# REHYDRATION WITH SODIUM ENRICHED COCONUT WATER AFTER EXERCISE-INDUCED DEHYDRATION



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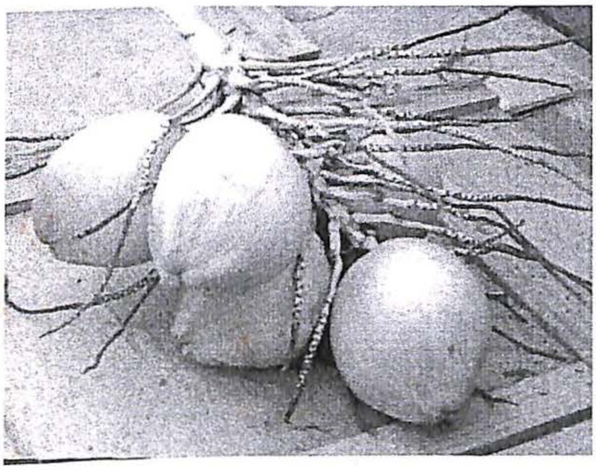

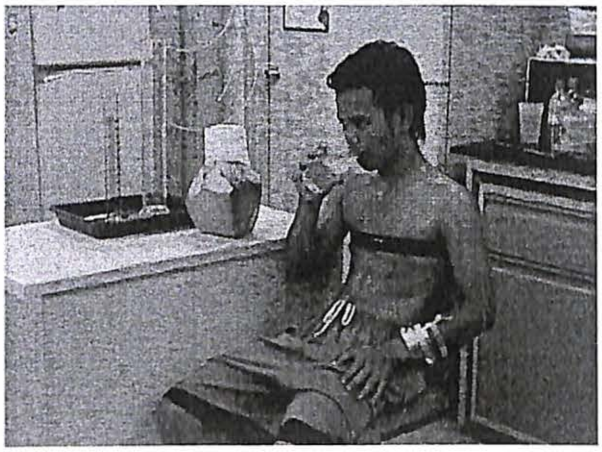

Sports Science Unit
School of Medical Sciences
Universiti Sains Malaysia

UNIVERSITI SAINS MALAYSIA

Sports Science Unit
Sports Science In Action

# BAHAGIAN PENYELIDIKAN & PEMBANGUNAN
# CANSELORI
# UNIVERSITI SAINS MALAYSIA

**Laporan Akhir Projek Penyelidikan Jangka Pendek**

1) Nama Pnyelidik: **Professor Rabindarjeet Singh**

Nama Penyelidik-Penyelidik Lain (Jika berkaitan) : **Prof. Madya R. G. Sirisinghe**

2) Pusat Pengajian/Pusat/Unit: **Unit Sains Sukan & Jabatan Fisiologi**

**Pusat Pengajian Sains Perubatan**

3) Tajuk Projek: **Rehydration with sodium enriched coconut water after exercise induced dehydration**



3.3.04

4) (a) Penemuan Projek/Abstrak

*(Perlu disediakan makluman di antara 100-200 perkataan di dalam Bahasa Malaysia dan Bahasa Inggeris. Ini kemudiannya akan dimuatkan ke dalam Laporan Tahunan Bahagian Penyelidikan & Pembangunan sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti)*

This cross over study assessed the effectiveness of plain water (PW), sports drink (SD), young coconut water (CW) and sodium enriched young coconut water (SCW) on whole body rehydration (R), plasma volume (PV) restoration after exercise-induced dehydration. Ten healthy male subjects (age range, 19 – 27 years) were exercised at 65% of $VO_{2max}$ at an environmental temperature of 32.06±0.02°C which a relative humidity (RH) of 53.32±0.17% for 90 minutes until 3.08± 0.04% (1.83±0.10 kg) of their body weight was loss. After which, the subjects moved to the thermoneutral environment (23.2±0.3°C) and rested for 30 minutes prior to begin the 2-hour R period. During R. Subjects drank either PW, SD, CW or SCW in randomized representing 120% of the fluid lost in three boluses representation 50% (915±54 ml), 40% (732± 37ml) and 30% (556±35 mL) of the fluid lost at 0, 30, 60-min respectively. In all the trials subject were somewhat hypohydrated (range 0.32 – 0.52 kg) body weight (BW) below euhydrated BW after the 2-h R period. The percent body weight loss that was regained (used as index of percent rehydration) during PW, SD, CW and SCW was 58±2%, 68±2%, 65±2% and 69±1% respectively with a significant better rehydration with SD and SCW than PW ($p<0.05$). The rehydration index (RI) for SD and SCW was significantly lower than PW ($p<0.01$). PV was restored similarly to euhydration levels after 2-h of rehydration with SD, CW and SCW but was significantly lower ($p<0.05$) with PW trials. Cumulative urine output was significantly higher for PW when compare to SD and SCW ($p<0.05$). Serum $Cl^-$ were significantly higher with CW and SCW trials ($p<0.05$). Serum $Na^+$, serum $K^+$, serum $Cl^-$ and serum and urine osmolality of PW trial were significantly lower ($p<0.05$) than SD, CW and SCW at the end of 2-h R period. Plasma glucose concentration were significantly higher when SD, CW and SCW were ingested during rehydration compared to PW ($p<0.01$). SCW were similar in sweetness with CW and SD but caused less nausea and stomach upset when compares either SD or PW, furthermore SCW was easier to consume in large volume. In conclusion, ingesting SCW was as good as ingesting a commercial sports drink for whole body rehydration after exercise-induced dehydration but with better fluid tolerance.

(b) Senaraikan kata Kunci yang digunakan di dalam abstrak:

| Bahasa Malaysia | Bahasa Inggeris |
|---|---|
| Dehidrasi akibat senaman | Exercise-induced dehydration |
| Pengantian cecair | Fluid replacement |
| Rehidrasi | Rehydration |
| Airkelapadiperkayadengan natrium | Sodium enriched coconut water |
| Air Kelapa | Coconut water |
| | |
| | |

5) Outpun Dan Faedah Projek

(a) Penerbitan (*termasuk laporan/kertas seminar)*
*(Sila nyatakan jenis tajuk, pengarang tahun terbitan dan di mana telah diterbit/dibentangkan)*

The results of the study indicated that fluid replacement after exercise-Induced dehydration with sodium enriched coconut water was as effective as the commercial Sports drink and was better than coconut water and plain water during 2-hour rehydration period.

Two Presentations:

Ishak Ismail, Rabindarjeet Singh, Roland Gamini Sirisinghe and Mohammad Nawawi Yasin (2003)
Rehydration with sodium enriched coconut water after exercise-induced dehydration
*18th Scientific Meeting of the Malaysian Society of Pharmacology and Physiology, Kuala Lumpur*

Ishak Ismail, Rabindarjeet Singh, Roland G, Sirisinghe (2003)
Can Coconut water be the Natural Sports Drink?
*4th National Conference on Medical Sciences, Kota Bharu*

Manuscript:

Rehydration with sodium enriched coconut water after exercise-induced dehydration (*in final stages*)

(b) Faedah-Faedah Lain Seperti Perkembangan Produk, Prospek Komersialisasi Dan Pendaftaran paten.
*(Jika ada dan jika perlu, sila gunakan kertas berasingan)*

1) **Second Prize Poster Award** at 18th Scientific Meeting of the Malaysian Society of Pharmacology and Physiology, Kuala Lumpur

2) Postgraduate Thesis Award from the Nutrition Society of Malaysia

3) Received interest from companies on coconut water as a drink.

(c) Latihan Gunatenaga Manusia

i) Pelajar Siswazah: Tiada

ii) Pelajar Prasiswazah: M.Sc.: En Ishak Ismail

iii) Lain-lain: Teknologis makmal: Mohammad Nawawi Yasin

6. Peralatan Yang Telah Dibeli:

Tiada

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UNTUK KEGUNAAN JAWATANKUASA PENYELIDIKAN UNIVERSITI

3/1/11

Professor Zahidi Azhar Mohd. Hussin
Chairman ...
KELANTAN ...

TANDATANGAN PENGERUSI
JAWATANKUASA PENYELIDIKAN
PUSAT PENGAJIAN

**Abstract**

This cross over study assessed the effectiveness of plain water (PW), sports drink (SD), young coconut water (CW) and sodium enriched young coconut water (SCW) on whole body rehydration (R), plasma volume (PV) restoration after exercise-induced dehydration. Ten healthy male subjects (age range, 19 – 27 years) were exercised at 65% of $VO_{2max}$ at an environmental temperature of 32.06±0.02°C which a relative humidity (RH) of 53.32±0.17% for 90 minutes until 3.08± 0.04% (1.83±0.10 kg) of their body weight was loss. After which, the subjects moved to the thermoneutral environment (23.2±0.3°C) and rested for 30 minutes prior to begin the 2-hour R period. During R. Subjects drank either PW, SD, CW or SCW in randomized representing 120% of the fluid lost in three boluses representation 50% (915±54 ml), 40% (732± 37ml) and 30% (556±35 mL) of the fluid lost at 0, 30, 60-min respectively. In all the trials subject were somewhat hypohydrated (range 0.32 – 0.52 kg) body weight (BW) below euhydrated BW after the 2-h R period. The percent body weight loss that was regained (used as index of percent rehydration) during PW, SD, CW and SCW was 58±2%, 68±2%, 65±2% and 69±1% respectively with a significant better rehydration with SD and SCW than PW ($p<0.05$). The rehydration index (RI) for SD and SCW was significantly lower than PW ($p<0.01$). PV was restored similarly to euhydration levels after 2-h of rehydration with SD, CW and SCW but was significantly lower ($p<0.05$) with PW trials. Cumulative urine output was significantly higher for PW when compare to SD and SCW ($p<0.05$). Serum $Cl^-$ were significantly higher with CW and SCW trials ($p<0.05$). Serum $Na^+$, serum $K^+$, serum $Cl^-$ and serum and urine osmolality of PW trial were significantly lower ($p<0.05$) than SD, CW and SCW at the end of 2-h

R period. Plasma glucose concentration were significantly higher when SD, CW and SCW were ingested during rehydration compared to PW ($p<0.01$). SCW were similar in sweetness with CW and SD but caused less nausea and stomach upset when compares either SD or PW, furthermore SCW was easier to consume in large volume. In conclusion, ingesting SCW was as good as ingesting a commercial sports drink for whole body rehydration after exercise-induced dehydration but with better fluid tolerance.

**Keywords**: Exercise-induced dehydration, fluid replacement, rehydration, sodium enriched coconut water.

## Introduction

Rapid and complete restoration of fluid balance after exercise is an important part of the recovery process and becomes even more important in hot humid conditions and if repeated bouts of exercise have to be performed. Heavy sweating during exercise especially in heat can cause body fluid losses in excess of 1 liter per hour [1]. Following dehydration individuals must ingest sufficient fluids to recover from their hypohydrated state and be back to a state of euhydration. The choice of drinks to be consumed after exercise may be different depending on the individual and circumstances. Replacement of substrate in addition to water and electrolytes losses may be a concern in the period after exercise in preparation for a further bout of exercise or competition.

It is often reported that exercise performance is impaired when an individual is dehydrated by as little as 2% of body weight [2], and that losses in excess of 2.5% of body weight can decrease the capacity for high intensity work by about 15 % for exercise lasting 7 minutes [3]. Fluid losses are distributed in varying proportions among the plasma, extracellular water and intracellular water. The decrease in plasma volume which accompanies dehydration may be of particular importance in influencing work capacity. Blood flow to the muscles must be maintained at a high level to supply oxygen and substrates, but a high blood flow to the skin is also necessary to convect heat to the body surface where it can be dissipated [4]. When the ambient temperature is high and blood volume has been decreased by sweat loss during prolonged exercise, there may be difficulty in meeting the requirement for a high blood flow to both these tissues. In this situation, skin blood flow is likely to be compromised, allowing central venous pressure and muscle blood flow to be maintained but reducing heat loss and causing core body temperature to rise [5].

Rehydration after exercise requires replacement of electrolytes, primarily sodium, lost in sweat [3, 6, 7, 8, 9]. Ingestion of plain water results in a rapid fall in plasma sodium concentration and in plasma osmolality [10, 4]. These changes have the effect of reducing the stimulus to drink (thirst) and of stimulating urine output, both of which will delay the rehydration process [11]. It is clear from the results on various studies, that rehydration after exercise can be achieved only if sweat electrolyte losses as well as water are replaced [12, 11, 41]. The sodium content of most of the major commercial sports drink is in the range 10 – 20 $mmol.L^{-1}$ [4]. Most commonly consumed soft drinks contain virtually no sodium, and these drinks are therefore unsuitable when the need for rehydration is crucial.

The requirement for sodium replacement stems from its role as the major ion in the extracelullar fluid. It may be speculated that inclusion of potassium, the major cation in the intracellular space, would enhance the replacement of intracellular water after exercise and thus promote rehydration [13]. The inclusion of potassium has been shown to be as effective as sodium in retaining water ingested after exercise-induced dehydration, in spite of the low levels of potassium lost through sweat [7]. Most commonly available sports drinks contain significant amount of potassium together with other electrolytes, often in concentrations similar to those estimated to be present in sweat [4].

Many special formulation drinks have been used as rehydration drinks after exercise-induced dehydration [14-15, 16]. However, recently naturally occurring fruit drink such as young coconut water has been used as rehydration drink [17]. This natural young coconut drink which has low sodium content but high potassium content [18-19, 20] has been shown to have a fairly low rehydration index. The question whether the addition of sodium to the natural young coconut water to make it a better rehydration drink has not been studied.

Coconut water contains all major electrolytes but with a high potassium content. However, in contrast, the sodium content of coconut water is lower than most sports drink[17, 21, 18]. Due to coconut water having a low sodium content (5 – 10 $mmol.L^{-1}$), the purpose of this study was, therefore, to investigate the effectiveness of young coconut water with addition of sodium made up to 20 mmol, equivalent to the sodium content of a sports drink as a rehydration drink after exercise-induced dehydration on whole body rehydration. The effectiveness of sodium enriched coconut water was compared with a sports drink, plain young coconut water and plain water.

## Material and Methods

### Subjects

Ten healthy male physically active subjects were selected from a group of trainee Physical Education teacher population for this study. The study protocol was approved by the Universiti Sains Malaysia Ethics Committee. All the subjects completed all trials. Their mean (±SEM) age, body weight, height, and maximal oxygen uptake ($VO_{2max}$) were 20.7 (±0.9) yrs, 60.2 (±2.6) kg, 169 (±1.6) cm and 59.9 (±1.0) $ml.kg^{-1}.min^{-1}$ respectively. Before participating in the experimental trials, the nature and risks of the experimental procedures were explained and written informed consent was obtained.

### Preliminary testing

Each subject was required to run on a motorised treadmill (Quinton 18-60, USA) at four different submaximal speeds to obtain the oxygen consumption. $VO_{2max}$ was determined using a continuous incremental running protocol on a treadmill until volitional exhaustion[42]. From the data obtained in the submaximal exercise test and the $VO_{2max}$ test, the speed which would elicits 65% $VO_{2max}$ of a subject was calculated. The subjects completed a familiarization trial, simulating the experimental conditions one week before starting the four experimental trials.

### Experimental Design

All experimental trials began at 9.00 in the morning and subjects were required to abstain from strenuous exercise for at least 48 hours prior to each trial. Four experimental trials were undertaken by the subjects which were separated by at least 2 weeks between each trial. To eliminate any training effect, the cross-over randomized counterbalance method was used. Each subject consumed a standardized breakfast and drank 500 mL of water two hours before each exercise trial to ensure a normal hydration status [22].

On reporting to the laboratory, subjects voided their bladder as completely as possible and the entire volume was collected and measured. Nude body weight, was then measured (Tanita, TBF-410, Japan). Subject then sat in a normal temperature room of 23°C (± 0.3) for 15 minutes before, a Teflon venous catheter was inserted into a forearm vein, fitted with a three-way stopcock for blood sampling without stasis. This catheter remained in place for the remainder of the study. An initial blood sample was obtained. This blood sample represented the euhydrated state and was analyzed for hemoglobin, hematocrit, serum osmolality and serum electrolytes ($Na^+$, $K^+$ and $Cl^-$).

At 0900 hrs the subjects then began the exercise in a hot environment (32±0.1°C, RH 53±0.2%) at a pre-determined intensity of 65% $VO_{2max}$ for 90 minutes to dehydrate ~3% body weight. Immediately after completion of the dehydration exercise, a second blood sample was obtained while the subject remained on the treadmill. Subjects were then allowed 10 minutes to move and sat in a thermoneutral room (23.2±0.3°C, RH 70±0.4%) which was then followed by determination of the second nude body weight after the subjects had completely wiped the sweat. Thirty minutes after exercise and after twenty minutes of sitting, a third blood sample was obtained which represented the dehydrated state. A second urine sample was then collected followed by the determination of the third nude body which represented the dehydration level. Immediately afterwards, subjects consumed one of the rehydration beverages. The subjects drank the beverage in a volume (in milliliters) equal to the mass (in grams) that was equivalent to 50% of the fluid loss during exercise-induced dehydration trial. This signaled of the beginning of the 2 h rehydration period. Thirty minutes later, the subjects drank 40% of the fluid loss and the remaining 30% of the rehydration beverages necessary to replace 120% of the fluid lost, was ingested at 60 minutes post-exercise. Blood and urine samples were collected at 30-minute intervals. After each fluid ingestion, and at 0, 30, 60, 90 and 120-min the subjects were shown a fluid sensation scale (scale 1 to 5) to determine their thirst status, sweetness of the drink, feeling of nausea, their sense of stomach fullness and stomach upset which was adapted from Peryam & Pilgrim [23]. At the end of the 2-h rehydration period, a final nude body weight was obtained after completely emptying the bladder.

**Beverages**

Four types of beverages were used during this study. They were fresh young coconut water (CW), sodium enriched young coconut water (SCW), sports drink (SD) (Isomax – Ace Canning Corp. Sdn. Bhd) and plain water (PW). The compositions of the beverages used are listed in Table 1. Fresh young coconut water was obtained from Green Malayan Tall Species. An average of four coconuts was used from the same bunch to obtain 3000 ml of fresh coconut water for each trial, which were thoroughly mixed. To prepare the sodium enriched young coconut water, the 3000 ml from the four young coconuts fruits were first measured for its sodium content using flame photometer (Corning 450 – USA). After the sodium content determination, sodium chloride was added to increased the sodium contain of the coconut water to a level equivalent to approximately 20 $mmol.L^{-1}$ , which is similar to that found in the sports drink. The sodium content of sports drinks which was used in this study contained approximately 20 $mmol.L^{-1}$. For the sports drink, the cans were opened and poured into a container to degas the drinks two to three hours before consumption. This was to ensure that the subjects did not suffer from stomach discomfort as a result of the gas (Ryan et al., 1991., Passe, et al 1997). All the beverages were kept cool in refrigerator at temperature 7°C and were given in random order.

**Analytical procedures**

1 mL from the 3mL of the blood was transferred immediately into a EDTA tube and used for measurement of haematocrit and haemoglobin levels. Haematocrit was determined in triplicate after centrifugation in a micro-haematocrit centrifuge (Hettich-Haematokrit 20, Germany). Haemoglobin (Hb) was analyzed by the cyanmethemoglobin method (Drabkins reagent). The percentage of change in plasma volume was calculated using changes in haematocrite and haemoglobin according to Dill and Costill (1974). Another one milliliter (1 mL) of blood was transferred into tube containing Natrium Fluoride (NaFl) and the balance 1 mL was transferred into a plain tube. Plasma and serum were separated by bench-top centrifugation (Hettich-Rotina 46 RS., Germany at 15,000 rpm) at 10,000 rpm for 10 min. Plasma, serum and urine were stored at -20°C for later analysis. Glucose

was analysed using glucose kits enzymatic calorimetric method (Randox-Germany). Serum and urine sodium ($Na^+$), potassium ($K^+$) were measured using flame photometer (Corning, 450. USA) and chloride ($Cl^-$) was measured using ion selective electrode analyser (Hitachi, 912 Random Access Chemistry Analyzer-Japan) Serum and urine osmolality was measured by freezing depression (Osmomat 030, Gonotec, Germany).

**Cumulative Urine Output**

Total urine collected at selected time intervals was recorded and accumulated during 2- hour rehydration period [7], which did not included before and after exercise urine samples.

**Net Fluid Balance**

Net fluid balance was calculated based on body mass loss during exercise-induced dehydration, total volume of fluid ingested and cumulative urine volume voided.

**Percent of body weight loss**

Percent of body weight loss through exercise was calculated from the difference of nude body weight before and after exercise-induced dehydration divided by with nude body weight before exercise multiplied by 100, on the assumption that one liter of fluid is equivalent to one kilogram of body weight.

**Table 1** Nutrient composition, osmolality, specific gravity and pH of plain water, sports drink, young coconut water and sodium enriched young coconut water. Data presented as Mean±SEM

| Constituent | PW | SD | CW | SCW |
|---|---|---|---|---|
| Glucose ($mmol.L^{-1}$) | - | 204.1±19.5*+ | 167.9±3.9 | 165.5±3.6 |
| $Na^{+}$ ($mmol.L^{-1}$) | - | 20.0±0.2* | 9.0±0.1+ | 20.1±0.2* |
| $K^{+}$ ($mmol.L^{-1}$) | - | 3.5±0.1*+ | 50.7±1.6a | 51.9±0.6a |
| $Cl^{-}$ ($mmol.L^{-1}$) | - | 10.6±0.1*+ | 34.9±0.6a | 44.0±1.4a |
| Osmolality ($mOsm.kg^{-1}$) | - | 321.0±1.2*+ | 384.5±7.7a | 411.6±12.8a |
| pH | 7.3±0.1 | 3.5±0.0*+ | 4.6±0.1a | 4.7±0.1a |
| Specific Gravity | - | 1.026* | 1.020 | 1.026 a |

PW = Plain water
SD = Sports drink
CW = Young coconut water.
SCW = Sodium enriched young coconut water.
* , significantly different from young coconut water at $p<0.01$.
+, significantly different from sodium enriched young coconut water at $p<0.01$
a, significantly different from sports drink at $p<0.01$.

Breakfast at 8.00 am, resting period start at 8.15am, exercise start at 9.00 am to 10.30 am – followed by a recovery period for 150min.

**Blood sample collection.**
**Before exercise, end of exercise, and during recovery period at 30-, 60-, 90- 120- and 150-min**

Time (min)- 15 | 0 | 30 | 60 | 90 | 30 | 60 | 90 | 120 | 150

← Exercise → | ← Rehydration Period →

**Nude body weight**
**Before exercise, after exercise, 30-min post exercise (dehydration level), and 150-min post exercise**

| | | |
|---|---|---|
| Resting (Temperature: 25 °C, 60% RH) | Running for 90 min at 60 % $\dot{V}O_{2max}$ Temperature: 32 °C, 70% RH | Recovery Period 22 °C, 60% RH Thermoneutral Environment |
| Base line recording on HR | Every 10 min: HR, Temperature (rectal, skin, environment) | Recording on HR, Temp. |
| | | |
| Urine collection and measurement (Before exercise) | | Urine collection and measurement at 30-min (dehydration level), 60-, 90-, 120-, 150- min. |
| | | 30- 60- 90- min |
| | | Fluid ingestion: (Every 30 min)<br>30-min post exercise (50% of fluid lost)<br>60-min post exercise (40% of fluid lost)<br>90-min post exercise (30% of fluid lost) |
| 48 hours no strenuous exercise, record dietary intake and physical activity for 2 days before first experiment trial, subjects dietary intake and physical activity were then replicate for each of the subsequence experimental trials | | |
| 4 experimental trials are separated by interval of two weeks. First trial either water, carbohydrate-electrolyte beverage, CW or sodium enriched CW. Order of test condition was a cross-over randomised counterbalance method. | | |

**Fig. 1** Research protocol. Rehydration with sodium enriched coconut water after exercise induced dehydration

**Percent rehydration**

The percent of body weight loss that was regained was used as an index of whole body rehydration (percent rehydration). The percent rehydration represented the amount of ingested fluid that was retained in the body at the end of two hours rehydration protocol [11].

$$\% \text{ Rehydration} = \left[ \frac{\text{BWlost during exercise} - (\text{BWeuh} - \text{Bwreh}) \text{ (kg)}}{\text{Fluid intake (kg)}} \right] \times 100$$

BWeuh represented the nude body weight in euhydrated conditions (before exercise) and BWreh represented nude body weight at the end of 2 h rehydration period.

**Reydration index**

Rehydration index (RI) provided an indication of how much of what was ingested actually was used for body weight restoration (Mitchell *et al.*, 1994).

$$\text{RI} = \frac{[\text{ vol. admin. (ml) / wt. gain (g) }]}{[\%\text{ rehydration /100 }]}$$

**Nutrient composition of beverage.**

All samples of the beverages that were consumed during all trials were stored -20°C and later analyzed of $Na^+$ and $K^+$ using Flame Photometer. $Cl^-$ and osmolality of the beverages were measured using ion selective electrode and the cryoscopic osmometer (Osmomat 030, Gonotec, Germany) respectively.

**Statistical analysis.**

All data were analyzed using two-way analysis of variance (ANOVA) for repeated measurement. The significant differences between the four trials at difference times were determined with Tukeys minimum significant difference (MSD) test. Differences was considerd significant at $p>0.05$. All values are reported as means ± Standard Error of Measurement (SEM) of 10 subjects. The Statistical Package for Social Science (SPSS) programme was used for statistical analysis.

## Results

**Body weight changes, fluid intake, percent rehydration and rehydration index.**

On average, the subjects lost 3.08 ± 0.04% of their euhydrated body weight after exercise-induced dehydration procedure in the heat. The total volume of fluid consumed during the 2-hour rehydration period were 2196±269 ml, 2196±116 ml, 2304±150 ml and 2196±142 ml in the PW, SD, CW and SCW trials respectively with no significant differences between trials. At the end of the 2-hour rehydration period, the subjects were still somewhat hypohydrated in all trials (range at -0.32 to -0.52kg below the euhydrated body weight). The hypohydration was significantly greater ($p>0.05$) with PW when compared to the trials. Incompleted rehydration resulted from fluid loss during the rehydration period in urine, sweat and respiration.

The percent rehydration at the end of the 2-hour rehydration period was significantly higher with SD ($p<0.01$), SCW ($p<0.01$) and CW ($p<0.05$) when compared to PW (Fig. 2). The rehydration index (RI) was calculated as 2.50 ± 0.15, 1.80 ± 0.09, 2.00 ± 0.10 and 1.75 ± 0.07 for PW, SD, CW and SCW respectively. The RI which was calculated as 1.75 ± 0.07 for SCW was similar to the SD trial (1.80 ± 0.09) but lower than the CW trial (2.00 ± 0.10). RI for PW was significantly higher ($p<0.01$) when compared to the other trials.

**Changes of plasma volume**

Changes in plasma volume at the result of exercise-induced dehydration and during the 2-hour rehydration period are shown in Fig. 3. Similar responses were observed in all trials at the end of the 90-min exercise-induced dehydration period. At the end of rehydration period, plasma volume during CW, SCW and SD were similar to euhydrated plasma volume. Plasma volume in the PW was -3.2±0.5%, lower ($p<0.01$) than euhyrated plasma volume at the end of the rehydration period which was also significantly different ($p<0.05$) from SD and SCW trials.

**Urine volume and osmolality**

Cumulative urine volume at the end of the 2-hour rehydration period (Fig. 4) was significantly lower ($p<0.05$) after ingestion of SD (416.2 ± 57.1 mL) and SCW (440.4 ± 35.2 mL) when compared to PW (590.7± 48.40 mL) but it was not significant different from CW (513.8 ± 50.7 mL).

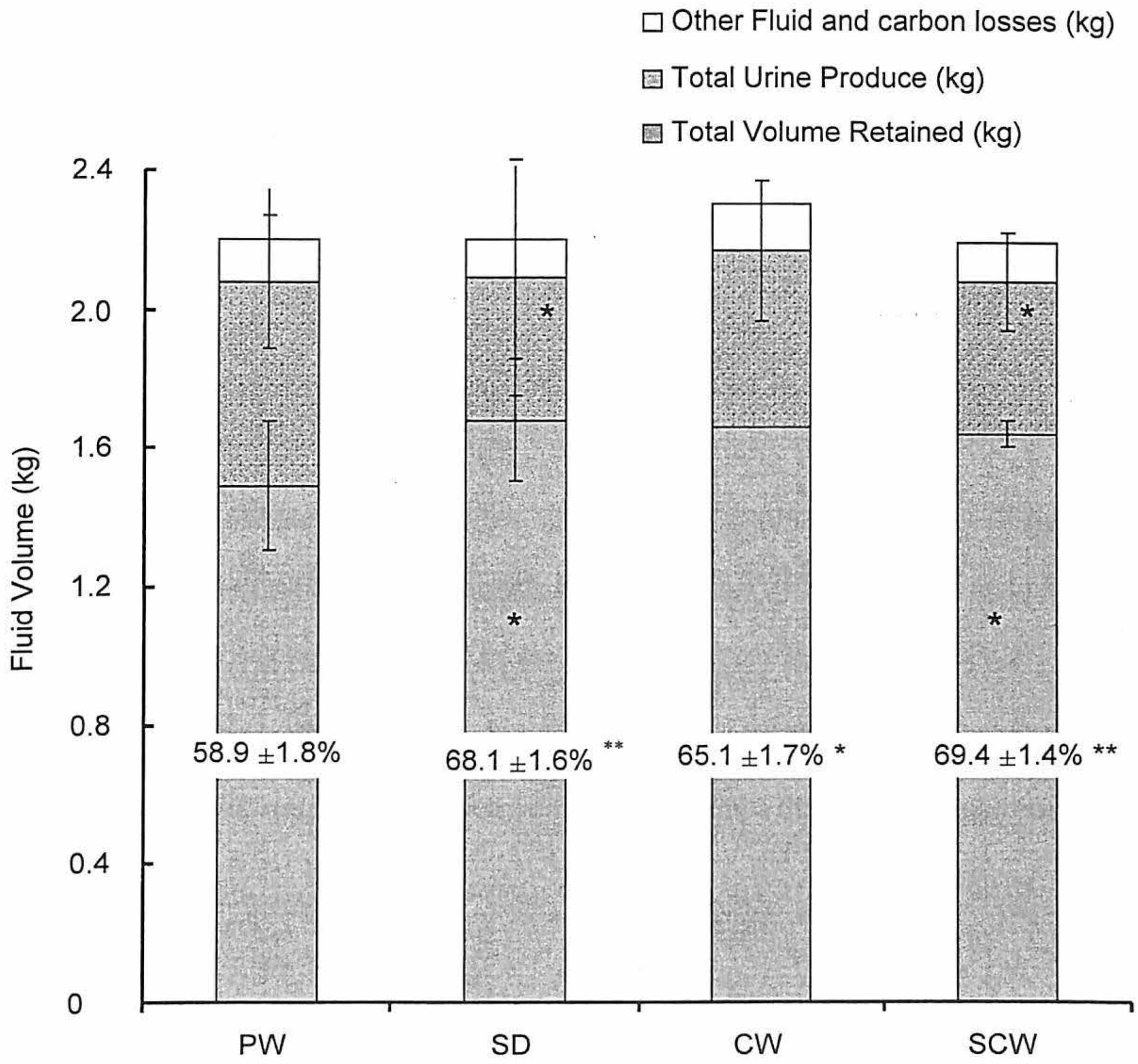


**Fig. 2** Fate of ingested volume when comparing PW, SD, CW and SCW. The height of the graph represents the total amount of fluid consumed (kg). The stacked bars represent the fate of the ingested volume: the ingested fluid was either retained in the body or lost in the form of urine, sweating, and respiration.

*, **, significantly different from PW at $p<0.05$ & $p<0.01$ respectively.

Urine osmolality at the end of 90-min exercise-induced dehydration was similar in all trials (Fig. 5). During the first 30 min of the rehydration period the urine osmolality was significantly higher ($p<0.01$) for all trials after which urine osmolality began to decrease. At the end 2-hour rehydration period, urine osmolality of the PW trial was significantly lower ($p<0.05$) when compared to SD and SCW.

**Net fluid balance**

Net fluid balance was negative at the end of exercise-induced dehydration exercise with no significant differences between trials (Fig. 6). Net fluid balance was positive with the SD (108.5 ± 41.89 mL) and SCW (66.1 ± 32.86 mL) trials at 90 min of the rehydration period. However at the end of the 2-hour rehydration period, all trials had negative balance with no significant differences between trials.

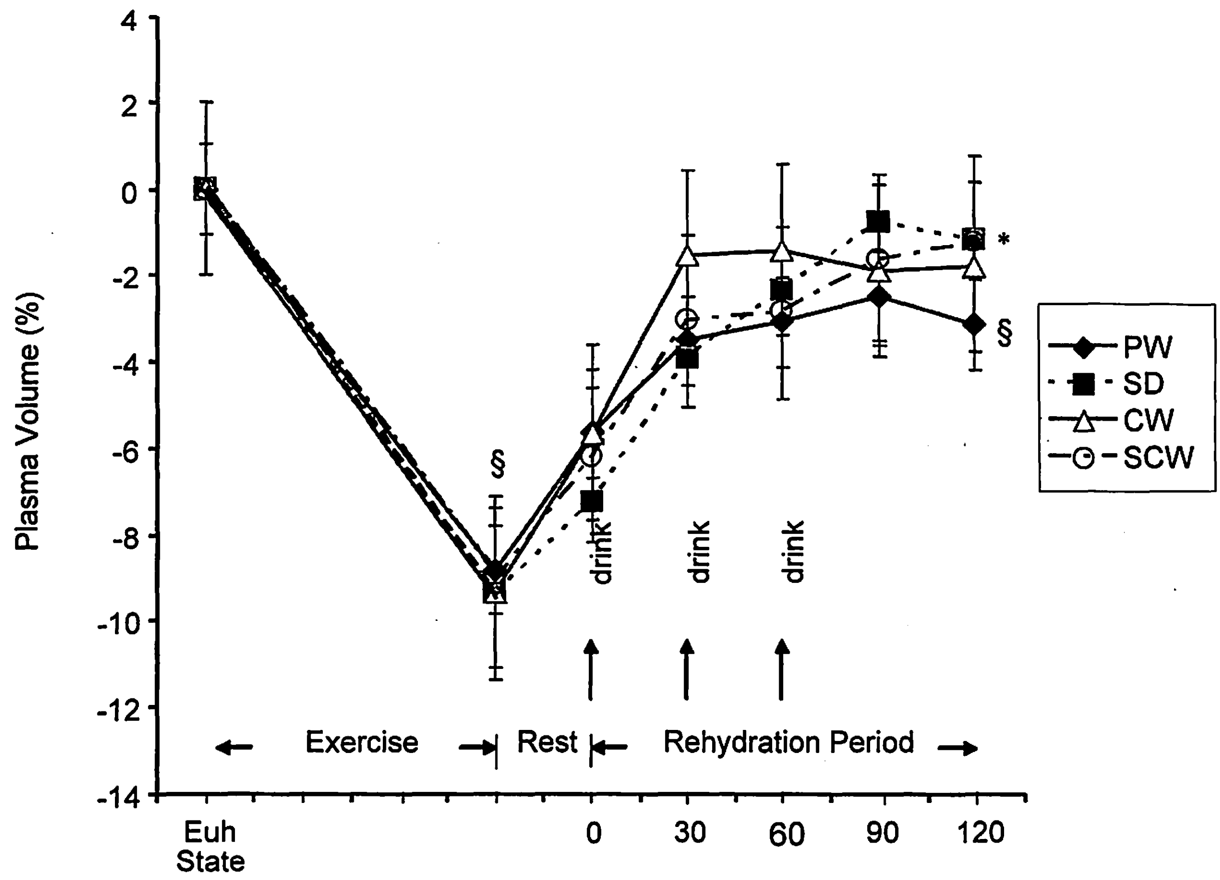


**Fig. 3** The change in plasma volume after exercise-induced dehydration and during 2-h rehydration period. All values are expressed as a percent change from the resting (euhydrated state).
§ significantly different from plasma volume in the euhydrated state at p<0.01. *, significantly different from PW at p<0.05.

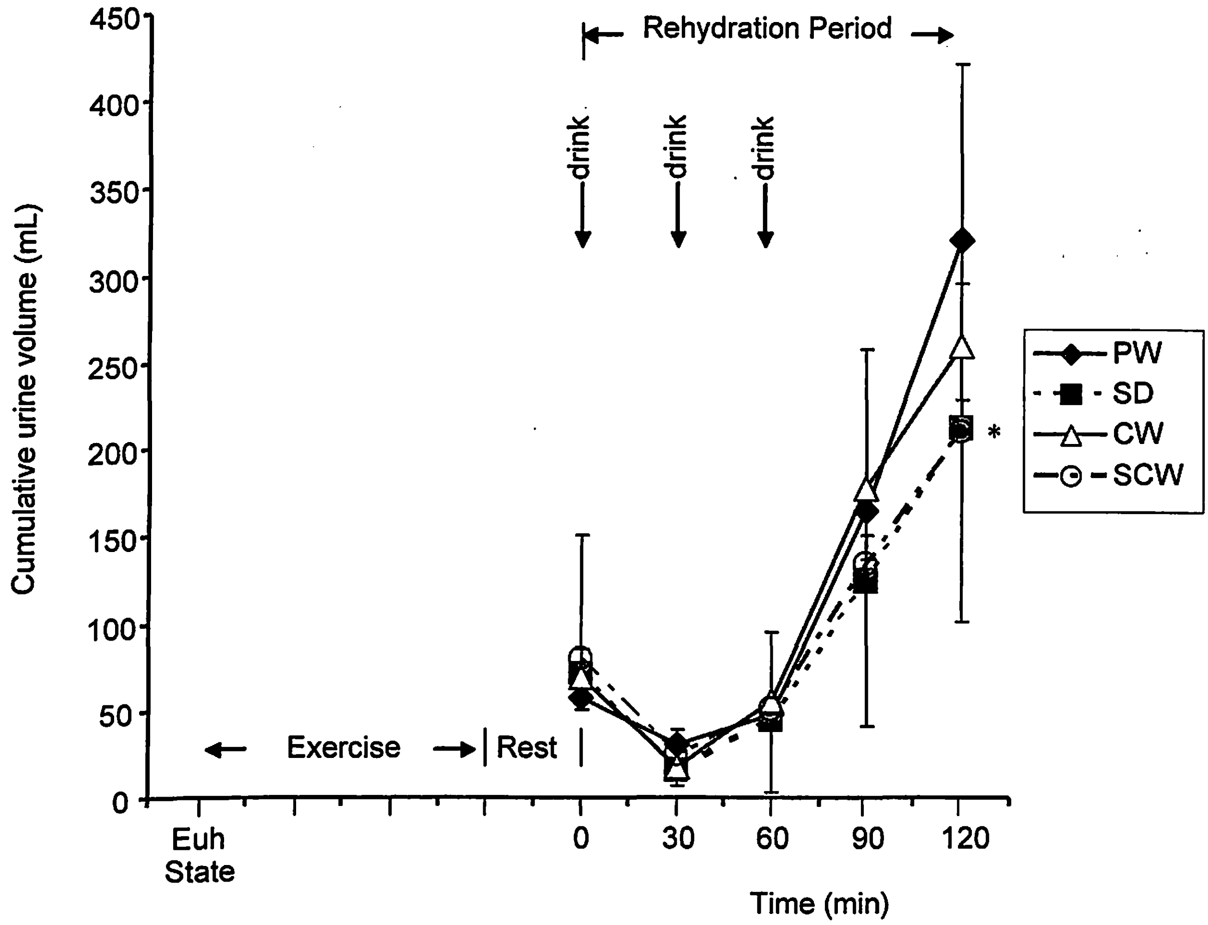


**Fig. 4.** Cumulative urine volume over time. The pre-exercise and samples obtained after exercise-induced dehydration was not included in the calculation of cumulative urine volume.
*, significantly lower from PW at $p<0.05$

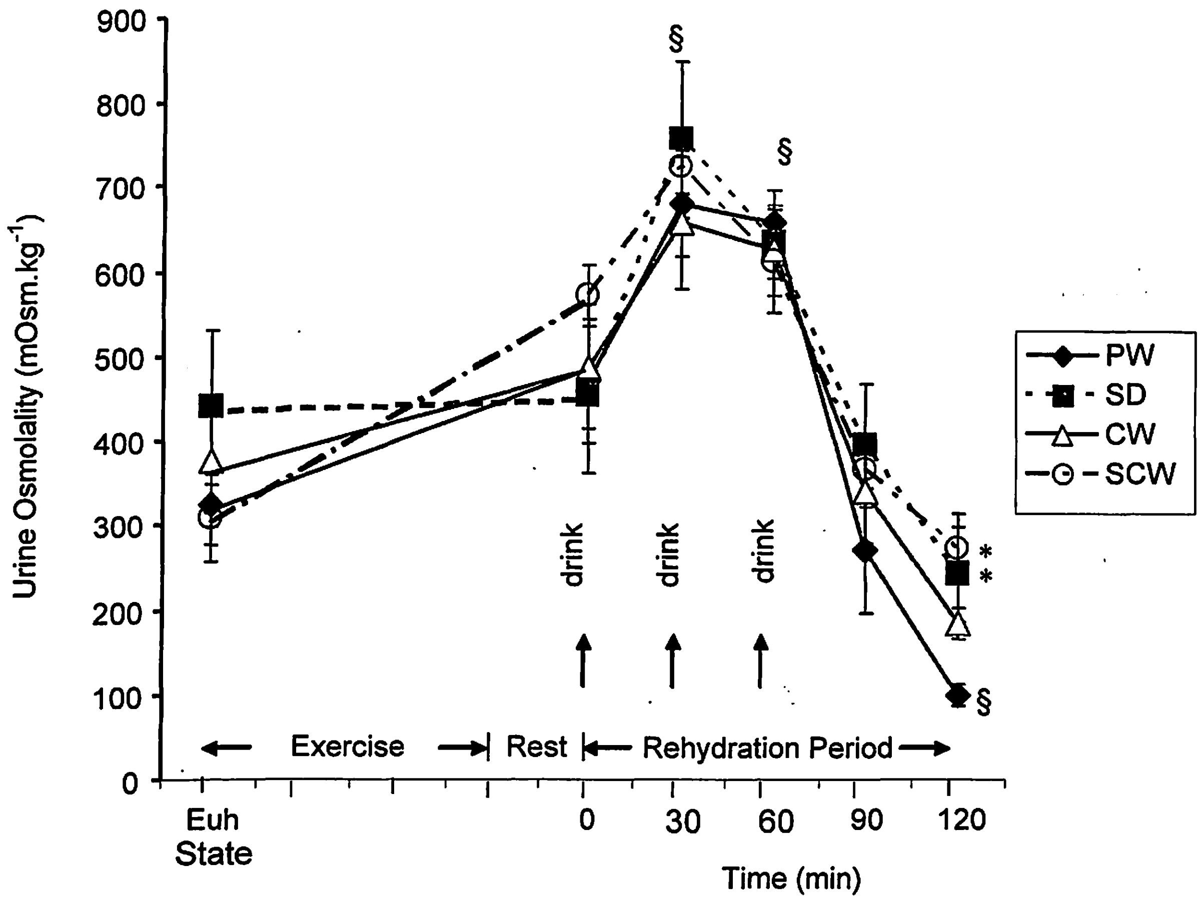


**Fig. 5** Urine osmolality response after exercise-induced dehydration and during 2-hour rehydration period. §, significantly different from Euh State at $p<0.01$. *, significantly different from PW at $p<0.05$.

**Serum sodium ($Na^+$) potassium ($K^+$) and chloride ($Cl^-$) concentrations**

Serum $Na^+$ was significantly higher after exercise-induced dehydration in all trials when compared to the pre-exercise euhydrated state. During the rehydration period, the sodium returned to the euhydrated levels in all trials. However, the sodium was significant lower in the PW trial when compared to the other three (Fig. 7). Serum potassium $K^+$ levels were significantly higher in all trials at the end of the exercise-induced dehydration period ($p<0.05$). There were no significantly differences in the $K^+$ levels between CW and SCW at any time point but the $K^+$ levels were significantly higher ($p<0.01$) than the PW and SD after 60-min during the rehydration period (Fig. 8). Serum chloride ($Cl^-$) concentrations were significantly higher ($p<0.05$) with CW and SCW when compared to SD and PW at the end of the 90-minute exercise-induced dehydration (Fig. 9).

**Serum Osmolality**

Serum osmolality were significantly higher ($p<0.01$) at the end of 90-minute exercise-induced dehydration period in all trials when compared to the pre-exercise euhydrated levels (Fig. 10). At the end of the 2-hour rehydration period serum osmolality returned to a level that was not significantly different from the euhydrated values in all trials except for PW. Serum osmolality of the PW trial was significantly lower ($p<0.05$) from euhydrated state at 90 and 120-min of the rehydration period which were also significant lower ($p<0.05$) from the other three trials.

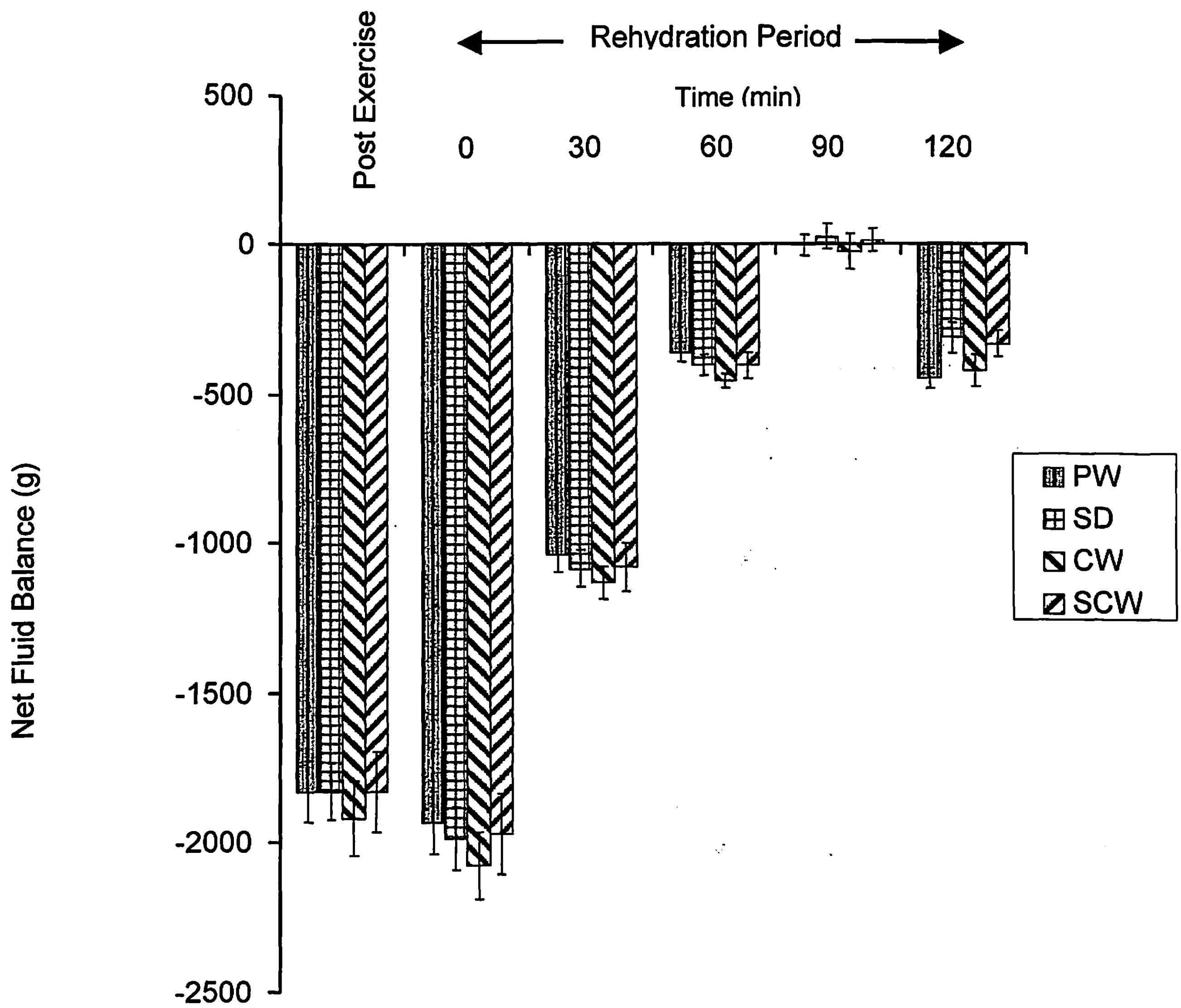


**Fig. 6** Net fluid balance during the 2-hour rehydration period. Drink volume ingested were 50%, 40%, and 3% of 120% fluid loss during exercise-induced dehydration at 0, 30 and 60-min of rehydration period respectively. Zero net fluid balance is state of euhydration.

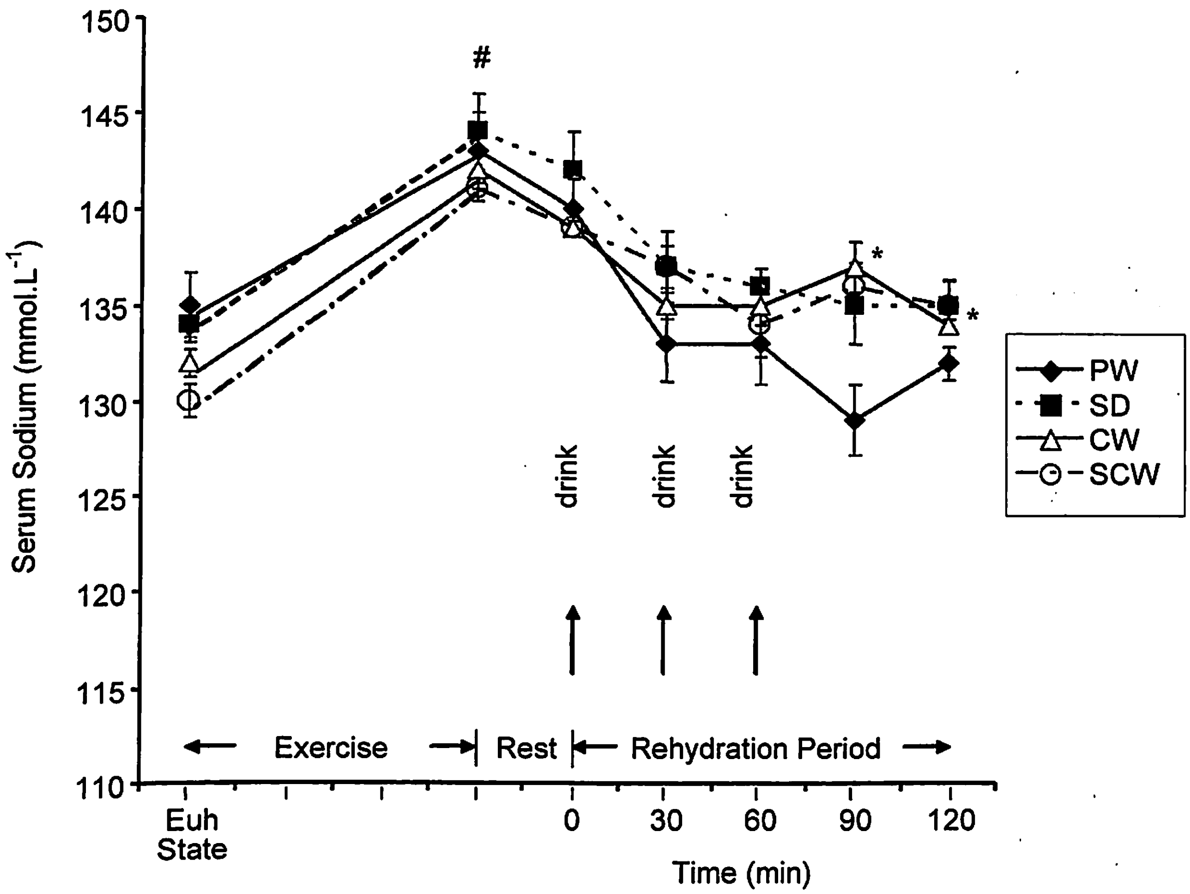


**Fig. 7** Serum sodium responses after exercised-induced dehydration and during the 2-hour rehydration period.
# significantly different from Euh State at p<0.05.
* significantly different from PW at p<0.05