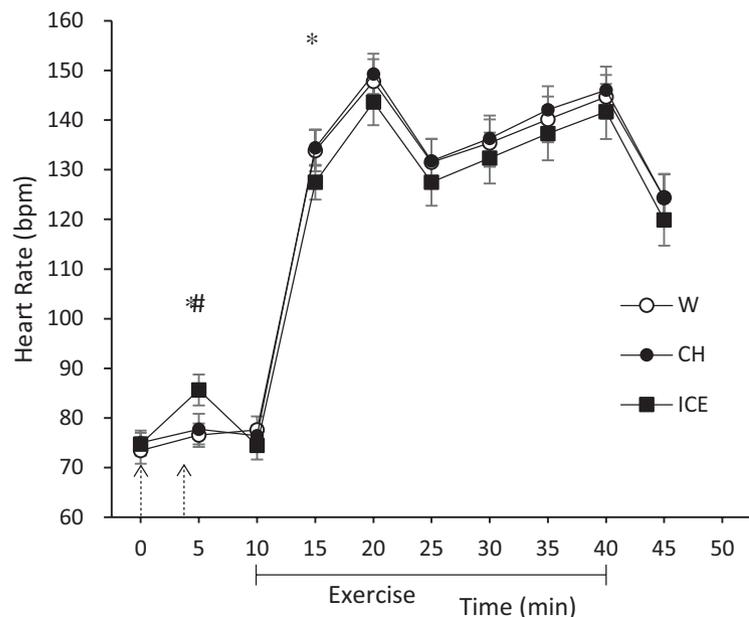
No significant differences in Hb were observed between the beverage conditions ( $P > .05$ ) (Figure 4). At 90 minutes after post-ingestion, Hct was significantly lower in the CH and ICE conditions than in the W condition, and the  $\% \Delta PV$  calculated from the Hb and Hct was significantly higher in the CH condition than in the W condition (W vs CH vs ICE:  $-0.49 \pm 2.84\%$  vs  $3.99 \pm 5.41\%$  vs  $2.85 \pm 4.50\%$ ; W vs CH,  $P = .021$ ; W vs ICE,  $P = .123$ ; CH vs ICE,  $P = 1.000$ ).

In the W condition, Sosm and serum  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations were significantly lower than those under the other two conditions from 45 minutes after post-ingestion onwards ( $P < .05$ : W vs other conditions) (Table 1). Serum  $\text{K}^+$  was higher in the W condition than in the other two conditions only at 45 minutes after post-ingestion ( $P < .05$ : W vs other conditions). No significant differences in AVP were observed between the beverage conditions ( $P > .05$ ).

Urine volume at 90 minutes in the W condition was significantly greater than that under the CH condition ( $P < .05$ : W vs CH conditions) (Table 2). While no significant differences were observed in  $\text{Na}^+$ ,  $\text{K}^+$ , or  $\text{Cl}^-$  concentrations between conditions ( $P > .05$ ), Uosm was significantly lower in the W condition than in the other conditions only at 90 minutes after post-ingestion ( $P < .05$ : W vs other conditions).

## 4 | DISCUSSION

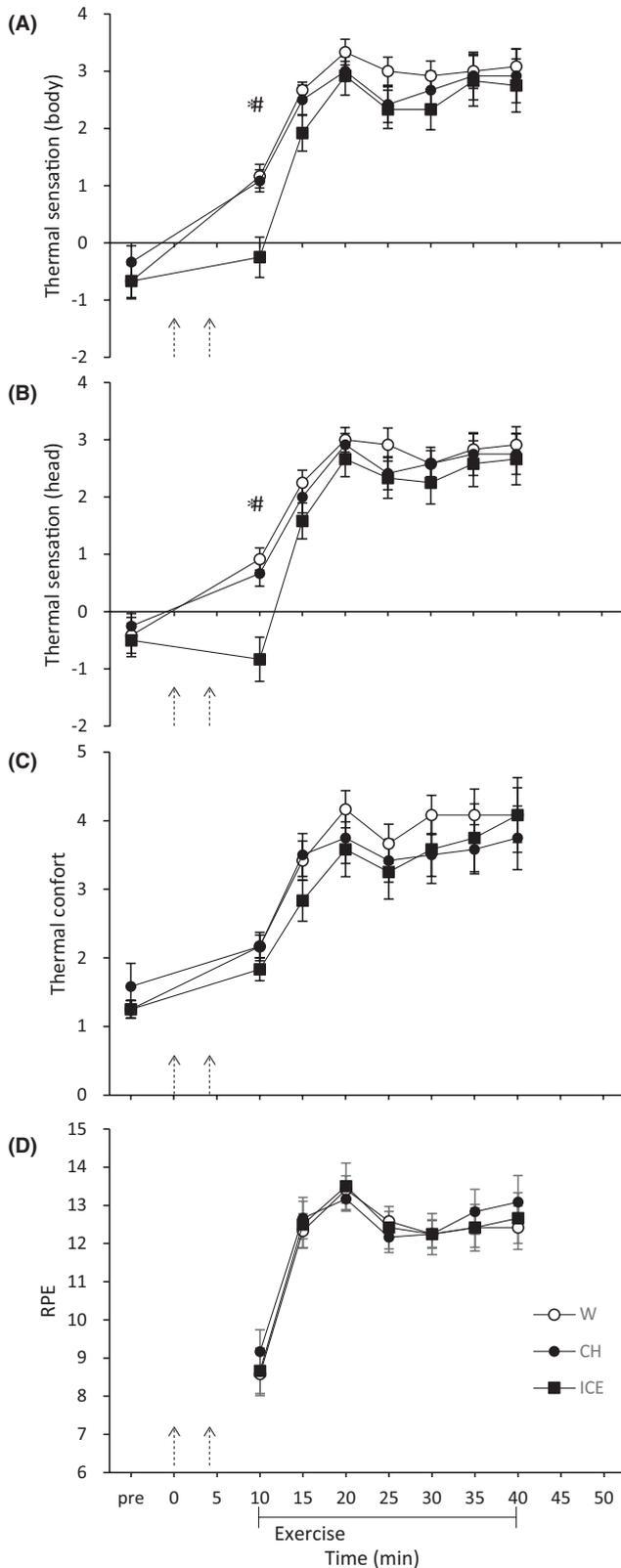
To verify practical hydration methods for firefighting, this study investigated precooling before simulated operations and beverage ingestion after operations in actual firefighters



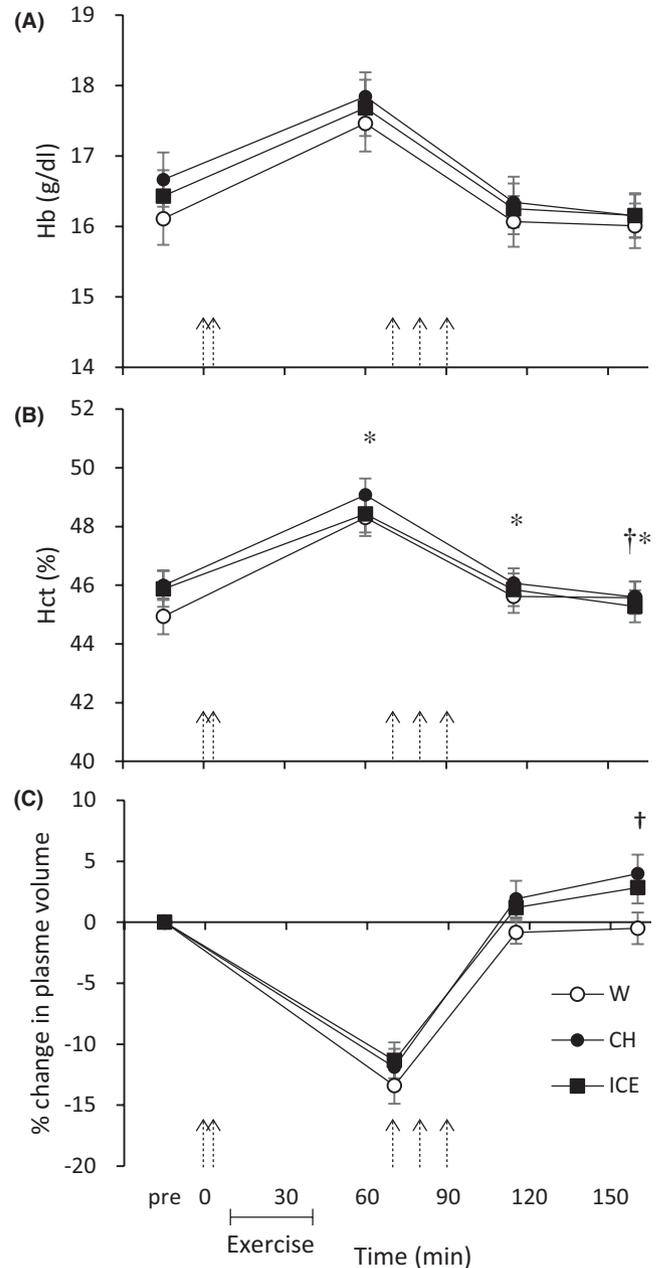
**FIGURE 2** Heart rate from the start of pre-ingestion to 5 min after the end of exercise for W, CH, and ICE conditions (means  $\pm$  standard error of the mean).

Arrows denote when the drink was ingested.

\* $P < .05$  (W vs ICE), # $P < .05$  (CH vs ICE)



**FIGURE 3** Whole-body and head thermal sensations (A, B), thermal comfort (C), and rating of perceived exertion (RPE) (D) during pre-ingestion and exercise for W, CH, and ICE conditions (means  $\pm$  standard error of the mean). Arrows denote when the drink was ingested. \* $P < .05$  (W vs ICE), # $P < .05$  (CH vs ICE)



**FIGURE 4** Hb (A), Hct (B), and relative change in plasma volume (% $\Delta$ PV; C) during the experiment for W, CH, and ICE conditions (means  $\pm$  standard error of the mean). Arrows denote when the drink was ingested. † $P < .05$  (W vs CH), \* $P < .05$  (W vs ICE)

wearing fireproof clothing widely used in Japan. The study demonstrated that the ingestion of 5 g/kg of ice slurry over 8 minutes while wearing fireproof clothing before exercise suppressed elevation of the body temperature and reduced the sweat volume during exercise. As for post-ingestion, the ingestion of a carbohydrate–electrolyte solution after exercise was useful for recovery from dehydration.

In a prior study using ice slurry and fireproof clothing, the ingestion of 7.5 g/kg of ice slurry over 30 minutes before exercise wearing wildland firefighting garments which lack the

**TABLE 1** Serum Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, osmolality (Sosm), blood glucose (Glc), and plasma arginine vasopressin (AVP) levels during the experiment for W, CH, and ICE conditions

	Before pre-ingestion	After exercise	45 min after post-ingestion		90 min after post-ingestion	
Serum Na <sup>+</sup> (mEq/L)						
W	139.9 ± 1.5	141.6 ± 1.9	136.5 ± 1.6		137.5 ± 1.5	
CH	139.9 ± 1.2	141.7 ± 1.5	138.8 ± 1.4	† <i>P</i> < .001	139.1 ± 1.2	† <i>P</i> = .001
ICE	139.8 ± 1.4	141.4 ± 1.8	139.0 ± 1.3	* <i>P</i> < .001	139.3 ± 1.1	* <i>P</i> < .001
Serum K <sup>+</sup> (mEq/L)						
W	4.23 ± 0.26	4.35 ± 0.14	4.33 ± 0.35		4.22 ± 0.26	
CH	4.18 ± 0.32	4.36 ± 0.16	4.03 ± 0.25	† <i>P</i> = .004	4.17 ± 0.25	
ICE	4.13 ± 0.18	4.34 ± 0.22	3.99 ± 0.25	* <i>P</i> = .019	4.08 ± 0.28	
Serum Cl <sup>-</sup> (mEq/L)						
W	103.8 ± 1.5	104.1 ± 2.5	100.7 ± 1.6		101.2 ± 1.7	
CH	103.5 ± 1.3	104.7 ± 1.5	102.2 ± 0.9	† <i>P</i> = .004	102.7 ± 0.9	† <i>P</i> = .004
ICE	103.0 ± 1.6	103.8 ± 1.7	101.7 ± 1.4	* <i>P</i> = .019	102.3 ± 1.6	* <i>P</i> = .012
Sosm (mOsm/kg H <sub>2</sub> O)						
W	282.5 ± 2.7	285.5 ± 3.8	273.8 ± 3.0		275.9 ± 3.1	
CH	282.9 ± 2.4	286.3 ± 3.3	283.0 ± 2.4	† <i>P</i> < .001	277.8 ± 1.9	
ICE	282.0 ± 2.8	285.9 ± 3.7	281.9 ± 2.6	* <i>P</i> < .001	278.8 ± 2.1	* <i>P</i> = .003
Glc (mmol/L)						
W	4.68 ± 0.33	4.66 ± 0.38	4.33 ± 0.20		4.32 ± 0.21	
CH	4.78 ± 0.40	4.77 ± 0.34	6.27 ± 0.91	† <i>P</i> < .001	3.70 ± 0.60	† <i>P</i> = .004
ICE	4.52 ± 0.21	4.86 ± 0.54	5.61 ± 0.72	* <i>P</i> < .001 # <i>P</i> = .048	3.75 ± 0.54	
AVP (pg/mL)						
W	1.48 ± 0.52	10.15 ± 16.12	1.28 ± 0.55		1.45 ± 0.54	
CH	1.65 ± 0.73	10.47 ± 11.57	1.60 ± 0.76		1.65 ± 1.16	
ICE	1.46 ± 0.66	5.53 ± 4.72	1.66 ± 0.68		1.52 ± 0.55	

Note: Means ± standard deviations for 12 subjects in the W, CH, ICE conditions, respectively.

†*P* < .05 (W vs CH).

\**P* < .05 (W vs ICE).

#*P* < .05 (CH vs ICE).

vapor barrier kept the  $T_{int}$  significantly lower for 30 minutes from the start of exercise.<sup>23</sup> The elevation in  $T_{re}$  for 20 minutes from the start of exercise was similarly suppressed in another prior study of 500 mL (6.75 ± 0.84 g/kg) of ice slurry consumption over 15 minutes before exercise in those wearing fireproof clothing.<sup>24</sup> It was also reported that ice slurry ingestion during exercise wearing fireproof clothing suppressed the elevation in  $T_{re}$ .<sup>33</sup> In our experiments, the elevations of  $T'_{ac}$  and  $T_{int}$  were significantly suppressed for approximately 30 minutes after the start of exercise in the ICE condition. It has been demonstrated that  $T'_{ac}$  and  $T_{int}$  reflect dynamic changes in contrast with  $T_{re}$ , which might have affected the results.<sup>31,34,35</sup> In particular, the elevation of  $T'_{ac}$ , which reflects the blood temperature of the external carotid artery, was suppressed.<sup>31</sup> It is therefore conceivable that the ingestion of ice slurry suppressed not only the intestinal temperature but also

the brain temperature as shown in a prior study.<sup>36</sup> Meanwhile, the continued elevation of body temperatures during the rest period after exercise must be attributed to insufficient heat dissipation that occurs when wearing fire protection clothing. The elevation of  $T_{re}$  was fairly suppressed in the ICE condition, and we thus considered that the ice slurry must efficiently prevent heat accumulation. These findings suggest that the ingestion of only 5.0 g/kg of ice slurry suppresses the elevation of body temperature.

In this study, the ingestion of ice slurry before exercise suppressed sweating during exercise. This result was found with a smaller amount of ice slurry than in a prior study.<sup>11</sup> It is thought that because the ingestion of ice slurry before exercise suppressed the elevation of body temperature in the present study, the sweat volume needed for thermoregulation was reduced. Moreover, prior studies often used ice slurry made of water,

**TABLE 2** Urine volume, Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, and osmolality (Uosm) levels during the experiment for W, CH, and ICE conditions

	Before pre-ingestion	After exercise	45 min after post-ingestion	90 min after post-ingestion	
Urine volume (g/kg body weight)					
W	2.04 ± 1.81	1.43 ± 1.05	0.82 ± 0.55	3.63 ± 1.89	
CH	1.60 ± 1.03	1.88 ± 1.24	0.44 ± 0.25	2.01 ± 1.87	† <i>P</i> < .001
ICE	1.69 ± 1.42	1.65 ± 1.19	0.61 ± 0.44	2.99 ± 2.43	
Urine Na <sup>+</sup> (mEq/L)					
W	83.9 ± 44.9	80.0 ± 34.0	89.7 ± 46.4	29.4 ± 28.6	
CH	79.7 ± 59.2	68.5 ± 50.8	85.3 ± 42.5	47.6 ± 28.9	
ICE	72.9 ± 44.3	79.0 ± 48.6	89.0 ± 37.6	45.6 ± 52.3	
Urine K <sup>+</sup> (mEq/L)					
W	21.5 ± 14.9	34.4 ± 16.6	41.5 ± 13.8	10.4 ± 8.2	
CH	18.4 ± 12.8	25.4 ± 14.0	45.4 ± 10.2	12.8 ± 7.9	
ICE	18.8 ± 10.1	30.5 ± 13.3	37.9 ± 12.2	9.6 ± 7.6	
Urine Cl <sup>-</sup> (mEq/L)					
W	93.8 ± 51.3	108.2 ± 50.6	105.1 ± 54.9	30.1 ± 33.2	
CH	91.5 ± 68.8	93.6 ± 70.2	112.5 ± 53.5	59.3 ± 33.4	
ICE	81.5 ± 43.1	103.3 ± 61.8	103.4 ± 44.7	51.4 ± 60.8	
Uosm (mOsm/kg H <sub>2</sub> O)					
W	544.8 ± 243.0	594.3 ± 232.0	638.4 ± 206.1	162.0 ± 123.4	
CH	486.1 ± 303.3	469.2 ± 275.1	773.8 ± 95.2	409.6 ± 240.7	† <i>P</i> = .001
ICE	446.7 ± 220.4	506.9 ± 264.7	725.3 ± 138.7	324.6 ± 295.3	* <i>P</i> = .0027

Note: Means ± standard deviations for 12 subjects in the W, CH, ICE conditions, respectively.

†*P* < .05 (W vs CH).

\**P* < .05 (W vs ICE).

while ice slurry made of carbohydrate–electrolyte solution was used in the present study. Using carbohydrate–electrolyte solution, the temperature of ice slurry can be maintained at slightly lower levels because of its lower freezing point. Furthermore, it is expected that a carbohydrate–electrolyte solution is absorbed into the body more quickly after ingestion than water alone and that the water ingested in a carbohydrate–electrolyte solution is retained in the body for a longer time.<sup>27,37</sup>

The ingestion of ice slurry had little change in the HR, thermal sensation, thermal comfort, or RPE in this study. In a firefighting operation, after arriving near the scene of a fire, firefighters rush to the scene carrying hoses on their backs—a physically intense activity, and then spray water and perform other operations. Firefighting can last from only several tens of minutes to several hours. In this study, we asked participants to use the bicycle ergometer at two intensities to replicate firefighters' activities using a standardized exercise as best as possible while ensuring safety. The intensity of physical workload was decided at the modest level that many of the participants may certainly complete the experimental protocol based on the preceding observation of pulse rate of firefighters during firefighting drills. Therefore, some participants might feel that the exercises in the experiments were

not as intense as those in actual firefighting operations or training. Although the elevation of body temperature and the estimated sweat volume were not markedly different from the observation in a preceding study,<sup>38</sup> the real activity of firefighters can be more physically demanding. The effects of ice slurry ingestion may have been demonstrated more clearly if the exercise load had been much greater.

Prior studies have demonstrated that after sweating due to exercise, the ingestion of carbohydrate–electrolyte solutions improved the plasma volume, S<sub>osm</sub>, and serum Na<sup>+</sup> concentration more quickly and increased the urine volume less than those following the ingestion of water.<sup>29,39</sup> Our study obtained similar results to varying degrees. Our study followed the participants for only 90 minutes after post-ingestion. More differences may have been found if the experimental time had been extended.

It is difficult to adjust hydration to the sweat volume of firefighters during actual firefighting. In this study, to prevent dehydration in participants in whom sweat does not easily evaporate due to wearing fireproof clothing in a hot environment, we made participants ingest a sufficient amount of fluids after exercise. However, because the actual sweat volume was a little smaller than the volume assumed prior to the

experiments, the amount of fluids consumed post-ingestion was more than the sweat volume. This trend was particularly striking in the ICE condition because the sweat volume was significantly lower. Overhydration may also occur in the real operation of firefighters; however, ample intake of beverage containing electrolyte reduces risk of dehydration and hyponatremia. We believe that if hydration had been adjusted to the sweat volume, the ingestion of ice slurry before exercise and ingestion of carbohydrate–electrolyte solution after exercise would have been demonstrated to be the most effective hydration methods.

The strength of the present study is that the experiments were conducted with actual firefighters. Even for these firefighters who routinely perform intense training, it was demonstrated that ice slurry suppressed the elevation of body temperature and reduced the sweat volume during exercise and that carbohydrate–electrolyte solution effectively supplied water after exercise. Moreover, some of these effects were demonstrated even when the amount of ingested ice slurry was less than that ingested in prior studies. In prior studies in which the timing of ice slurry ingestion was varied, the effect of ice slurry in lowering the body temperature was demonstrated; however, it is difficult to use a similar method in actual firefighting operations.<sup>40</sup> The results of the present study show that ice slurry can be used efficiently in a short time, even for firefighters who only have a short time from receiving a call for service to starting a firefighting operation.

A weakness of the present study is that the applicability of the results to the field is unknown. First, only a small sample of healthy young males was studied, which limits the generalizability of the results. Second, the participants performed bicycle ergometer exercises in a laboratory, which is different from the exercise performed in the field. Third, in the present study, ice slurry made from carbohydrate–electrolyte solution using a frozen-drink machine was used in the experiments; however, we consider that this beverage may be difficult to use in the field. It is not known whether ice slurry products on the market have similar effects. Further research is needed to demonstrate applicability in the field.

## 5 | CONCLUSIONS

The study demonstrated that the ingestion of 5 g/kg of ice slurry while wearing fireproof clothing before exercise suppressed elevation of the body temperature and reduced the sweat volume during exercise. Moreover, the ingestion of a carbohydrate–electrolyte solution after exercise was useful for recovery from dehydration. To our knowledge, this study was the first to investigate the ingestion of a small amount of ice slurry drinkable within 8 minutes before exercise and

of carbohydrate–electrolyte solution after exercise in actual firefighters wearing fireproof clothing. The use of hydration methods based on knowledge obtained in this study may protect firefighters from heat-related illness.

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## DISCLOSURE

*Approval of the research protocol:* This study was approved by the ethics committee of the University of Occupational and Environmental Health, Japan in 2017 (Approval number H28-229). *Informed consent:* Written consent was obtained from all participants. *Registry and the registration no. of the study/trial:* N/A. *Animal studies:* N/A. *Conflict of interest:* This study was funded by Otsuka Pharmaceutical and conducted as a collaborative study; however, the company had no influence over the scientific interpretation of the collected data or the publication of this article.

## AUTHOR CONTRIBUTION

ST, SH, SK, JI, CN, MS, and KH conceived and designed the study. ST, SH, SK, DI, SM, MS, and RS conducted the experiments. ST and SH analyzed and interpreted the data and drafted the manuscript. All authors were involved in the interpretation of the data. All authors contributed to the revision of the manuscript and approved the final version of the manuscript.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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