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

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Abstract. This crossover study assessed the effectiveness of plain water (PW), sports drink (SD), fresh young coconut water (CW) and sodium-enriched fresh young coconut water (SCW) on whole body rehydration (R) and plasma volume (PV) restoration after exercise-induced dehydration. Ten healthy male subjects ran at 65% of VO_{2max} in an environmental temperature of 32.06±0.02ºC with a relative humidity (rh) of 53.32±0.17% for 90 minutes to lose 3% body weight (BW). During the 2-hour rehydration period, subjects drank, in randomized order, PW, SD, CW or SCW equivalent to 120% of BW lost in three boluses representing 50, 40 and 30% of the fluid lost at 0, 30, and 60 minutes, respectively. In all trials subjects were still somewhat dehydrated even after the 2-hour rehydration period. Indexes of percent rehydration with PW, SD, CW and SCW were 58±2, 68±2, 65±2 and 69±1%, respectively, with significantly better rehydration with SD and SCW. The rehydration indexes for SD and SCW were significantly lower than PW ($p<0.01$). PV was restored to euhydration levels after 2 hours of rehydration with SD, CW and SCW but not with PW. The plasma glucose concentration were significantly higher when SD, CW and SCW were ingested. SCW was similar in sweetness to CW and SD but caused less nausea and stomach upset compared to SD and PW. 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.

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 when 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 (Costill, 1977). Following dehydration individuals must ingest sufficient fluids to recover from their dehydrated state. The choice of drink after exercise differs depending on the individual and the circumstances. Replacement of substrate in addition to water and electrolytes is a concern after exercise in preparation for further exercise or competition.

Exercise performance is impaired when an individual is dehydrated by as little as 2% of body weight (Murray, 1998), and 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 (Maughan and Leiper, 1995). 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 convert heat to the

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body surface where it can be dissipated (Maughan,1999). 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 requirements for a high blood flow to both these tissues. In this situation, skin blood flow is likely to be compromized, allowing central venous pressure and muscle blood flow to be maintained but reducing heat loss and causing core body temperature to rise (Rowell, 1986).

Rehydration after exercise requires replacement of electrolytes, primarily sodium, lost in sweat (Costill *et al,* 1976; Maughan *et al,* 1994; Maughan and Leiper, 1995; Shireffs *et al,* 1996; Ray *et al,* 1998). Ingestion of plain water results in a rapid fall in plasma sodium concentration and in plasma osmolality (Maughan, 1999; Nose *et al,* 1988a). 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 (Gonzalez-Alonzo *et al,* 1992). It is clear from the results of various studies that rehydration after exercise can be achieved only if electrolytes as well as water are replaced (Pradera, 1942; Hubbard *et al,* 1985; Gonzalez-Alonzo *et al,* 1992). The sodium content of most of the major commercial sports drinks is in the range 10-20 mmol.l^{-1} (Maughan, 1999). The most commonly consumed soft drinks contain virtually no sodium, and are therefore unsuitable for rehydration.

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 (Nadel *et al,* 1990). 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 (Maughan *et al*, 1994). The most commonly available sports drinks contain a significant amount of potassium along with other electrolytes, often in concentrations similar to those estimated to be present in sweat (Maughan, 1999).

Many special formulation drinks have been used as rehydration drinks after exercise-induced dehydration (Gisolfi *et al,* 1992; Murray *et al,* 1999; Coombes and Hamilton, 2000). However, recently young coconut water has been used as a rehydration drink (Saat *et al,* 2002). It has a low sodium content but a high potassium content (Iqbal, 1976; Olurin *et al,* 1972; Campbell-Falck *et al,* 2000) and has been shown to have a fairly low rehydration index. The question of 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 the major electrolytes but has a high potassium content. The sodium content of coconut water is about 5-10 mmol.l^{-1}, which is lower than most sports drinks (Iqbal, 1976; Adam and Bratt, 1992; Saat *et al,* 2002). The purpose of this study was to investigate the effectiveness of young coconut water with added sodium as a rehydration drink after exercise-induced dehydration for whole body rehydration. The effectiveness of sodium-enriched fresh coconut water was compared with that of a sports drink, plain fresh coconut water and plain water.

MATERIALS AND METHODS

Subjects

Ten healthy physically active male subjects participated in this study. Their physical characteristics (mean±SEM) were: age 20.7±0.9 years, body weight (BW) 60.2±2.6 kg; height 169±1.6 cm, and maximal oxygen uptake (VO_{2max}) 59.9±1.0 ml.kg^{-1}.min^{-1}. Before participating in the experimental trials, the nature and risks of the experimental procedures were explained and written informed consent was obtained. The study was approved by the Universiti Sains Malaysia Ethics Committee.

Experimental procedures

The study had a randomized crossover counterbalance design. The subjects participated in four experimental trials, at least 2 weeks apart.

Initial procedure

On the preliminary test, each subject performed a continuous incremental exercise test on a motorized treadmill (Quinton 18-60, USA) until volitional exhaustion to determine VO_{2max} (Taylor *et al*, 1955).

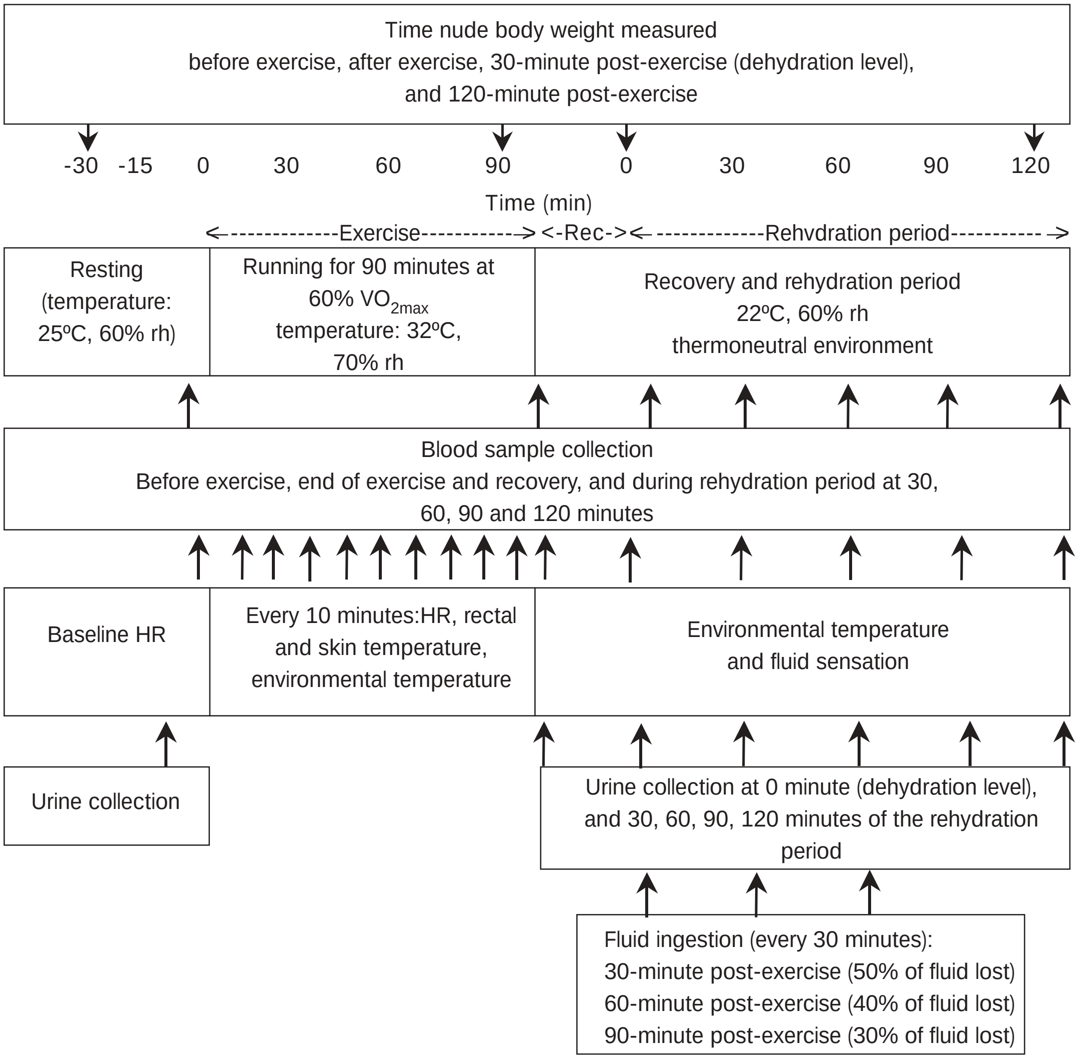
Experimental design

The subjects arrived at the laboratory at 7:00 AM and consumed a standardized breakfast and drank 500 ml of water before each exercise trial to ensure a normal hydration status (ACSM, 1996). An hour later, subjects then voided their bladder as completely as possible and a nude BW was then measured on a precision scale (Tanita, TBF-410, Japan, weighing accuracy of ±10g). Thereafter, a teflon venous catheter was inserted into a forearm vein, fitted with a three-way stopcock for repeated blood sampling. This catheter remained in place for the remainder of the study. An initial blood sample was obtained, which represented the euhydrated state.

At 9:00 AM the subjects ran on a treadmill (Quinton 18-60, USA) at a pre-determined intensity of 65% VO_{2max} for 90 minutes in an environmental chamber (32±0.1ºC, rh 53±0.2%) to dehydrate by ~3% body weight. Immediately after completing 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 cool down and then sat in a thermoneutral room (23.2±0.3ºC, rh 70±0.4%) which was then followed by the determination of the second nude body weight after the subjects had completely dried their 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 weight, which represented the dehydration level. Immediately afterwards, subjects consumed one rehydration beverage. The subjects drank the equivalent of 50% of BW loss, which signaled the beginning of the 2-hour rehydration period. Thirty minutes later, the subjects drank 40% of BW loss, and the remaining 30% of the rehydration beverage necessary to replace 120% of BW loss was ingested at 60 minutes, similar to the rate of consumption as described previously (Kovacs *et al,* 2002). The prescribed volume of drink was always ingested within the first 5 minutes of the ingestion period. Blood and urine samples were collected at 30-minute intervals during the 2-hours rehydration period. After each fluid ingestion and at 90 and 120 minutes the subjects were shown a fluid sensation scale (scale 1 to 5), which was adapted from Peryam and Pilgrim (1957) to determine their thirst status, sweetness of the drink, feeling of nausea, their sense of stomach fullness and stomach upset. At the end of the 2-hour rehydration period, a final nude body weight was obtained after completely emptying the bladder (Fig 1).

Beverages

Beverages used in this study were fresh young coconut water (CW), sodium-enriched fresh young coconut water (SCW), a sports drink (SD) (Isomax, Ace Canning Corp Sdn Bhd, Malaysia) 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 young coconuts was used from the same bunch to obtain 3,000 ml of fresh coconut water for each trial, which were thoroughly mixed. To prepare the sodium-



4 experimental trials were separated by intervals of two weeks. First trial either water, carbohydrate-electrolyte beverage, fresh CW or sodium-enriched fresh CW. Order of test condition was a crossover randomized counterbalance method. Forty-eight hours before trial no strenuous exercise, dietary intake and physical activity for 48 hours before first experiment trial recorded, subjects dietary intake and physical activity were then replicated for each of the subsequent experimental arms of the trial.

Fig 1–Research protocol for dehydration and rehydration arms of the trial.

enriched fresh young coconut water, the 3,000 ml from the four coconuts fruits was first measured for its sodium content using a flame photometer (Corning 450, USA). After sodium content determination, sodium chloride was added to increase the sodium content of the coconut water to a level equivalent to approximately 20 $mmol.l^{-1}$, which was similar to that found in the sports drink. For the sports drink, the cans were opened and poured into a container to degas the drinks for 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*

Table 1
Certain characteristics of rehydration solutions studied. Data presented as mean±SEM.

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

PW = Plain water; SD = Sports drink; CW = Young fresh coconut water.
SCW = Sodium-enriched young fresh coconut water.
[a]significantly different from young fresh coconut water at p<0.01.
[b]significantly different from sodium-enriched young fresh coconut water at p<0.01
[c]significantly different from sports drink at p<0.01.

al, 1991; Passe *et al,* 1997). All the beverages were kept cool in a refrigerator at 7ºC before consumption.

Measurement and analysis of blood, urine and composition of nutrients in beverages

From a 3-ml blood sample, 1 ml was transferred immediately into an EDTA tube for measurement of hematocrit and hemoglobin to calculate changes in plasma volume (Dill and Costill, 1974). Hemoglobin (Hb) was analyzed by the cyanmethemoglobin method (Drabkins reagent) and hematocrit by microcentrifugation (Hettich-Haematokrit 20, Germany). Another 1 ml of blood was transferred into a tube containing sodium fluoride (NaFl) and the balance of 1 ml was transferred into a plain tube. Plasma and serum were separated by bench-top centrifugation (Hettich-Rotina 46 RS, Germany) at 10,000 rpm for 10 minutes and were then stored at -20ºC for later analysis. Glucose was analyzed using a glucose kit enzymatic calorimetric method (Randox- Germany). Serum of blood samples and samples of beverages taken each time before each trial and urine were analyzed for Na^+ and K^+ using a flame photometer (Corning, 450. USA). The chloride (Cl^-) level and osmolality of the serum and the beverages were measured using an ion selective electrode analyser (Hitachi, 912 Random Access Chemistry Analyzer-Japan) and freezing depression (Osmomat 030, Gonotec, Germany), respectively.

Cumulative urine output

The total urine collected at the selected time intervals was recorded and accumulated during the 2-hour rehydration period, which did not include before and after exercise urine samples (Maughan *et al,* 1994).

Fluid balance, percent body weight loss and rehydration level

The net fluid balance was calculated based on body mass loss during exercise-induced dehydration, total volume of fluid ingested and the cumulative urine output. The percent body weight loss through exercise was calculated from the differences in the nude body weights before and after exercise-induced dehydration divided by nude body weight before exercise multiplied by 100, on the assumption that one liter of fluid is equivalent to one kilogram of body weight. The percent body weight loss that was regained was used as an index for whole body rehydration (percent rehydration). The percent rehydration represented the amount of ingested fluid that was retained in the body at the end of the two hour rehydration protocol (Gonzalez-Alonzo *et al,* 1992).

% Rehydration =

$$\frac{[\text{BW lost during exercise} - (\text{BW euh} - \text{Bw reh})\ (\text{kg})]}{\text{Fluid intake (kg)}} \times 100$$

BW euh represented the nude body weight in the euhydrated condition (before exercise) and BW reh represented the nude body weight at the end of the 2-hour rehydration period.

The rehydration index (RI), was calculated to provide an indication of how much of what was ingested actually was used for body weight restoration (Mitchell *et al,* 1994).

RI = [vol admin (ml) / wt gain (g)] / [% rehydration/100]

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 the Tukey minimum significant difference (MSD) test. The differences were considered significant at $p<0.05$. All values are reported as means±standard error of measurement (SEM) for the 10 subjects. The Statistical Package for Social Science (SPSS) program 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 in the heat. The total volume of fluid consumed during the 2-hour rehydration period was 2,196±269 ml, 2,196±116 ml, 2,304±150 ml and 2,196±142 ml for the PW, SD, CW and SCW arms, respectively, with no significant differences between the arms of the trial. At the end of the 2-hour rehydration period, the subjects were still somewhat dehydrated in all the trials (range of -0.32 to -0.52 kg below the euhydrated body weight). Hypohydration was significantly greater ($p<0.05$) with PW compared to the other trials. Incomplete rehydration resulted from fluid loss during the rehydration period in urine, sweat and respiration.

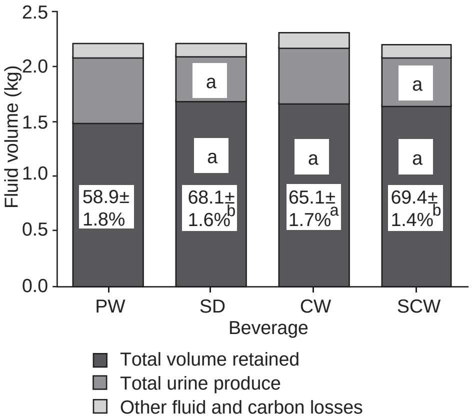
The percent rehydration at the end of the 2-hour rehydration period was significantly higher with the SD ($p<0.01$), SCW ($p<0.01$) and CW ($p<0.05$) compared to PW (Fig 2). The rehydration indexes (RI) were 2.50±0.15, 1.80±0.09, 2.00±0.10 and 1.75±0.07 for the PW, SD, CW and SCW arms of the trial, respectively.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

Changes in plasma volume

The changes in plasma volume during the four trials are shown in Fig 3. At the end of rehydration period, the plasma volume with CW, SCW and SD were similar to the euhydrated plasma volume levels. The plasma volume with the PW was -3.2±0.5%, lower ($p<0.01$) than euhydrated plasma volume at the end of the rehydration period which was significantly different ($p<0.05$) from the SD and SCW trials.

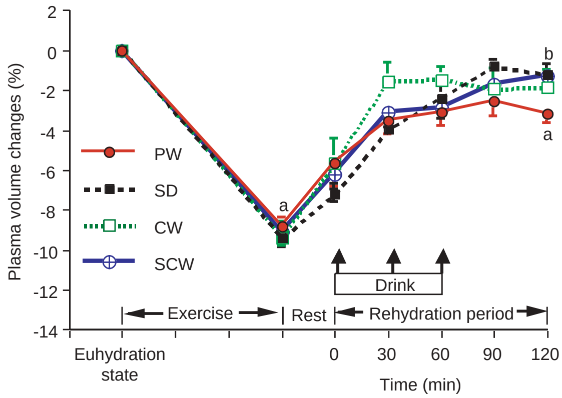
Urine volume and osmolality

The cumulative urine volume at the end of the 2-hour rehydration period was significantly lower ($p<0.05$) after ingestion of SD (416.2±57.1 ml) and SCW (440.4 ± 35.2 ml) compared to PW (590.7±48.40 ml) but it was not significant different from the CW (513.8±50.7 ml) (Fig 4). The urine osmolality at the end of exercise-induced dehydration was similar in all the arms (Fig 5). During the first 30 minutes of the rehydration period the urine osmolality was significantly higher ($p<0.01$) for all the trials after which the urine osmolality began to decrease. At the end of



[a]significantly different from PW (p<0.05)
[b]significantly different from PW (p<0.01).

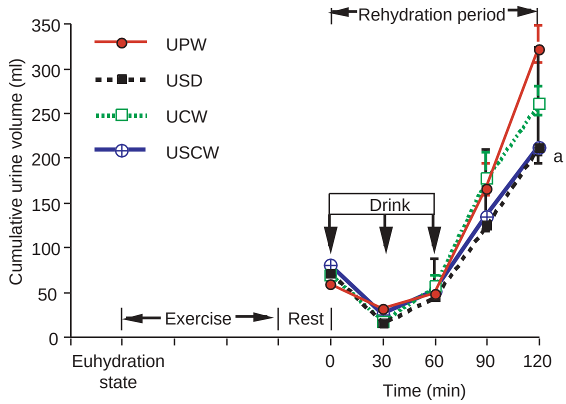
Fig 2–Fate of ingested volume when comparing PW, SD, CW and SCW. The height of the bars represents the total amount of fluid ingested (kg). The stacked bars represent the fate of the ingested volume: the ingested fluid was either retained in the body or lost in the form of urine, sweating, or respiration.



[a]significantly different from plasma volume in the euhydrated state at p<0.01.
[b]significantly different from PW at p<0.05.

Fig 3–The change in plasma volume after exercise-induced dehydration and during the 2-hour rehydration period. All values are expressed as percent change from the resting, euhydrated state.

the 2-hour rehydration period, the urine osmolality of the PW arm was significantly lower (p<0.05) compared to SD and SCW.



[a]significantly lower than PW at p<0.05

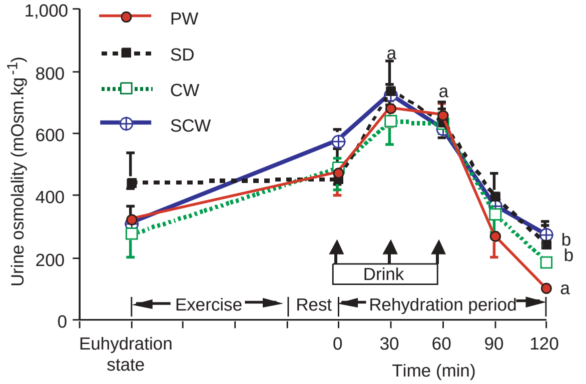
Fig 4–Cumulative urine volume over time. Samples obtained pre-exercise and after exercise-induced dehydration were not included in the calculation of cumulative urine volume.

Net fluid balance

The net fluid balance was negative at the end of exercise-induced dehydration with no significant differences between trials (Fig 6). The net fluid balance was positive with the SD (108.5±41.89 ml) and SCW (66.1±32.86 ml) arms at 90 minutes of rehydration but became negative at the end of the rehydration period, with no significant differences between trials.

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

Serum Na^+ and K^+ levels were 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 significantly lower in the PW arm compared to the other three arms (Fig 7). There were no significant differences in the K^+ levels between the CW and SCW at any time, but the K^+ levels were significantly higher (p<0.01) than the PW and SD arms by 60 minutes during the rehydration period (Fig 7). Serum chloride (Cl^-) concentrations were significantly higher (p<0.05) with CW and SCW compared to SD



[a]significantly different from euhydration state at $p<0.01$.
[b]significantly different from PW at $p<0.05$.

Fig 5–Urine osmolality response after exercise-induced dehydration and during 2-hour rehydration period.

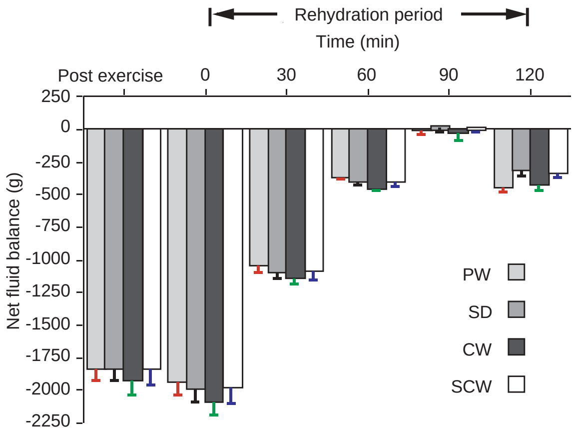
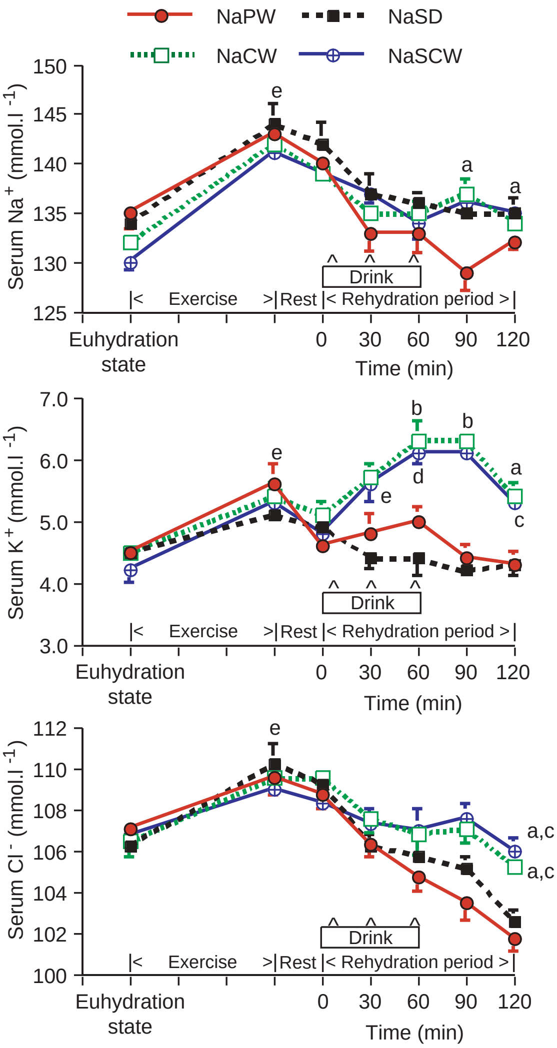


Fig 6–Net fluid balance during the 2-hour rehydration period. Drink volumes ingested were 50, 40, and 30% of 120% fluid loss during exercise-induced dehydration at 0, 30 and 60 minutes of the rehydration period, respectively. Zero net fluid balance is state of euhydration.



[a]significantly higher than PW at $p<0.05$
[b]significantly higher than PW at $p<0.01$
[c]significantly higher than SD at $p<0.05$
[d]significantly higher than SD at $p<0.01$
[e]significantly different from the euhydration state at $p<0.05$

Fig 7–Serum Na^+, K^+ and Cl^- responses after exercised-induced dehydration and during the 2-hour rehydration period.

and PW at the end of the 90-minute exercise-induced dehydration (Fig 7).

Serum osmolality

Serum osmolality was significantly higher ($p<0.01$) at the end of the 90-minute exercise-induced dehydration period in all trials compared to the pre-exercise euhydrated levels. 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 arms except for PW. Serum osmolality in the PW arm was significantly lower ($p<0.05$) than the euhydrated state at 90 and 120 minutes of the rehydration period which were also significantly lower ($p<0.05$) than the other three arms (Fig 8).

Plasma glucose concentration

Plasma glucose concentrations were similar in all four trials before and after the 90-minute exercise-induced dehydration period (Fig 9). As expected, the ingestion of the carbohydrate containing beverages (SD, CW and SCW) resulted in significantly higher plasma glucose levels during the rehydration period compared to ingestion of PW.

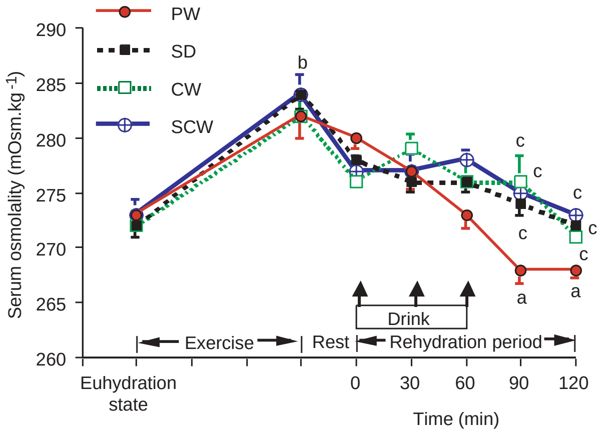
Fluid sensation scale

Data from the fluid sensation scale are presented in Table 2. There were no significant differences in thirst sensation among the arms of the study at any time during the 2-hour rehydration period. The CW, SD and SCW were significantly sweeter than PW at all time points and there were no significant differences in sweetness among SD, CW and SCW. The sensation of nausea was similar for all beverages but was significantly lower for SCW at 30 and 60 minutes during the rehydration period. Fullness was significantly less ($p<0.05$) at 30 and 60 minutes for SCW compared to PW and SD. Sensation of stomach upset was generally lower with SCW and CW compared to PW and SD at each time point with a significantly lower sensation at 30, 60 and 90 minutes.

DISCUSSION

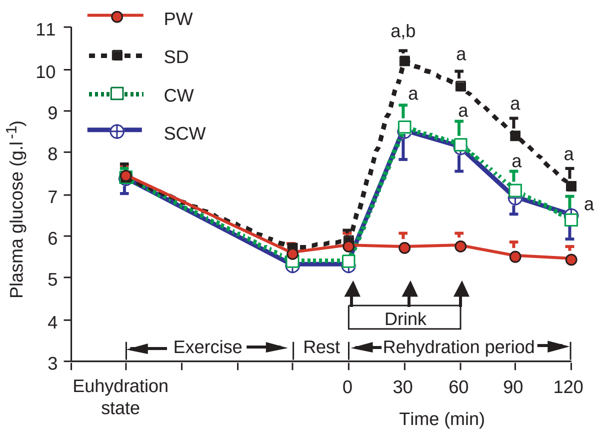
The main purpose of this investigation was to compare the effectiveness of SCW and SD with that of young fresh coconut water (CW) and plain water (PW) on whole body rehydration and plasma volume restoration during a 2-hour rehydration period following exercise-induced dehydration. The data from this investigation suggests: (1) sodium-enriched young fresh coconut water (SCW) was as effective as the sports drink (SD) for fluid replacement and recovery following dehydration and (2) rehydration was similar when CW and SD solutions were ingested.

To our knowledge, the study of Saat *et al* (2002) is the only available study with regard



[a]significantly different from euhydration state at $p<0.05$
[b]significantly different from euhydration state at $p<0.01$
[c]significantly different from PW at $p<0.05$

Fig 8–Serum osmolality responses after 90 minutes of exercise-induced dehydration and during the 2-hour rehydration period.



[a]significantly different from PW at $p<0.01$.
[b]significantly different from euhydration state at $p<0.01$

Fig 9–Plasma glucose responses after 90-minute exercise-induced dehydration and during the 2-hour rehydration period.

Table 2
Fluid sensation scale for thirst, sweetness, nausea, fullness and stomach upset (mean±SEM).

Drink	Time (minutes) of the 2-hour rehydration period				
	0	30	60	90	120
Thirst (1=not thirsty; 5=extremely thirsty)					
PW	1.5±0.2	1.2±0.1	1.1±0.0	1.0±0.0	1.0±0.0
SD	1.5±0.2	1.2±0.2	1.1±0.1	1.4±0.2	1.1±0.1
CW	2.0±0.3	1.4±0.2	1.2±0.1	1.2±0.1	1.1±0.1
SCW	1.7±0.3	1.2±0.1	1.1±0.1	1.1±0.1	1.1±0.1
Sweetness (1=not sweet; 5=extremely sweet)					
PW	1.0±0.0	1.0±0.0	1.0±0.0	-	-
SD	2.5±0.2[a]	2.4±0.2[a]	2.4±0.2[a]	-	-
CW	2.9±0.1[a]	2.7±0.2[a]	2.8±0.2[a]	-	-
SCW	2.5±0.2[a]	2.4±0.2[a]	2.5±0.2[a]	-	-
Nausea (1=no nausea; 5=extremely nausea)					
PW	1.5±0.2	1.7±0.2	1.7±0.2	1.4±0.2	1.3±0.2
SD	1.6±0.3	1.8±0.3	1.4±0.2	1.3±0.2	1.5±0.3
CW	1.4±0.2	1.4±0.2	1.6±0.2	1.3±0.2	1.4±0.2
SCW	1.4±0.2	1.1±0.1[a]	1.1±0.1[a]	1.2±0.2	1.0±0.0
Fullness (1=no fullness; 5=extreme fullness)					
PW	2.0±0.2	2.2±0.3	2.5±0.2	1.9±0.1	1.9±0.1
SD	1.7±0.2	2.3±0.2	2.2±0.3	1.4±0.2	1.5±0.3
CW	1.5±0.2	1.9±0.2	1.8±0.3	1.5±0.2	1.7±0.3
SCW	1.4±0.2	1.2±0.1[a,b]	1.2±0.1[a,b]	1.3±0.2	1.2±0.1
Stomach upset (1=not upset; 5=extremely upset)					
PW	2.0±0.4	2.2±0.2	2.3±0.2	1.6±0.2	1.6±0.2
SD	1.5±0.2	1.8±0.2	1.9±0.3	1.6±0.2	1.4±0.2
CW	1.5±0.2	1.4±0.2	1.70.3	1.3±0.2	1.3±0.3
SCW	1.2±0.1[a]	1.1±0.1[a,b]	1.1±0.1[a,b]	1.0±0.0	1.0±0.0

[a]significantly different from PW at $p<0.05$
[b]significantly different from SD at $p<0.05$

Table 3
Composition of coconut water from different studies.

Study	Specific gravity	pH	Na^+ (mmol.l^{-1})	K^+ (mmol.l^{-1})	Cl^- (mmol.l^{-1})	Glucose (g. l^{-1})
Pradera *et al,* 1942	1.018	-	5.0	64.0	45.5	1.2
Eiseman, 1954	-	5.6	4.2	53.7	57.6	1.8
Rajasuriya *et al*, 1954	1.020	4.8	-	38.2	21.3	-
DeSilva *et al,* 1959	1.020	4.9	-	-	-	-
Olurin *et al,* 1972	1.020	5.6	0.7	81.8	38.6	-
Iqbal, 1976	1.019	4.8	5.0	49.0	63.0	2.1
Kuberski, 1979	-	-	4.0	35.1	41.0	2.8
Msengi *et al,* 1985	1.023	6.0	2.9	49.9	-	-
Campbell-Falck *et al,* 2000	-	4.2	9.7	43.1	39.8	1.73
Saat *et al,* 2002			5.1	52.7	-	2.5
Current study	1.020	4.8	9.0	50.7	34.9	3.0

to rehydration after exercise-induced dehydration using coconut water as a rehydration drink. In that study they found the percent rehydration after exercise-induced dehydration was better with a sports drink compared to coconut water perhaps due to the lower sodium content in the coconut water. In this study, sodium was added to coconut water to raise its concentration to 20 mmol.l^{-1} (SCW) which is equivalent to that of most sports drinks, then we investigated its effectiveness as a rehydration drink.

In this study, after drinking a volume equal to 120% of the body fluid loss during exercise, we observed that SCW and SD showed similar results in percent rehydration and rehydration index which were different than CW and PW. CW also gave better rehydration (Fig 2) than PW ($p<0.05$). Previous studies have shown percent rehydration ranges between 50 and 80% during a rehydration period of 2-3 hours using a variety of rehydration regimens (Costill and Sparks, 1973; Gonzalez-Alonzo *et al,* 1992; Lamberts *et al,* 1992; Murray, 1998; Nose *et al,* 1988a; Ray *et al,* 1998; Saat *et al,* 2002; Singh *et al,* 2002) or *ad libitum* rehydration protocol (Nose *et al,* 1988b). From these studies, Costil and Sparks (1973), Nielsen *et al* (1986), Ray *et al* (1998) and Saat *et al* (2002) did not find any significant differences in the percent rehydration among the rehydration solutions used, however both Gonzalez-Alonso *et al* (1992) and Singh *et al* (2002) found significant differences in the percent rehydration of carbohydrate-electrolyte solution when compared with diet cola, placebo or water. The 68% and 69% rehydration rates with SD and SCW during the 2-hour rehydration period in our study were similar to other studies (Gonzalez-Alonzo *et al,* 1992; Singh *et al,* 2002).

A variety of rehydration protocols have been reported in the literature over the past several years (Costill and Sparks, 1973; Gonzalez-Alonzo *et al,* 1992; Lamberts *et al,* 1992; Maughan *et al,* 1994; Mitchell *et al,* 1994; Ray *et al,* 1998; Saat *et al,* 2002), many of which have been designed to investigate the influence of electrolyte content and fluid volume on rapid rehydration. Conflicting findings regarding the concentration of Na^+ in the beverage and volume necessary to produce optimal rehydration have been reported. Variations in the rehydration protocols employed may partially explain these discrepancies (Costill and Sparks 1973; Gonzalez-Alonzo*et al,* 1992; Lamberts *et al,* 1992; Mitchell *et al,* 2000; Nielsen *et al,* 1986; Nose *et al,* 1988b; Saat *et al,* 2002; Singh *et al,* 2002). Although many studies have employed serial feedings, the protocols typically employed by Gonzales-Alonso *et al* (1992), Nielsen *et al* (1986), Ray *et al* (1998), Saat *et al* (2002) and Singh *et al* (2002) involved the ingestion of large volumes (100-120% of fluid losses) and monitoring over a 2-hour rehydration period. In the present study, the volume of fluid consumed over the 2-hour period was given in a series of feedings every 30 minutes. This protocol closely resembles ingestion patterns that might be used in actual practice, as extreme stomach fullness could be avoided. On the other hand, studies by Maughan and Leiper (1995), Maughan *et al* (1994) and Kovacs *et al* (2002) followed the rehydration process for 5-6 hours, which provides a more complete picture of the effects of the fluid consumed on kidney function.

Studies by Mitchell *et al* (1994) and Maughan *et al* (1997) have shown that, to maximize rehydration, a drink volume greater than that of the body mass lost after exercise should be consumed. In addition, the solution must contain a certain amount of Na^+ or other cation sufficient to prevent significant urine production. When Na^+ levels in the rehydration drinks are relatively low, even large volumes of fluid consumed do not appear to be adequate to produce rapid rehydration (Shirreffs *et al,* 1996). With the ingestion of a fluid with 14 mmol.l^{-1} Na^+ (volume equivalent to 150% of fluid loss), Mitchell *et al* (1994), achieved only 73% rehydration after 3 hours of rehydration. Maughan and Leiper (1995) showed 5.5-hours after ingesting 150% of fluid lost with a Na^+ level of 26 mmol.l^{-1}, subjects only achieved 80% rehydration. Even with ingesting volumes of 150 and 200% of the loss, Shirreffs *et al* (1996) reported that full fluid balance was not achieved after 6 hours with 23 mmol.l^{-1} Na^+ solution. These findings suggest that optimal Na^+ concentration is above 25 mmol.l^{-1}. In the present investigation, increasing Na^+ concentration in CW from 9 to 20 mmol.l^{-1} to become sodium-enriched young coconut water (SCW) improved rehydration by 4% (65 to 69%), suggesting that increasing Na^+ concentration levels to that present in sports drinks can improve the percent rehydration with CW.

Percent rehydration has been used as a useful indicator to measure the effectiveness of a particular rehydration drink in a particular protocol. However, due to the variations in the degree of dehydration, volume ingested, duration of rehydration period and composition, it is difficult to make a meaningful comparison between various protocols. Mitchell *et al* (1994) used the term "Rehydration Index" (RI) to arrive at some useful conclusions and suggested that a value of 1.0 is optimum for rehydration fluid and that anything greater than 1.0 indicates less effective use of an ingested fluid.

The RI for PW in our study is similar to that reported in other studies where a volume equivalent to 71-100% fluid loss during exercise was consumed (Costill and Sparks, 1973; Nose *et al,* 1988b; Gonzalez-Alonzo *et al,* 1992). However, our RI result for PW was higher those that reported by Saat *et al* (2002) although a similar protocol was used. This difference may be due to the percentage of dehydration obtained after exercise-induced dehydration.

The presence of sodium in the rehydration solution may also improve the RI. RI ranges of 1.80 to 2.60 have been reported with sodium levels of 20 mmol.l^{-1}, typical of most sports drinks consumed (Costill and Sparks, 1973; Gonzalez-Alonzo *et al,* 1992; Singh *et al,* 2002). The RI of 1.80 obtained with a sports drink containing 20 mmol.l^{-1} in our study is similar to the expected range. However, the RI for SCW in our study of 1.75 was better than that reported in studies using sports drinks. This may be due to the higher potassium content in SCW compared to the sports drink. The higher potassium content of SCW may be due to intracellular rehydration that produces a better RI.

The volume of urine produced is also related to the ingested volume; the smallest volume of urine produced was when 50% of the fluid loss was consumed and the greatest volume of urine produced was when 200% of the fluid loss was consumed (Shirreffs *et al,* 1996). Subjects could not return to euhydration state when they consumed a volume equivalent to, or less than, their sweat losses, irrespective of the drink composition (Shirreffs *et al,* 1996; Wemple *et al,* 1997). In this study, the rehydration volume equivalent of 120% of sweat loss may still not be sufficient to restore lost fluid as the net fluid balance was only slightly positive for SD and SCW arms at the end of 90 minutes (Fig 6). However, all the ingested fluid arms of the trial were in negative balance at the end of the 2-hour rehydration period with no significant differences between trials. This incomplete rehydration during the rehydration period may have resulted from fluid losses in the form of urine, sweat and respiration (Fig 2).

The major target for fluid replacement during exercise and recovery is to maintain plasma volume, so that circulation and sweating can progress at optimal levels (Leiper and Maughan, 1986). Rehydration evaluated from body weight and plasma volume restorations in this study were similar but incomplete in the four arms of the trial. The percent change in plasma volume as a result of exercise-induced dehydration and the 2-hour rehydration period were similar and no differences were observed among the various arms up to 90 minutes in the rehydration period (Fig 3). However, due to the high volume of urine production throughout the rehydration period with PW (Fig 4), plasma volume restoration was significantly lower ($p<0.05$) at the end of the 2-hour rehydration period when compared to the SD and SCW arms. Plasma volume levels in the CW arm at the end of the 2-hour rehydration period were also lower than the SD and SCW arms, but better than PW.

Our data suggest that SD and SCW are better fluid replacement solutions to restore plasma volume after exercise-induced dehydration where the plasma volume restoration was greater in drinks containing high sodium concentrations, which is similar to other studies (Nielsen *et al,* 1986; Maughan *et al,* 1997, 2000; Saat *et al,* 2002; Singh *et al,* 2002).

Previous studies have suggested that ingestion of beverages high in potassium concentation may delay rates of plasma volume recovery because of restoration of the intracellular fluid compartment at the expense of extracellular fluid (Nielsen *et al,* 1986; Nadel *et al,* 1990; Maughan *et al,* 1994). However, in this present study, we observed no differences among the rates of plasma volume restoration for CW and SCW, which had high concentrations of K^+ (~51 mmol.l^{-1}) compared to SD. This was similarly seen in a study by Ray *et al* (1998).

Despite ingesting a volume of fluid equivalent to 120% of that lost during exercise-induced dehydration, the subjects were still not able to replace the fluid losses that occurred. Utilizing a protocol very similar to the one employed in this study, Lamberts *et al* (1992) and Costill and Sparks (1973) also reported that rehydration was incomplete despite the ingestion of a quantity of fluid equal to that lost during dehydration. Ray *et al* (1998) also showed that plasma volume was not restored completely with a carbohydrate electrolyte beverage or plain water after a 2-hour rehydration period. Conversely, Saat *et al* (2002) showed blood volume was restored to higher levels than that of the euhydrated values when they followed a protocol similar to this study. This difference may be due to the percent decrease in blood volume which was only 4% at the end of the dehydration trial (Saat *et al,* 2002) compared to a decrease of 9% in our study. Gonzalez-Alonso *et al* (1992) also reported incomplete restoration of blood volume in the water trial with dehydration of 2.6% and fluid replacement of 100% of weight loss which is similar to our study in the PW arm. The incomplete restoration of plasma volume with PW in our study could be due to a number of reasons including urine production during the rehydration period. In addition all the subjects were still somewhat dehydrated after 2 hours of rehydration (ranging from 0.20 to 0.60 kg below the euhydrated body weight).

Plasma glucose concentrations before the exercise-induced dehydration trial were similar in all arms and within normal range of 7.39 to 7.55 mmol.l^{-1} (Fig 9). These values were obtained due to the fact that a standard breakfast was given 1 hour before the exercise-induced dehydration run and after an overnight fast. The primary benefit of giving a standard breakfast was the standardization of the exogenous carbohydrate stores.

Significantly higher plasma glucose levels were obtained with carbohydrate containing beverages (SD, CW and SCW) compared to the ingestion of PW (Fig 9). The rise in glucose concentrations was due to the glucose content of the trial drinks (204.1±19.5, 167.90±3.94, and 165.52±3.62 mmol.l^{-1} for SD, CW and SCW, respectively). This indicates the carbohydrate containing beverages were emptied and absorbed well. During the 2-hour rehydration period, plasma glucose concentration were significantly higher with the SD compared to CW, SCW ($p<0.05$) and PW ($p<0.01$) at certain time periods. However, in the CW and SCW arms, plasma glucose was similar at all time periods.

The ingestion of carbohydrates during rapid rehydration is advantageous, since the rate of muscle glycogen resynthesis is reportedly 3 times faster if carbohydrates are ingested immediately after exercise as opposed to a delay of two hours (Ivy *et al,* 1988a). Ivy *et al* (1988b) reported ingestion of carbohydrates at a rate of 1.5 $g.kg^{-1}$ body weight per hour elicited rates of muscle glycogen resynthesis of 5.8 and 4.5 $mmol.l^{-1}$ kg in wet weight of muscle during the first and second two-hour periods of recovery from exhaustive exercise. Thus, fluid replacement and carbohydrate consumption with a 10% carbohydrate solution is of practical importance for the athlete who must train or compete in the hours or days following exercise-induced dehydration (Lamberts *et al,* 1992; Burke, 2000).

Serum potassium levels after ingestion of CW and SCW were significantly higher ($p<0.05$) than SD and PW at 60 minutes and 120 minutes during the rehydration (Fig 8). Both CW and SCW contained high K^+ levels (~51 $mmol.l^{-1}$) and were significantly different ($p<0.01$) from SD and PW. The high K^+ level in young coconut water (Table 3) is consistent with those reported previously (Pradera *et al,* 1942; Campbell-Fack *et al,* 2000). The electrolyte composition of coconut water resembles intracellular fluid more closely than extracellular plasma (Goldsmith, 1962; Campbell-Fack *et al,* 2000). Our study showed that serum K^+ levels increased by ~1.6 $mmol.l^{-1}$ after ingesting either CW or SCW during the rehydration period (Fig 8). This observation is similar to the study by Olurin *et al* (1972) who reported a rise in serum K^+ levels by 1.5 $mEq.l^{-1}$ after infusion of 2,000 to 3,000 ml of coconut fluid over a period of 6 to 12 hours. It has also been postulated that the inclusion of K^+ in drinks consumed after sweat loss may aid in rehydration by enhancing the retention of water in the intracellular space (Nadel *et al,* 1990). In this study, there was no reliable method to distinguish body water in the intracellular from the extracellular space, so the losses from and replacement of the intracellular and extracellular water are unknown. Our data showed that plasma volume restoration (Fig 3) and percent rehydration (Fig 2) were similar between SCW and SD during the 2-hour rehydration period. One reason for these similarities in plasma volume restoration and percent rehydration between the SD and SCW despite the high K^+ concentration in the SCW (similar sodium) may be due to the short rehydration period. As such, within the 2-hour rehydration period, there appears to be no additive effect of the high K^+ in SCW. The high concentration of K^+ in the coconut water together with Na^+ would be expected to restore higher plasma volume if they acted independently on different body fluid compartments, as shown by Maughan *et al* (1994).

In another study, Ray *et al* (1998) showed that consuming chicken broth with high concentrations of K^+ (25.3 $mmol.l^{-1}$) and Na^+ (109.5 $mmol.l^{-1}$) as one of the rehydration beverages, resulted in a significantly greater plasma volume restoration than consuming water, carbohydrate-electrolyte drink (16.0 $mmol.l^{-1}$ Na^+, 3.3 $mmol.l^{-1}$ K^+) or soup (333.8 $mmol.l^{-1}$ Na^+, 13.7 $mmol.l^{-1}$ K^+). That study and the present study suggest that consuming high concentrations of potassium does not impair rehydration provided the sodium concentration of the beverage is adequate.

Previous studies have shown ingestion of plain water after exercise-induced dehydration resulted in a rapid fall in plasma osmolality and in plasma sodium concentration (Nose *et al,* 1988a; Maughan, 1999), both these effects will stimulate urine output. The significantly lower ($p<0.05$) urine osmolality during the PW trial is the result of increased fluid clearance by the kidneys. Costill and Sparks (1973) showed that ingestion of a glucose-electrolyte solution (22 mmol.l^{-1}) after dehydration (4% of body weight losses) resulted in a greater restoration of plasma volume than did plain water. A higher urine output was observed in the water trial which was similarly seen in this present study.

There were no significant differences in thirst sensation among the arms of the trial at any time point during the 2-hour rehydration period. CW, SD and SCW were significantly sweeter that PW at all time points and there were no significant differences in sweetness among SD, CW and SCW. The sweet taste of CW and SCW also increased the palatability, which was important, especially when large volumes of fluid have to be consumed or taken *ad libitum.* The sensation of fullness reduced the stimulus to drink in the PW trial, especially when they had to ingest the last 30% of the 120% bolus, during this period. Incidentally, there was a higher rating for fullness with SD (2.2 ± 0.3) compared to SCW (1.2 ± 0.1) at this time point as well.

Throughout this study, the subjects rated SCW as causing significantly less fullness and stomach upset compared to the commercial SD. This was an interesting finding which may establish the use of SCW as a natural rehydration drink after exercise since the SD was reported as causing stomach upset when used in large volumes. Stomach upset sensation was generally lower with SCW and CW compared to PW and SD at each time point.

The subjects at the 60-minute time point during the rehydration period, when they had to ingest the last 30% of the 120% of weight loss, took a longer time to finish drinking PW and SD. Interestingly, SCW was rated to cause less stomach upset, nausea and fullness compared to CW. Our data on fluid sensation showed that SCW is suitable and had better ratings by subjects when compared to SD and PW.

In conclusion, the results of the present study indicate that fluid replacement after exercise-induced dehydration with SCW was as effective as commercial SD and was better than CW and PW. The restoration of plasma volume was similar with SD and SCW and was significantly better compared with PW. The percent rehydration and rehydration index of the SCW was similar to SD but was significantly better than PW ($p<0.01$) but was not significantly different from CW.

SCW was rated lower in terms of fullness and stomach upset and was better than SD, CW and PW, thus making SCW easier to consume in larger quantities compared with PW, SD and CW. It can be concluded that SCW may be used for rehydration after exercise-induced dehydration and its physiological effects are as effective as commercial sports drinks available on the market.

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