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Rehydration after Exercise with Fresh Young Coconut Water, Carbohydrate-Electrolyte Beverage and Plain Water

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Abstract This is to cross-over study to assess the effectiveness of fresh young coconut water (CW), and carbohydrate-electrolyte beverage (CEB) compared with plain water (PW) for whole body rehydration and blood volume (BV) restoration during a 2 h rehydration period following exercise-induced dehydration. Eight healthy male volunteers (mean age and $\dot{V}O_{2max}$ of 22.4 ± 3.3 years and 45.8 ± 1.5 ml min kg^{-1} respectively) exercised at 60% of $\dot{V}O_{2max}$ in the heat (31.1 ± 0.03°C, 51.4 ± 0.1% rh) until 2.78 ± 0.06% (1.6 ± 0.1 kg) of their body weight (BW) was lost. After exercise, the subjects sat for 2 h in a thermoneutral environment (22.5 ± 0.1°C; 67.0 ± 1.0% rh) and drank a volume of PW, CW and CEB on different occasions representing 120% of the fluid loss. A blood and urine sample, and the body weight of each subject was taken before and after exercise and at 30 min intervals throughout a rehydration period. Each subject remained fasted throughout rehydration. Each fluid was consumed in three portions in separate trials representing 50% (781 ± 47 ml), 40% (625 ± 33 ml) and 30% (469 ± 28 ml) of the 120% fluid loss at 0, 30 and 60 min of the 2 h rehydration period, respectively. The drinks given were randomised. In all the trials the subjects were somewhat hypohydrated (range 0.08–0.18 kg BW below euhydrated BW; $p>0.05$) after a 2 h rehydration period since additional water and BW were lost as a result of urine formation, respiration, sweat and metabolism. The percent of body weight loss that was regained (used as index of percent rehydration) during CW, PW, and CEB trials was 75 ± 5%, 73 ± 5% and 80 ± 4% respectively, but was not statistically different between trials. The rehydration index, which provided an indication of how much of what was actually ingested was used for body weight restoration, was again not different statistically between trials (1.56 ± 0.14, 1.36 ± 0.13 and 1.71 ± 0.21 for CW, CEB and PW respectively). Although BV restoration was better with CW, it was not statistically different from CEB and PW. Cumulative urine output was similar in all trials. There were no difference at any time in serum Na^+ and Cl^-, serum osmolality, and net fluid balance between the three trials. Urine osmolality decreased after 1 h during the rehydration period and it was lowest in the PW trial. Plasma glucose concentrations were significantly higher compared with PW ingestion when CW and CEB were ingested during the rehydration period. CW was significantly sweeter, caused less nausea, fullness and no stomach upset and was also easier to consume in a larger amount compared with CEB and PW ingestion. In conclusion, ingestion of fresh young coconut water, a natural refreshing beverage, could be used for whole body rehydration after exercise. *J Physiol Anthropol 21 (2): 93–104, 2002* http://www.jstage.jst.go.jp/en/

Keywords: exercise-induced dehydration, carbohydrate-electrolyte beverage, fresh young coconut water, blood volume, fluid retention

Introduction

The restoration of body fluid balance following dehydration induced by exercise occurs through regulatory responses which stimulate ingestion of water and sodium. Heavy sweating during exercise can cause body fluid losses in excess of 1 liter per hour (Costill, 1977). Assuming that the rehydration strategy before and during exercise has been effective, there should be no need for rehydration postexercise. This appears to be the view from the American College of Sports Medicine position stand (1996), as there is no mention of postexercise rehydration in the document. However, as has been highlighted in the review, fluid replacement before and during exercise is unlikely to be sufficient to offset the ongoing fluid loss. This is especially true during prolonged exposure to a hot environment. An athlete is then faced with the possibility of being significantly dehydrated when due to compete again soon. A decision must be made on the most effective postexecise rehydration strategy to restore body fluid balance while providing carbohydrate to restore depleted muscle glycogen stores. If there is limited time (~2 hrs) before the next event, an athlete should replace fluid loss in order to achieve euhydration. If sufficient time is available (~6 hrs), fluid ingestion or fluid plus solid food are the options (Galloway, 1999).

The restoration of body fluid losses is necessary for optimal cardiovascular function and thermoregulation during subsequent exercise (Costill and Sparks, 1973; Morimoto et al., 1981; Sproles et al., 1976). Replacement of water and electrolytes during rehydration may be limited by gastric emptying and intestinal absorption as well as the body's ability to retain ingested fluid that is, to prevent diuresis (Gisolfi et al., 1990; Mitchell and Voll, 1991).

One of the factors in achieving optimal post exercise rehydration is that drink volume should be greater than the volume of fluid loss (Shirreffs et al., 1996). Drink palatability is important since an individual will not drink a sufficient quantity of a drink he/she does not like (Hubbard et al., 1990). Plain water is not the most effective post-exercise rehydration drink. The addition of electrolytes, in particular sodium, helps to maintain thirst and stimulates drinking (Maughan and Leiper, 1995; Nose et al., 1988; Takamata et al., 1994).

Rehydration after exercise requires not only replacement of volume loss, but also replacement of electrolytes, primarily sodium, lost in the sweat. Drink containing approximately 50 mmol l^{-1} sodium are likely to be most effective for most people provided the required volume is consumed. In contrast, the sodium content of most sports drinks is in the range of 10−25 mmol l^{-1}; in some cases it is even lower. Soft drinks which are most commonly consumed, contain virtually no sodium and therefore, these drinks are unsuitable when the need for rehydration is crucial. The problem with a high sodium concentration in drinks is that some people find the taste undesirable, resulting in reduced consumption. Where sweat loss is high, rehydration with a carbohydrate solution has implication for energy balance and will improve palatability (Shirreffs, 2000).

Most hydration studies have been carried out using either a carbohydrate-electrolyte solution or water as rehydration fluid. To the present author's knowledge there has been no study of using a natural "fruit drink" such as coconut water which contains sodium, potassium, chloride and glucose, as a rehydration fluid. Coconut water however, has been used as an oral rehydration in patients with diarrhoea to replace fluid loss from the gastrointestinal tract (Chavalittamrong et al., 1982) and in an extreme situation such as short-term intravenous hydration fluid in a patient (Campbell-Faick et al., 2000). The primary purpose of this investigation was to compare the effectiveness of fresh young coconut water and carbohydrate-electrolyte beverage to that of water on whole body rehydration and blood volume restoration during a 2 h period after exercise-induced dehydration.

Methods

Subjects

Eight healthy males volunteered to take part in this study. All the subjects regularly participated in physical activity on a recreational basis, but none was engaged in a systematic training programme at the time of this investigation. Subjects were briefed on the purpose of the study and the experimental procedure before signing a consent form. Their mean (± SEM) age, body weight, height and maximal oxygen uptake ($\dot{V}O_{2max}$) were 22.4 ± 3.3 yrs, 56.6 ± 2.3 kg, 168.5 ± 1.8 cm and 45.8 ± 1.5 ml min kg^{-1} respectively.

Test procedure

Each subject was required to run on a treadmill for four minutes at four different submaximal speeds during a period of 16 minutes. Expired gas was measured throughout the test, but only the values during the final minute of each 4-minute increment were recorded. This was based on the fact that a subject reached a steady state of $\dot{V}O_2$ after running for three to four minutes. The protocol for a ($\dot{V}O_{2max}$) test required a subject to run to exhaustion using a continuous incremental running protocol on a treadmill to fatigue in 10−12 min (Talyor et al., 1955). From the data obtained in the submaximal exercise test and the $\dot{V}O_{2max}$ test, the speed which would elicit 60% $\dot{V}O_{2max}$ of a subject was calculated.

Experimental design

The effectiveness of two beverages compared with plain water for promoting rehydration following exercise-induced dehydration was determined during a 2 h rehydration period while the subjects sat in a thermoneutral environment (22.5 ± 0.1°C, 67.0 ± 1.0% rh). The three experimental trials were separated by at least one week. The beverages used during these trials were, fresh young coconut water (CW) a carbohydrate-electrolyte beverage (CEB) (Isomax-Ace Canning Corp. Sdn. Bhd) and plain water (PW). An average of 5 coconuts were used to obtain the coconut water which was throughly mixed for each trial. For the carbohydrate-electrolyte beverage the cans were opened and poured into a container to degas for two to three hours before consumption. The drinks were kept cool in a refrigerator (4°C) and were given in random order. Composition of the beverages used are listed in Table 1. Subjects reported to the laboratory 2−3 hours following a

Table 1 Nutrient composition and osmolality of plain water, fresh young coconut water and carbohydrate-electrolyte beverage. Data presented as Mean ± SEM.

Variables	PW	CW	CEB
Glucose (mmol l^{-1})	0	139.63 ± 4.95	179.40 ± 2.40++
Na^+ (mmol l^{-1})	0	5.09 ± 0.40	19.01 ± 0.29++
K^+ (mmol l^{-1})	0	52.66 ± 0.94	3.75 ± 0.14++
Cl^- (mmol l^{-1})	0	1.11 ± 0.59	0
Osmolality (mOsm kg^{-1})	0	405 ± 10.89	404 ± 10.73

PW = Plain water CW = Fresh young coconut water. CEB = Carbohydrate-electrolyte beverage. ++, significantly different from CW at p<0.01.

standardized breakfast and drank ~500 ml of water to ensure a normal hydration state. All experimental trials began in the morning and the subjects were required to abstain from strenuous exercise for at least 48 hours prior to each test. On arrival, each subject voided his bladder as completely as possible, and the entire volume was collected and measured. Nude body weight was then obtained. The subject then sat in a thermoneutral environment and remain in a comfortable sitting position for 15 minutes before a teflon venous catheter was inserted into a forearm vein fitted with a three-way stopcock for blood sampling; this remained in place for the remainder of the study. An initial blood sample was obtained. All blood samples were obtained without stasis. Then, the subject exercised in a hot environment (31.1 ± 0.03°C, 51.4 ± 0.1% rh) at a pre-determined intensity of 60% $\dot{V}O_{2max}$ for 90 minutes until 2.5–3.0% body weight (BW) was lost.

Immediately after the dehydration exercise, a second blood sample was obtained and this was followed by determination of nude body weight. After the subject has completely wiped the sweat from the skin, the subject was then allowed to cool, change clothes, and resume a seated position in a thermoneutral environment. Thirty minutes after the exercise, a third blood sample was obtained (dehydrated state) and this was followed by determination of nude body weight, which represented the dehydration level. A second urine sample was collected from the subject and measured. The subject then drank one of the test drinks in a volume amount equal to the measured 50% fluid loss. This signalled the beginning of a 2 h rehydration period. At 30 minutes postexercise, the subject drank 40% of the fluid loss in the exercise. The remaining 30% of the rehydration drink necessary to replace 120% of the fluid lost was ingested 60 minutes post-exercise. Blood and urine samples respectively were collected at 30-minutes intervals. In addition at, 0, 30, 60, 90 and 120 minutes of rehydration, the subject answered questions regarding 1) their fluid sensation, 2) their sense of thirst, 3) the sweetness of the drink, 4) their feeling of nausea and 5) their sense of fullness and stomach upset. Each subject's answers were scaled from 1 to 5 using a fluid sensation scale where 1 was the least and 5, the highest score (Peryam and Pilgrim, 1957). At the end of the 2 h rehydration period, a final nude body weight was taken for the subject (Fig. 1).

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

From the five milliliters (5 ml) of venous blood drawn, half a milliliter (0.5 ml) was transferred to an EDTA tube for estimation of hematocrit and hemoglobin level respectively. Hematocrit was determined in duplicate after microcentrifugation and Hemoglobin (Hb) concentration was determined using the cyanmethemoglobin method. The percent change in blood volume was calculated from the change in Hb concentration as described by Gonzalez et al. (1992). Another 1.5 ml of blood was transferred to a tube containing Sodium Flouride (NaF) and the remaining 3 ml of blood was transferred into a plain tube. Plasma and serum were separated by bench-top centrifugation and urine was frozen and later analyzed for serum and urine osmolality respectively (freezing point method: cryoscopic osmometer, Osmomat 030, Gonotec, Germany). The plasma was analysed for glucose using glucose kits enzymatic calorimetric method. Serum of blood samples and samples of the beverages taken each time before each trial and urine were analysed for sodium (Na^+), potassium (K^+), and chloride (Cl^-) by using ion selective electrode (Hitachi-912 Random Access Chemistry Analyzer).

Cumulative urine output

Total urine collected at selected time intervals was recorded during the 2 h rehydration period (not including before and immediately after exercise) (Maughan et al., 1994).

Net fluid balance

Net fluid balance was calculated based on body mass loss, volume of fluid ingested and urinary volume voided (Maughan et al., 1994).

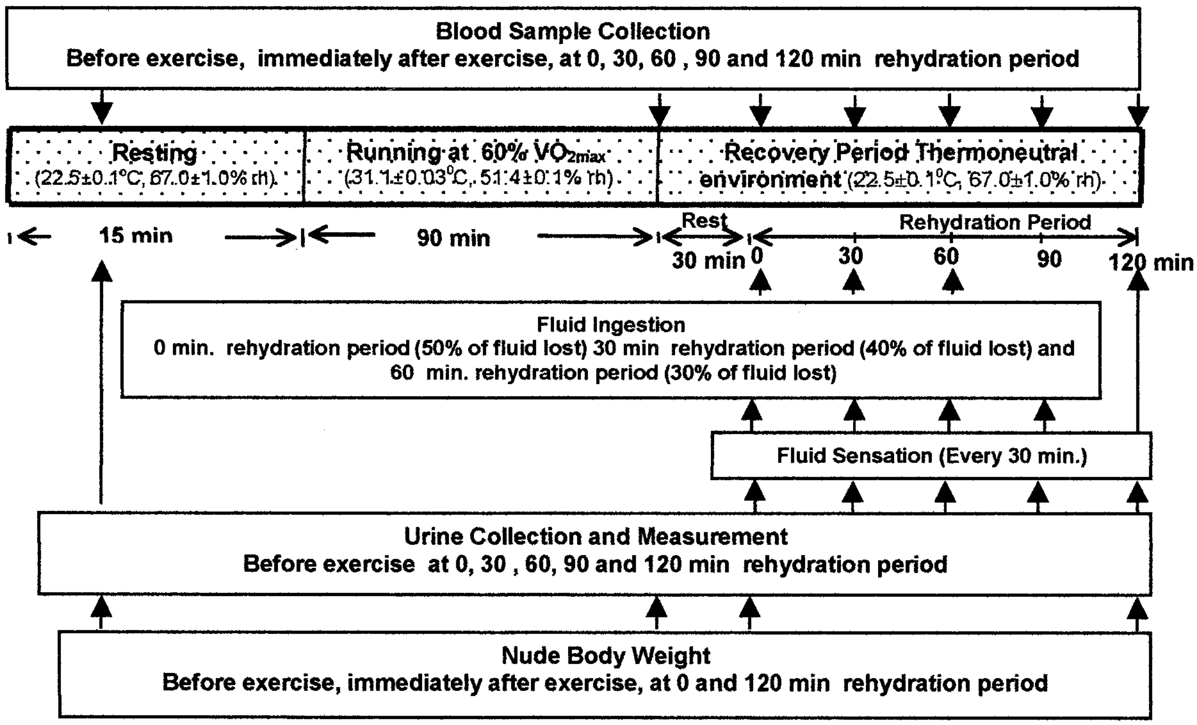

Fig. 1 Research protocol. Rehydration following exercise induced dehydration, with fresh young coconut water, carbohydrate-electrolyte beverage and plain water.

Results of measurement and calculations

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 the 2 h rehydration period (Gonzalez-Alonso et al., 1992).

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

BWeuh represented the nude body weight in euhydrated conditions and BWreh represented the nude body weight after the 2 h rehydration period.

Rehydration index: Rehydration index (RI) provides an indication of how much of the fluid ingested was actually was used in body weight restoration (Mitchell et al., 1994).

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

Statistical analysis: All data were analyzed using two-way analysis of variance (ANOVA) for repeated measurement. The Statistical Package for Social Sciences (SPSS) programme, version 9.0 was used for statistical analysis. Differences was considered significant at $p<0.05$. Results were presented as mean ± Standard Error Mean (SEM).

Results

Body weight change, fluid intake, percent rehydration and rehydration index

By exercising in the heat, the subjects lost an average (± SEM) of 2.78 ± 0.06% (1.6 ± 0.1 kg) of their initial euhydrated body weight (BW) in this study. During the rehydration period, each subject drank an average of 1875 ± 114 ml. At the end of the 2 h rehydration, the subjects were still somewhat hypohydrated under all conditions studied (range 0.08–0.18 kg BW below the euhydrated BW; $p>0.05$) (Fig. 2). Incomplete rehydration resulted from fluid lost during the rehydration period in urine, sweat and respiration and the body weight lost due to metabolism. The percent rehydration, was similar in all trials of fluid type although it was highest with CEB (80 ± 4%). The rehydration index was again not different statistically between fluid trials 1.56 ± 0.14, 1.36 ± 0.13 and 1.71 ± 0.21 for CW, CEB and PW respectively.

Change of blood volume

The percentage change of blood volume during the three trial is shown in Fig. 3. No significant differences were noted at any time point, although the blood volume change was higher during the rehydration period with CW.

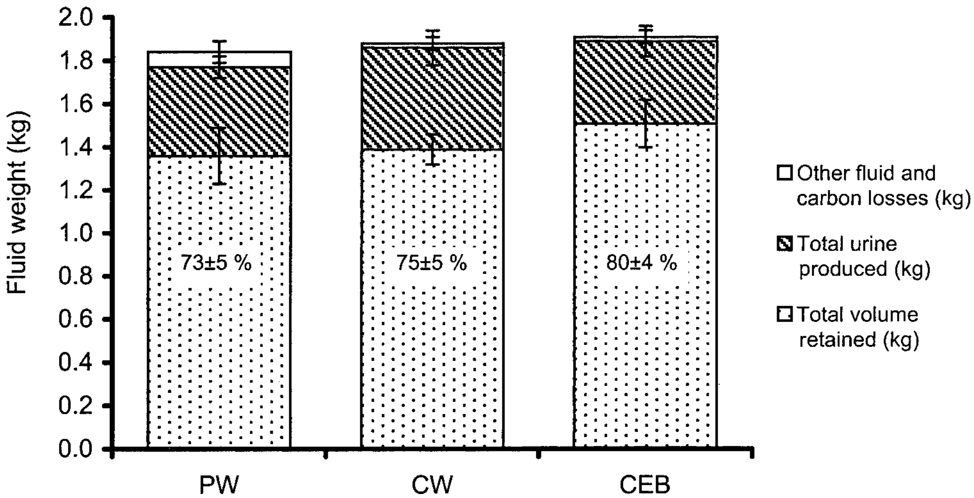

Fig. 2 Fate of ingested volume when comparing PW, CW and CEB. Fluid consumed is expressed in kg. The stacked bars represent the fate of the ingested volume: the ingested fluid was either retained in the body or lost in the form of urine, sweating, respiration. The percent of the body weight loss that was regained, percent rehydration, was used as indicative of the volume retained.

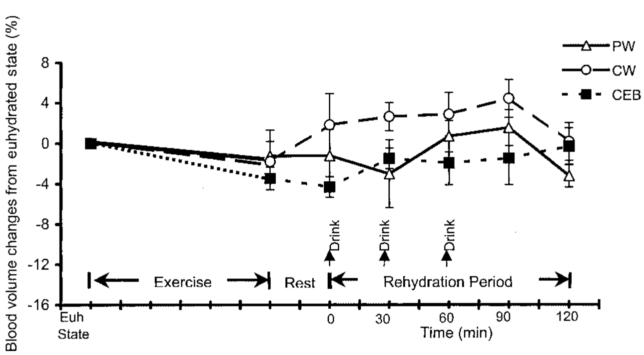

Fig. 3 Blood volume response after exercise-induced dehydration and during the 2 h rehydration period. Euhydration state is represented by Euh State. PW, CW and CEB represent plain water, fresh young coconut water and carbohydrate-electrolyte beverage respectively.

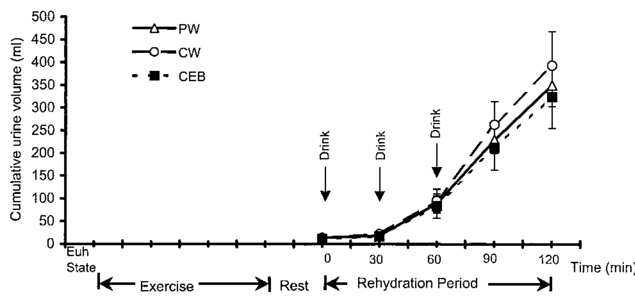

Fig. 4 Cumulative urine output during rehydration. The pre-exercise sample and the sample obtained immediately after exercise are not included in the calculation of cumulative urine volume.

Urine volume and osmolality

Cumulative urine volume during and at the end of the rehydration period was similar in all trials (Fig. 4). Urine osmolality at the end of the exercise-induced dehydration exercise was similar in all trials (Fig. 5) although the osmolality was higher in the CEB trial. During the first 60 min of the rehydration period urine osmolality was higher than at the end of the exercise period in all trials, after which urine osmolality began to decrease. Urine osmolality was significantly lower in the PW trials compared with CEB and CW trials at 90 min and 120 min of the rehydration period.

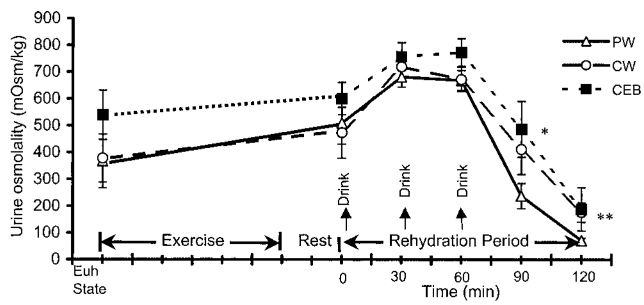

Fig. 5 Urine osmolality response after exercise-induced dehydration and during the 2 h rehydration period. *, ** significantly different from PW at p<0.05 and p<0.01 respectively.

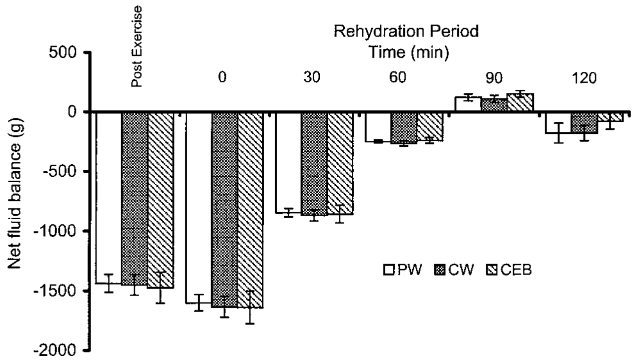

Fig. 6 Net fluid balance during the 2 h rehydration period. Drink volume consumed was 50%, 40%, and 30% of 120% of the fluid lost at 0, 30, and 60 min of the 2 h rehydration period respectively. Zero net fluid balance is the state of euhydration.

Net fluid balance

Net fluid balance was negative at the end of the exercise-induced dehydration exercise in all three trials with no significant differences between trials (Fig. 6). Net was positive in all trials at the 90 minute point of the rehydration period, but became negative at the end of the 2 h rehydration period with no significant difference between trials.

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

Serum Na^+ was significantly higher at the end of exercise-induced dehydration in the CEB trial compared with the pre-exercise euhydrated level. During the rehydration period, Na^+ returned to its euhydrated level and there was no significant difference noted between any of the trials at any time point (Fig. 7).

Serum Cl^- was significantly lower initially with CW trial when compared to PW trial. However, serum Cl^- concentration was significantly higher immediately at the point of exercise-induced dehydration in all trials compared with their pre-exercise euhydrated level. During the rehydration period, there was no significant difference noted between the three trials at any time point (Fig. 7).

Serum K^+ was significantly lower initially in the CW trial when compared with the PW trial but at the end of the dehydration period there was no significant differences in K^+ levels in any trial (Fig. 7). However, K^+ concentration rose significantly during the rehydration period using CW and a significant difference was noted at 60 min, 90 min, 120 min, compared with PW, K^+ concentration decline with CEB trial during the rehydration period and a significant difference was noted at 60 min, 90 min, and 120 min, respectively compared with the CW trial. At the end of the 2 h rehydration period, the K^+ concentration during the CEB trial was also significantly lower than the

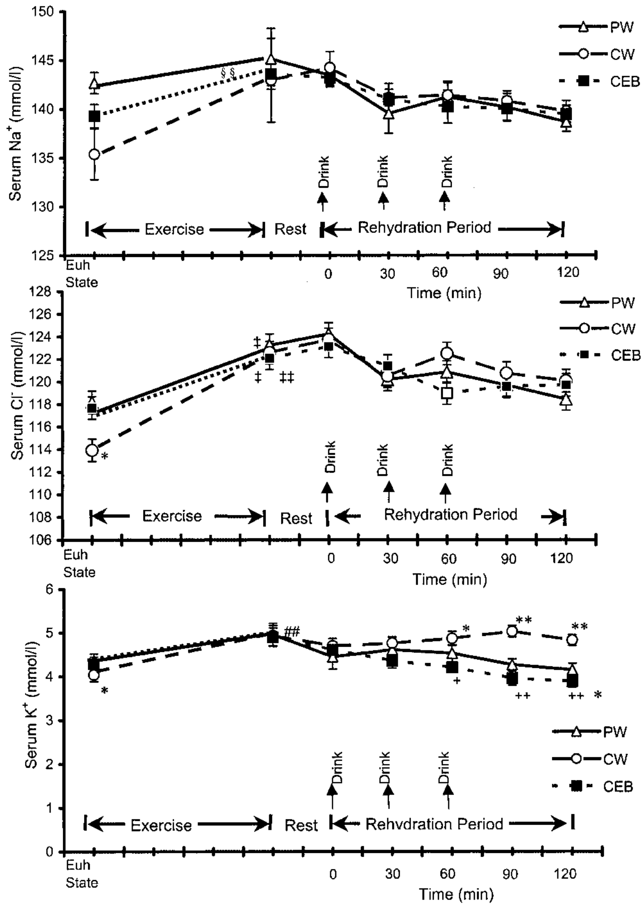

Fig. 7 Serum Na^+, Cl^- and K^+ response after exercise-induced dehydration and during the 2 h rehydration period. §§ significantly different from Euh (CEB) State at p<0.01. ‡, ‡‡ significantly different from Euh State at p<0.05 & p<0.01 respectively. *, ** significantly different from PW at p<0.05 & p<0.01 respectively. +, ++ significantly different from CW at p<0.05 & p<0.01 respectively. ## significantly different from Euh (CW) State at p<0.01.

K^+ concentration of the PW trial.

Serum osmolality

Serum osmolalities were significantly higher immediately at the exercise-induced dehydration period in all trials when compared with the pre-exercise euhydrated levels. At the end of the 120 min, rehydration period serum osmolality returned to a level that was not significantly different from the euhydrated value in any trial. During the rehydration period, there was no significant difference noted between the three trials at any time point (Fig. 8).

Plasma glucose concentration

Plasma glucose concentration before exercise was within the normal range at 5.04 to 5.24 mmol l^{-1} (Fig. 9).

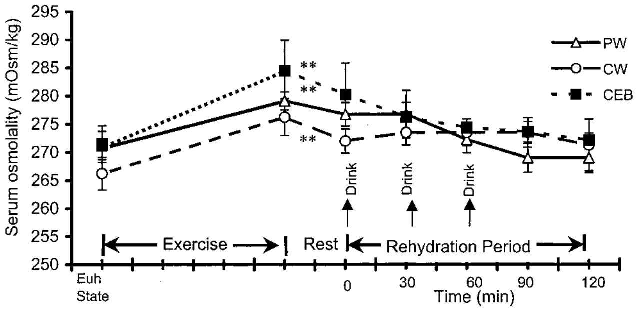

Fig. 8 Serum osmolality response after exercise-induced dehydration and during the 2 h rehydration period. **, significantly different from Euh State at p<0.01.

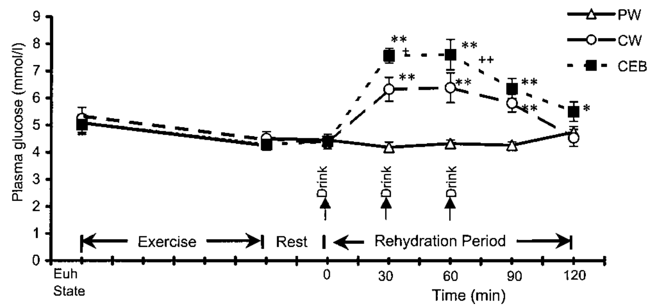

Fig. 9 Plasma glucose response after exercise-induced dehydration and during the 2 h rehydration period. *, ** significantly different from PW at p<0.05 & p<0.01 respectively. +, ++ significantly different from CW at p<0.05 & p<0.01 respectively.

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

Drink	Time (minutes) 2 h Rehydration Period				
	00	30	60	90	120
Thirst (1 = not thirsty; 5 = extremely thirsty)					
PW	4.00 ± 0.50	2.00 ± 0.42	1.50 ± 0.33	1.50 ± 0.27	1.50 ± 0.27
CW	3.38 ± 0.56	2.13 ± 0.48	1.63 ± 0.32	1.38 ± 0.26	1.38 ± 0.38
CEB	4.13 ± 0.52	2.25 ± 0.53	1.75 ± 0.41	1.50 ± 0.27	1.50 ± 0.27
Sweetness (1 = not sweet; 5 = extremely sweet)					
PW	1.13 ± 0.13	1.50 ± 0.27	1.25 ± 0.16	X	X
CW	1.88 ± 0.30*	2.38 ± 0.42*	2.63 ± 0.56*	X	X
CEB	1.50 ± 0.27	2.13 ± 0.52	1.75 ± 0.31	X	X
Nausea (1 = not nausea; 5 = extremely nausea)					
PW	1.75 ± 0.31	2.38 ± 0.46	3.00 ± 0.60	2.63 ± 0.56	2.25 ± 0.53
CW	1.50 ± 0.27	1.38 ± 0.18	1.25 ± 0.16*	1.38 ± 0.26	1.00 ± 0.00*
CEB	1.50 ± 0.19	1.50 ± 0.27	1.75 ± 0.37	1.25 ± 0.16*	1.13 ± 0.13*
Fullness (1 = not full; 5 = extremely full)					
PW	1.13 ± 0.13	2.88 ± 0.40	3.38 ± 0.46	2.38 ± 0.56	1.88 ± 0.40
CW	1.13 ± 0.13	2.13 ± 0.35*	2.63 ± 0.53	1.75 ± 0.25	1.25 ± 0.25
CEB	1.75 ± 0.31	2.88 ± 0.44	3.38 ± 0.53	2.38 ± 0.50	1.75 ± 0.41
Stomach upset (1 = not upset; 5 = extremely upset)					
PW	1.13 ± 0.13	2.00 ± 0.50	2.75 ± 0.62	2.25 ± 0.56	1.75 ± 0.31
CW	1.50 ± 0.33	1.75 ± 0.37	1.75 ± 0.31*	1.13 ± 0.13	1.00 ± 0.00*
CEB	2.00 ± 0.33	2.63 ± 0.53	3.25 ± 0.67+	1.88 ± 0.40	1.25 ± 0.16

*, Significantly different from PW at p< 0.05. +, Significantly different from CW at p<0.05.

However after exercise-induced dehydration the plasma glucose concentration was between 4.30 to 4.52 mmol l^{-1} but still within the normal range. During the 2 h rehydration period, plasma glucose concentration was significantly higher with CEB compared with PW. However, during the CW trial, plasma glucose was only significantly higher compared with PW during the first 90 min but at 120 min it was similar to PW. When compared with the CW trial, the plasma glucose concentration of CEB was significantly higher at 30 and 60 min of the rehydration period.

Fluid sensory scale

Data from the fluid sensation scale are presented in Table 2. There were no significant difference for thirst sensation between the three trials at any time point during 2 h rehydration period. CW was sweeter than PW at the time when the drinks were given but was not significantly sweeter than CEB at the same time point. Sensation of nausea with PW trial was significantly greater than CW at 60 min and 120 min during 2 h rehydration period and similarly significantly greater than CEB at 90 min and 120 min.

No significant differences for fullness were noted

Table 3 Rehydration results from selected references

Reference	% Dehd.	Dur	Rehy Sol.	Vol	Na	RI
Costill and Sparks 1973	3.82	3 h	C-E (Na, K, Cl)	100%	22.00	2.60
	3.82	3 h	H_2O	100%	–	2.60
Gonzales et al., 1992	2.63	2 h	C-E (Na, K, Cl)	100%	20.00	1.88
	2.63	2 h	H_2O	100%	–	2.37
Lambert et al., 1992	4.12	4 h	C-E (Na, K, Cl)	100%	10.90	2.38
	4.12	4 h	E (Na, K, Cl)	100%	10.90	2.70
Nielsen et al., 1986	3.14	2 h	C-E (high Na)	107%	128.00	1.44
	3.14	2 h	C-E (high K)	107%	43.00	1.78
	3.14	2 h	C-E (low Na)	107%	43.00	2.01
Nose et al., 1988	2.30	3 h	H_2O (Na caps)	78%	77.00	1.76
	2.30	3 h	H_2O	71%	–	2.49
Mitchell et al., 1994	2.45	3 h	E (Na, K, Cl)	100%	14.98	4.15
	2.45	3 h	E (Na, K, Cl)	150%	14.98	3.25
Current results	2.74	2 h	H_2O	120%	–	1.71
	2.79	2 h	Natural drink	120%	5.00	1.56
	2.82	2 h	C-E (Na, K, Cl)	120%	19.00	1.36

Dur = duration of rehydration procedure: Na^+ expressed in mmol.l^{-1}; C = carbohydrate; E = electrolyte; Natural drink = fresh young coconut water; Vol = volume ingested expressed as a percentage of weight lost; RI = rehydration index.

during the 2 h rehydration period except at 30 min. where the fullness sensation was the lowest in CW. Stomach upset sensation was generally lower with CW after the first 30 min of the 2 h rehydration period with significantly lower sensation at 60 min when compared with PW and CEB.

Discussion

In this study, after drinking a volume equal to 120% of the body fluid loss during exercise, we observed that the percent rehydration and rehydration index of CW are similar to CEB and PW but the index appears better than PW during the 2 h period following exercise (Fig. 2). The difference was however not significant statistically CW (75 ± 5%), CEB (80 ± 4%) and PW (73 ± 5%).

Previous investigations have produced a degree of rehydration ranging between 50–80% during a rehydration period of 2–3 h using a variety of rehydration regimens (Costill and Sparks, 1973; Gonzales et al., 1992; Lambert et al., 1992; Nielsen et al., 1986; Nose et al., 1988). Although percent rehydration is a useful measure of the effectiveness of a particular regimen, because of the variations in the degree of dehydration, volume ingested, duration of rehydration, drink composition, and other parameters, it is difficult to make a meaningful comparison between any previous rehydration protocols. To overcome these differences, Mitchell et al. (1994) suggested use of the term "rehydration index" to arrive at some useful conclusion on rehydration effectiveness. A brief summary of the methods and results of selected investigations is presented in Table 3.

Mitchell et al. (1994) suggested a value of 1.0 is optimal and anything greater indicates less effective use of ingested fluid. The RI therefore accounts for differences in percent dehydration and the volume administered. The use of the percent rehydration factor in the formula prevents erroneous results that might be obtained if a very small volume was consumed with high utilization of ingested fluid but low actual body weight restoration.

The RI in our study for CW, CEB, and PW is 1.56, 1.36 and 1.71 respectively, where 120% of the weight loss through dehydration was replaced. This RI for PW in our study is lower than that reported in other studies where the RI for water is more than 2.0 for subjects who drink a volume equivalent to 71–100% body weight loss during exercise (Costill and Sparks, 1973; Gonzales et al., 1992; Nose et al., 1988).

The presence of sodium in the rehydration solution may improve the RI. RI of 1.44 and 1.76 has been reported following ingestion of solution with 128 mmol l^{-1} NaCl (Nielsen et al., 1986) and water with a NaCl capsule corresponding to 77 mmol l^{-1} (Nose et al., 1988) but using a volume equivalent to 107% and 78% of the body weight loss respectively. However, when a sodium concentration that is typical of most sports drinks (20 mmol l^{-1}) is used the results of the RI were higher ranging from 1.88 to 2.60 (Gonzales-Alonso et al., 1992; Costill and Sparks, 1973).

With on RI of 1.56 for CW with a sodium content of 5 mmol l^{-1} and RI of 1.36 for CEB with a sodium content of 19 mmol l^{-1} it appears that the RI is better when a relatively large sodium content in the rehydration solution is present. The sodium content of CEB of 19 mmol l^{-1} is close to that recommended for a rehydration beverage for the purpose of replacement of fluid and to stimulate absorption (20–30 mmol l^{-1}) (Mitchell et al., 1994).

With reference to the volume ingested, a drink volume equivalent to 120% of the sweat loss was consumed in the present study. This volume was appropriate as shown by Shirreffs et al., (1996) although in their study they the latter the investigators were examining the possible interaction between beverage volume and its sodium content (low: 23 mmol l^{-1} and high 61 mmol l^{-1}). The urine volume produced was related to the beverage volume consumed; the smallest urine volume was produced when 50% of the fluid loss was consumed and the greatest when 200% of the fluid loss was consumed. The subject could not return to euhydration if he only consumed a volume equivalent to, or less than, their sweat loss, irrespective of the drink composition. When a drink volume equal to 150% of the sweat loss was consumed, the subject became slightly hypohydrated 6 h after drinking if the test drink had a low sodium concentration, and he was in a similar condition when he drank the same beverage of a volume twice his sweat loss. With the high sodium drink, enough fluid was retained to keep the subject in a state of hyperhydration 6 h after drink ingestion when he consumed either 150% or 200% of his sweat loss. The excess would eventually be lost by urine production or by further sweat loss if the person resumed exercise or moved to a warm environment. The value of 120% of sweat loss attained in the present study maybe sufficient to restore lost fluid as net fluid balance was slightly positive at the end of 90 minutes (Fig. 6).

Complete restoration of fluid balance after exercise is an important part of the recovery process and becomes even more important in hot, humid conditions. If a second bout of exercise has to be performed after a relatively short interval, the speed of rehydration becomes of crucial importance. Rehydration after exercise requires not only replacement of volume losses, but also replacement of the electrolytes, primarily sodium, lost in sweat. The electrolyte composition of sweat is highly variable among different people and matching electrolyte loss with an equal quantity from a drink is virtually impossible in a practical situation. Ingesting excess sodium is rarely a problem if the volume intake is sufficient and if renal function is unimpaired. Any excess sodium ingested will be lost in the urine as the kidneys restore equilibrium (Shirreffs and Maughan, 2000).

The percentage change of blood volume during the three trials were lower immediately after exercise-induced dehydration when compared with pre-exercise levels. The blood volume changes were higher but not significantly different during the rehydration period with CW when compared with PW and CEB (Fig. 3), although the CW has a high potassium content (53 mmol l^{-1}) with same carbohydrate. This change in blood volume is similar to the findings of Nielsen et al., (1986) using a high potassium beverage. The plasma volume increase was greater when a drink with sodium as the only added cation (at concentration of 43 and 128 mmol l^{-1}) was consumed. When a drink containing additional potassium (at concentration of 51 mmol l^{-1}) or less electrolyte and more carbohydrate was consumed the plasma volume also increased. It is suggested that the rate and extent of change in the plasma volume in recovery from exercise-induced dehydration is different when different carbohydrate and electrolyte solutions are consumed (Nielsen et al., 1986).

Sweat-induced dehydration will decrease plasma volume and increase plasma osmotic pressure in proportion to the level of fluid loss. Plasma volume decreases because it provides the precursor fluid for sweat. Osmolality of plasma increases because sweat is ordinarily hypotonic relative to plasma (Kubica et al., 1980; Senay, 1968).

The results showed that urine osmolality in the CW trial at 120 minutes and CEB trial at 90 minutes rehydration period was significantly higher compared to PW (Fig. 5). The higher tonicity observed with CW and CEB may have been responsible for its greater fluid retention. Conversely, rehydrating with plain water diluted the blood since osmolality at the end of the rehydration period was lower compared with the euhydrated value. The low urine osmolality during PW is the result of an increased fluid clearance by the kidneys leading to additional urine formation and restoration of osmolality during the 2 h rehydration period. This is evident with the cumulative urine volume (Fig. 4).

Besides urine formation, another factor causing the incomplete rehydration observed in the present study is the result of additional body water loss incurred as a result of insensible sweating and respiration, along with the body weight lost due to substrate metabolism during the 2 h rehydration period.

Studies have shown that the ingestion of plain water after exercise-induced dehydration results in a rapid fall in plasma osmolality and in the plasma sodium concentration (Nose et al., 1988). Both these effects will stimulate urine output. Costill and Sparks (1973) showed that ingestion of a glucose-electrolyte solution after dehydration resulted in a greater restoration of plasma volume than did plain water; a higher urine output was observed on the water trial.

Nielsen et al. (1986) did not find significant differences in the calculated "net water gained" and thus, total body water ingestion (110% fluid lost) of four carbohydrate-electrolyte solutions (osmolalilty range, 229–465 mOsm kg^{-1}) was observed during a 2 h rehydration period. They observed 68%, 73% and 81% rehydration with the normal sugar and Na^{+}, high K^{+}, high sugar and high Na^{+} solution, respectively. However, they observed significant difference in the calculated rehydration of the various body fluid compartments. Nose et al., (1988) found a significantly higher net gain or percent rehydration with a hypotonic NaCl (0.45 $g.l^{-1}$) solution compared with plain water (71% & 51%, $p<0.05$) after a 3 h ad libitium rehydration period. The difference in the degree of rehydration among these solutions appeared to be related to changes in the renin-angiotensin-aldosterone system (Nose et al., 1988; Wade et al., 1980). However, results from studies using ad libitum rehydration procedures should be interpreted with caution when compared with studies that use forced fluid consumption (as in our study), because during the former, different amounts of fluid are ingested and the subjects do not voluntarily drink a volume equal or more to their fluid losses (Nose et al., 1988; Costill and Sparks, 1973).

It is noted that from the effects of the solute content of the drinks on the rehydration of the different body fluid compartments in human (Nielsen et al., 1986; Nose et al., 1988) and animal models (Morimoto et al., 1981), incomplete rehydration appears to be partially due to an electrolyte deficit available from intra and extracellular spaces (Nose et al., 1988a; Nose et al., 1988b).

Serum Cl^- and osmolality were significantly higher immediately at the point of exercise-induced dehydration in all trials when compared with a pre-exercise euhydrated level, however, the increase was within the normal range (Fig. 7 & Fig. 8). Serum Na^+ and K^+ were significantly higher during an exercise-induced dehydration period in CEB and CW trials respectively when compared with the pre-exercise euhydrated concentration but, they were still within the normal range (Fig. 7).

Sodium and chloride are primarily responsible for an elevated plasma osmolality (Senay, 1968). It is the plasma hyperosmolality that mobilizes fluid from the intracellular to the extracellular space to enable mount a plasma volume defense in hypohydrated subjects.

Sodium is present primarily in the extracellular space, which accounts for about two-thirds of the total body water content. The plasma sodium concentration is normally about 140 mmol l^{-1}, compared with an intracellular concentration of about 10 mmol l^{-1}. Potassium is present mainly in the intracellular space, at a concentration of about 150 mmol l^{-1} and the plasma potassium concentration is normally about 4–5 mmol l^{-1}. Water loss during exercise in the heat is derived from both intracellular and extracellular compartment (Maughan et al., 1994). In the initial few minutes of exercise, there is a redistribution of body water in response to increased capillary filtration pressure in the muscle vascular bed and an increase in the osmolality of metabolically active tissues; these factors generally result in a 5–15% reduction in the plasma volume within the first 10–15 minutes of exercise (Senay et al., 1980). If exercise continues beyond this time, a net water loss occurs due to sweating, but there is little further change in the plasma volume in the absence of fluid intake.

The distribution of body water loss during prolonged exercise is influenced by several factors, including the ambient temperature (Harrison, 1985). The proportion of water loss derived from the extracellular space appears to increase with the ambient temperature (Kozlowski and Saltin, 1964), but because of the difficulty in measuring the change in the volume of the different body water compartments, there are few reliable data. Subjects in the present study were dehydrated by exercise in an environment maintained at a temperature of 31°C, and it is possible that about one-third of the water loss was derived from the intracellular space (Costill et al., 1976).

Serum K^+ was significantly higher in CW compared with CEB and PW due to the higher content of K^+ which was naturally found in CW (± 53 mmol l^{-1}). High electrolyte in the rehydration solution is necessary to rehydrate the body and replace lost electrolytes as a result of sweating. According to Yawata (1990) there was tendency for a greater restoration of the intracellular fluid space in the KCl group despite ingestion of a smaller volume of the KCl solution.

Sweat composition not only varies among different people, but also varies with time during exercise and is further influenced by the state of acclimatization. Typical sweat values for respective sodium and potassium concentration are about 50 mmol l^{-1} and 5 mmol l^{-1} (Maughan and Shirreffs, 1998). Drinks intended specifically for rehydration should therefore have higher electrolyte content than drink formulated for consumption during exercise.

During the rehydration period plasma glucose increased during the CW and CEB trial as both contain glucose at a concentration of 139.63 ± 4.95 mmol l^{-1} and 179.40 ± 2.40 mmol l^{-1} respectively. Hence, at the end of 2 h rehydration period, the glucose levels of CW was similar to PW but significantly lower than CEB (Fig. 9). During exercise, the rate of glucose intake by the active muscles was 20 times greater compared to the resting state. The blood glucose concentration was regulated by the process of glycolysis or gluconeogenesis (Wolinsky, 1998).

Ingestion of carbohydrate during rapid rehydration would be advantagous, as the rate of muscle glycogen resynthesis is as reportedly 3 times faster if carbohydrate is ingested immediately after exercise as opposed to delaying feeding by 2 h (Ivy et al., 1988). These authors have also reported that the ingestion of carbohydrate at a rate of 1.5 g kg $weight^{-1}$ $hour^{-1}$ elicited a rate of muscle glycogen resynthesis of 5.8 and 4.5 mmol l^{-1} kg wet weight of muscle respectively during the first and second two-hour periods of recovery from exhaustive exercise. Thus, uncompromised fluid replacement and a high rate of carbohydrate delivery 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 (Lambert et al., 1992).

Recent evidence suggests that the ingestion of solutions with a relatively high carbohydrate concentration (7.5–10%) during exercise did not impair fluid replacement relative to water or a water placebo, as determined from plasma volume changes and gastric emptying (Mitchell et al.,1988; Owen et al., 1986). The data from Lambert et al., (1992) as well as the earlier work of Costill and Sparks (1973) suggested that 10% carbohydrate solutions and non-carbohydrate solutions are equally effective in replacing a body water deficit. Thus, in addition to providing a substantial amount of carbohydrate, it appears that a high rate of fluid replacement can be attained at rest even when the carbohydrate concentration is as high as 10%. Thus the presence of glucose in CW makes it an interesting beverage for restoration of both fluid and glucose during the rehydration phase.

The results obtained show that, CW was sweeter, caused less nausea, fullness and no stomach upset (Table 2). These characteristics are ideal when taking into consideration the determination of an ideal rehydration fluid. Due to its palatability, it is also easier to consume a larger amount of CW despite having a low Na^+ and high K^+. Although a low sodium content is ineffective in rehydrating due to its reduced stimulus to drink, but on the other hand a high Na^+ concentration in drinks makes the taste undesirable resulting in reduced consumption (Shirreffs and Maughan, 2000).

Throughout this study, the subjects found that consumption of PW reduced the stimulus to drink especially when they had to consume 120% of the body weight lost. In one case, PW caused nausea and some subjects' vomited. This trial was then repeated on another day.

In addition, from the present author's observation, the subjects could drink the last bolus of CW which was 30% of 120% of body weight lost, at 60 minutes rehydration period without having the sensation of fullness and no stomach upset whilst with PW and CEB, the subjects took a longer time to finish drinking and suffered fullness and stomach upset. Hence, our data of fluid sensation showed that CW is suitable as a rehydration solution.

Conclusion

The rehydration index showed the same trend with percent rehydration. Plasma glucose concentration was significantly higher when CW and CEB were ingested when compared with PW ingestion during the rehydration period. CW was significantly sweeter, caused less nausea, fullness and no stomach upset and it is also easier to consume a larger amount of CW when compared with CEB and PW ingestion. Ingestion of CW, a natural drink, is similar to the ingestion of CEB, carbohydrate-electrolyte beverage which was used as a reference drink for whole body rehydration. Hence, it can be concluded that CW could be used for whole body rehydration after exercise-induce dehydration. For further investigation, to see the effectiveness of fresh young coconut water on whole body rehydration after exercise-induced dehydration, it was suggested to increase the sodium content of CW equivalent to a recommended sports drink.

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