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Effects of hydration strategies on physiological and performance parameters in national level school athletes

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Abstract

The study was conducted as a randomized, counterbalanced crossover study to determine the relative effectiveness of four hydration drinks on various physiological and performance criteria in the adolescent athletes playing on the national school level (n=23). The drinks under investigation were Jeevani (J) a conventional electrolyte solution; plain water (W); a commercially available carbohydrate-electrolyte sports drink (Y) and king coconut water (KC). All the participants were subjected to a standardized endurance exercise protocol at each beverage condition and there was 7 days wash out between the sessions. The state of hydration was measured utilizing bioelectrical impedance analysis (BIA) to estimate the overall body water changes and through determining the rate of sweat. Aerobic capacity (maximal oxygen uptake (VO 2 max) measured using the multi-stage beep test), neuromuscular performance (dominant and non-dominant handgrip strength and vertical jump), psychomotor (reaction time in the drop-stick test), cardiovascular responses (heart rate and blood pressure kinetics), and subjective performance (visual analogue thirst scale and symptom checklist) were performance measures. Shapiro-Wilk tests was used to assess normality of data, test of Friedman and repeated-measures ANOVA with Greenhouse-Geisser correction was used to determine statistically significant differences. Post-hoc comparisons were performed using Wilcoxon signed-rank tests and a Bonferroni-adjusted significance level of 0.0083. There was a significant overall impact of of the beverage used for the intervention ($p < 0.001$). The isotonic solution had better hydration effects with little fluid loss, the lowest sweat rate (2.10 ml/min) and a positive body mass change (+0.10 kg), and the highest VO 2max (44.8 ± 4.9 ml kg^{-1} min^{-1}). King Coconut water also exhibited good fluid retention as compared to plain water. Jeevani enhanced handgrip strength (44.0 ± 5.1 kg) and had a positive subjective thirst rating. On the other hand, plain water always resulted in larger loss of sweat, slower rate of heart-rate recuperation and symptoms. Overall, the beverages that were found to be more effective in maintaining euhydration and improving performance during prolonged exercise sessions were electrolyte based and natural coconut water compared to plain water.

Keywords: Cognitive function; electrolyte beverages; endurance performance; Hydration; neuromuscular function

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Introduction

Hydration is a pillar of human physiology, which has a direct effect on thermoregulation, cardiovascular stability, neuromuscular .coordination, cognitive processing, and general athletic performance. Water is a fluid that comprises about fifty to sixty percent of total body mass, which is essential in maintaining plasma volume, regulating body temperature, transferring nutrients, and metabolic reactions (Sawka et al., 2007; Cheuvront & Kenefick, 2014; Maughan & Shirreffs, 2008).When body exertion occurs, especially in hot and humid conditions, the heat production by the metabolic system is remarkably high and evaporative cooling by the body is the main route of cooling down (Adams et al., 2018). This inevitably leads to the loss of fluids and electrolytes and when these are not replaced significantly, hypohydration occurs and this reduces the effectiveness of thermoregulation, increases the load on the heart, and decreases physical and mental performance (Sawka et al., 2007).

Accumulating empirical evidence supports the claim that dehydration of one to two percent of body weight can increase the heart rate and perceived exertion, reduce endurance, attention, working memory and reaction time (Masento et al., 2014; Sawka et al., 2007; Cheuvront & Kenefick, 2014). These findings have specific implications on sporting activities that require quick sensorimotor reactions and sustained aerobic performance. Comparative study of beverages also indicates that the composition of drinks has significant influence on the post exercise fluid retention and recovery (Millard-Stafford et al., 2021; Choi et al., 2021). The Beverage Hydration Index (BHI) concept helps to emphasize that the electrolytes and carbohydrates in the beverages cause an improved fluid retention in comparison with plain water (Millard-Stafford et al., 2021). Electrolyte-carbohydrate fluids promote intestinal sodium-glucose cotransport, increase restoration of plasma volume, elicit thirst in an appropriate way and reduce the risk of dilution hyponatremia during intense exercise (Jeukendrup, 2011; Hew-Butler et al., 2020).

Natural substitutes such as coconut water have also been considered as culturally viable rehydration method in tropical weather. Coconut water contains high levels of potassium, moderate sodium, natural sugars, and biomolecules which could aid in fluid homeostasis and neuromuscular restoration (Kalman et al., 2012; Saat et al., 2002). Several controlled trials have indicated that coconut water has rehydration effects similar to commercial sports beverages when there is moderate dehydration, but its reduced sodium content might decrease effectiveness in situations of excessive loss of sweat (Laitano et al., 2014; Ly et al., 2023). Although the data is promising, the results are inconsistent when it comes to environmental stress, formulation of the beverage, and other characteristics of the participants.

The hydration condition also affects the operations of the central nervous system. The systematic reviews report that mild dehydration has adverse effects on psychomotor velocity, vigilance, mood, and decision-making (Masento et al., 2014; McMorris, 2016). A very important factor in determining the performance and safety in most sports, reaction time has been demonstrated to slow with regulated dehydration conditions (Cheuvront & Kenefick, 2014). These effects can be enhanced in tropical regions with the higher rate of perspiration, sodium loss, and reduced cooling efficiency with evaporative cooling (Rivera-Brown & Pagan-Lassalle, 2023; Surapongchai et al., 2021). Studies on athletes who are training in hot environments have continued to note significantly higher fluid losses as compared to their counterparts in temperate habitats, which underscores the need to adopt context specific hydration plans (Rivera-Brown & Pagan-Lassalle, 2023; Cheuvront & Kenefick, 2014).

However, most of the literature focuses on adult or elite athletes who were studied in a laboratory environment in temperate climates. Little research has been done on school-aged athletes in tropical South Asian settings using empirical studies on hydration strategies (Sawka et al., 2007; Maughan & Shirreffs, 2008; Cheuvront & Kenefick, 2014).In Sri Lanka, national school athletes are used to use plain water as it is available and cheap, but the domestic alternatives like king coconut water and traditional electrolyte beverage Jeevani are also used. Few studies have simultaneous determination of hydration indices, neuromuscular activity, cognitive reaction speed, cardiovascular recovery, and perceptual changes among endurance athletes in a single experimental design in adolescent groups. Scientific comparisons of such culturally relevant beverages with commercial isotonic beverages are limited.

The current study aims to fill this gap in evidence by making comparative assessments of four hydration options, such as commercial isotonic beverage, Jeevani (traditional electrolyte beverage), king coconut water, and plain water through a randomized crossover design among the national school athletes training under tropical weather (Jones & Kenward, 2014). The state of hydration was measured using bioelectrical impedance analysis (BIA), changes in body mass, and estimation of the sweat rate (Kyle et al., 2004; Sawka et al., 2007). Maximal oxygen uptake (VO 2max) measured through the 20-m multistage fitness test, height of vertical jump, handgrip strength, reaction time, cardiovascular recovery indices, and subjective thirst and fatigue scores were included as performance outcomes (Léger et al., 1988; Marković et al., 2004; Hopkins et al., 2009; Achten & Jeukendrup, 2003).

The proposed investigation is based on the well-known physiological theories of fluid balance and thermoregulation (Sawka et al., 2007), the mechanisms of sodium-glucose transport (Jeukendrup, 2011), and central fatigue theories which relate the state of hydration and the cognitive and neuromuscular performance(Cheuvront & Kenefick, 2014).The hypothesis around which the study was developed implied that electrolyte containing beverages either commercial or natural were going to result in better hydration retention, better endurance and neuromuscular performance, faster reaction time and better perceptual recovery than plain water in adolescent athletes under the influence of tropical environmental stress.

As a result, the major objective of the study was to evaluate and compare the acute outcomes of four hydration interventions on the hydration state, endurance performance, neuromuscular functioning, reaction-time, cardiovascular recovery, and subjective perceptions of national school-level athletes. The hypothesis was that beverages containing electrolytes and king coconut water would have more physiological and performance advantages compared to pure water, especially in terms of keeping the body hydrated and in relation to exercising in a tropical environment.

The present study provides region-specific evidence to sports science by incorporating physiological, neuromuscular, cognitive, and perceptual aspects in a contextually relevant population. The results are expected to be used to make practical hydration guidelines to youth athletes and coaches in Sri Lanka and similar climates, and close the gap in knowledge between the existing models of hydration in laboratory settings and ecologically valid, culturally relevant models of hydration.

Methodology

Study design

This study followed a carefully designed quantitative experimental design where the study design had a randomized counterbalanced crossover study where each respondent acted as a control group thus reducing the level of inter-individual variation in terms of fitness level, metabolic, and hydration response. The crossover protocol was implemented based on the current recommendations regarding nutritional intervention (Hopkins et al., 2009), and no modifications to the basic protocol were made except that the environment was closely monitored and the test sessions were fixed with the purpose of avoiding circadian effects (Hopkins et al., 2009; Reilly & Waterhouse, 2009).

The controlled indoor environment was used to test all the tests to rule out the variable of changing weather. The testing room temperature and humidity were not continuously recorded; however, all trials were conducted under the same indoor laboratory conditions to maintain consistency across sessions. The target population was all male, national-level school athletes aged 15-19 years, who participated in rugby, basketball, swimming and athletics, and Male athletes were selected to minimize physiological variability associated with sex-related differences in body composition, hydration regulation, and hormonal fluctuations, thereby improving internal validity within the crossover design. Participants were recruited using purposive sampling because the study required athletes who met specific performance and training characteristics relevant to the research objectives. Only athletes with national-level competitive experience and the required training background were included, ensuring a homogeneous sample appropriate for evaluating hydration interventions under controlled conditions. Although this sampling approach enhanced the precision of within-subject comparisons, the absence of female participants further limits the generalisability of the findings beyond male adolescent athletes, in addition to the previously noted sampling limitations.

The eligibility criteria included that the person must have had at least two years of competitive training experience with a minimum training load of five hours per week, medical clearance that the person has not sustained any injury in the previous six months, and that the person has not taken hydration-altering medication or supplements (Shirreffs & Sawka, 2011). The exclusion criteria were cardiovascular disorders, renal disorders, and metabolic disorders, acute illness, and the use of supplements that might alter the state of hydration (Shirreffs & Sawka, 2011).

The determination of sample size was conducted with the help of G*Power version 3.1.9.7 (Faul, Erdfelder, Lang, & Buchner, 2007), with alpha = 0.05, power=0.80, and medium effect size (f=0.25), which led to a minimum of 20 participants. Taking into consideration the possible attrition, 23 athletes were recruited, and each of them represented an independent observational unit.

All the participants had four sessions of the experiment with a period of 7 days to allow the participants to be hydrated and to restore electrolyte balance (Maughan & Shirreffs, 2010). Assigned the beverage order randomly. The hydration conditions included: (1) Commercially available Isotonic Sports Drink (Y), (2) Jeevani Herbal Electrolyte Drink (3) fresh king coconut water (*Cocos Nucifera var aurantiaca*), locally obtained and normalized at 500mL, and (4) potable water, The participants were asked to consume 500 mL of the given beverage both at a temperature of 8–10°C over 10 minutes and a 30 minutes rest sitting in one position to ensure fluid absorption (Sawka et al, 2007; Maughan & Shirreffs, 2008). There were no sessions that fell outside the period of 10:00 AM and 12:00 PM to ensure there was control of circadian variation (Reilly & Waterhouse, 2009).

Before participation in the study, the participants were instructed to avoid vigorous physical activity 24 hours prior to the testing, avoid caffeine and alcohol 12 hours before testing, keep normal hydration and starve three hours before the experiment (Shirreffs & Sawka, 2011). On arrival the participants emptied their bladder and put on light sporting clothes.

A Digital Health Scale (Fuji Model FDHC-160/350L, Fujian, China; accuracy = ±0.1kg) was used to record baseline anthropometric and physiological measurements (weight), a Portable Stadiometer (Seca 213, Seca GmbH, Germany) to measure height, and a multi-frequency Bioelectrical Impedance Analyzer (Biody Xpert ZM II, Aminogram, France; Model BXZ-II) to measure total body water (TBW), according Automatic Blood Pressure Monitor (Omron HEM-7120, Omron Healthcare Co., Kyoto, Japan) was used to record the resting heart rate and blood pressure.

The handgrip strength measured with Takei Digital Grip Dynamometer (Model T.K.K.5401, Takei Scientific Instruments Co., Japan), vertical jump height measured with Jump Mat (Model JM-01, FS Electronics, Australia), and reaction time measured with Drop-Stick Test (50 cm ruler method) were used to measure muscle performance. Each of the variables was tested three times and the optimal was saved to be analyzed (Hopkins et al., 2009).

The participants then undertook Multistage Fitness Test (Beep Test), 20 m as detailed by Ramsbottom et al. (1988). The last shuttle level was documented and transformed to predicted VO_2-max with formula: VO_2 max ($mL \cdot kg^{-1} \cdot min^{-1}$) = 3.46 × (final speed) + 14.4. This value represents an estimated VO_2 max derived from the beep test. There was no deviation from the standard protocol (Ramsbottom et al., 1988).

The body weight, heart rate, and blood pressure were quickly measured right after the exercise. Heart rate was measured 1 minute after the exercise as a measure of cardiovascular recovery (Achten & Jeukendrup, 2003). Thus, cardiovascular recovery was assessed at 1-minute post-exercise as the primary recovery time point. The grip strength, vertical jump, and reaction time was measured again. The subjective thirst was measured by a 10-point visual analogue, whereas the symptoms were recorded with the help of a 12-item dehydration checklist (Cheuvront & Kenefick, 2014).

Outcome variables included sweat rate as (Pre -exercise weight) / exercise time (hours), change in total body water (Post -Pre exercise weight) - Post -Pre exercise weight)(Sawka et al., 2007), muscle performance change (Post -Pre exercise values), reaction time delay (Post -Pre exercise values) and cardiovascular recovery (post-exercise heart rate -pre-exercise heart rate)(Achten and Jeukendrup, 2003).

Statistical analysis

IBM SPSS Version 23.0 (IBM Corp., 2019). were used to perform the statistical analyses. The result of descriptive statistics was presented as mean, mean standard deviation of parametric data and median, (interquartile range) of non-parametric data (Field, 2018). The assessment of normality was done by the Shapiro Wilk test. The test of sphericity was considered through the test of Mauchly and Greenhouse-Geisser corrections were done in cases where the assumptions were not met (Field, 2018).

Parametric variables were investigated by parametric ANOVA, non-parametric variables by the Friedman test, pairwise comparisons adjusted by Bonferroni (0.0083), and non-parametric post-hoc by the Wilcoxon signed-rank test (Field, 2018). The effect sizes were expressed in terms of partial eta squared (ηp^2) and interpreted according to proposed guidelines: 0.01 (small), 0.06 (medium), and 0.14 (large) (Field, 2018). A $p < 0.05$ was considered statistically significant .

To optimize the sequencing of the procedures, a pilot study (n = 5) was performed. To prevent activation bias, baseline physiological measurements of the body were always taken before the performance tests. The reliability of test-retest assessed through Intraclass Correlation Coefficients indicated that grip strength (0.96), vertical jump (0.95), total body water (0.94), and reaction time (0.89) had high reliability (Hopkins et al., 2009). All instruments were calibrated according to the manufacturer requirements, and all measurements were done by a single trained investigator to reduce the inter-rater variability. Construct validity was ensured by using established and validated testing protocols (Ramsbottom et al., 1988; Sawka et al., 2007).

Ethical Clearance Statement

Ethical approval for this study was obtained from the University of Kelaniya Ethics Review Committee, approval number UOK/ERC/FS/2025/052, dated 12/09/2025. The study was conducted in accordance with the Declaration of Helsinki(World Medical Association,2013). Written informed consent was obtained from all participants and their legal guardians prior to participation. Participant confidentiality and data protection were strictly maintained throughout the study.

Results

The comparative study examined the differences of four hydration drinks, Jeevani (J), plain water (W), a commercial isotonic sports drink (Y), and King Coconut water (KC) on the status of hydration, endurance performance, neuromuscular capacity, reaction time, cardiovascular recovery, and subjective experiential measures in a group of young athletes. The demographic and anthropometric characteristics of the study participants are given in Table 01.

Table 1: Participant demographic and anthropometric characteristics (N=23)

Characteristic	Mean ± SD	Range	95% Confidence Interval
Age (years)	16.5 ± 1.2	15 – 19	15.9 – 17.0
Height (cm)	171.5 ± 6.2	161 – 181	168.8 – 174.2
Body Mass (kg)	70.2 ± 15.2	50.5 – 111.0	63.5 – 76.9
BMI (kg/m^2)	23.8 ± 4.8	18.3 – 38.0	21.7 – 25.9
Training Experience (years)	5.1 ± 2.3	3 – 10	4.1 – 6.1

Hydration Outcomes

Friedman tests found that there are meaningful differences in modalities of drinks in comparison with sweat rate, body mass change, and total body water change (all $p < 0.05$). The isotonic solution (Y) recorded the lowest rate of sweat and ideal body mass maintenance, including a small positive change in mass change (+0.10 kg). Plain water was related to maximum loss of fluid and high rate of sweat; king Coconut water showed average fluid loss in comparison to plain water but slightly lower than isotonic beverage (Table 2). These observations directly relate to the main goal of the hydration efficacy.

Table 2: Hydration status measures across beverage conditions (median ± I)

Beverage condition	Sweat rate (ml/min)	ΔBody mass (kg)	Δ BIA hydration (%)
Jeevani (J)	5.80 (3.10 – 9.80)^{ab}	-0.40 (-0.80 – 0.00)^{a}	0.00 (-0.05 – 0.06)^{b}
Water (W)	7.50 (4.50 – 10.70)^{a}	-0.40 (-0.60 – -0.10)^{a}	-0.10 (-0.15 – -0.03)^{a}
Isotonic (Y)	2.10 (1.60 – 2.90)^{c}	0.10 (-0.03 – 0.20)^{b}	0.01 (-0.03 – 0.07)^{b}
King Coconut (KC)	3.90 (2.40 – 5.60)^{bc}	0.00 (-0.10 – 0.10)^{b}	0.03 (0.00 – 0.08)^{b}
Friedman $\chi^2(3)$	33.626	24.180	18.335

VO_2 max performance (endurance)

Sphericity on repeated-measures ANOVA conditions was tested with Mauchly test, violations ($p<0.05$) supported the use of the Greenhouse Geisser adjustments. The repeated-measures ANOVA showed the presence of significant beverage-condition main effect on the estimated VO_2 max (Greenhouse Geisser adjusted $F = 12.89$, $p = 0.001$, partial $\eta^2 = 0.37$). Follow-up post hoc tests suggested that the isotonic drink had significantly higher VO_2 max values as compared to all other drinks (Table 3). The magnitude of the effect was high, highlighting an important role of the beverage composition on the aerobic capacity.

Table 3: Endurance performance (VO_2 max) across beverage conditions (mean ± SD)

Beverage condition	VO_2 max (ml/kg/min)
Jeevani (J)	41.33 ± 8.05^{b}
Water (W)	41.08 ± 8.30^{b}
Isotonic (Y)	45.43 ± 6.88^{a}
King Coconut (KC)	42.23 ± 6.75^{b}
RM ANOVA	$F(2.13, 46.84) = 12.89$, $p < .001$, $\eta p^2 = .37$

Different superscript letters denote significant pairwise differences at $p < 0.05$ (Bonferroni-adjusted). Sphericity was violated (Mauchly's W = .482, p = .010); Greenhouse-Geisser corrected degrees of freedom are reported.

Neuromuscular performance

Vertical jump performance (p = 0.004) and grip strength (p < 0.001) showed significant differences between them based on Friedman analyses. Isotonic beverage produced the most significant increase in the jump height, and the isotonic and King Coconut beverages maintained grip strength better than plain water. Water alone always gave the lowest performance points (Table 4).

Table 4: Neuromuscular function measures across beverage conditions (median ± IQR)

Beverage Condition	Δ Vertical jump (cm)	Δ Grip strength – Right (kg)	Δ Grip strength – Left (kg)	Δ Grip strength – average (kg)
Jeevani (J)	5.00 (-10.00 – 45.00)^{b}	0.00 (-2.00 – 2.00)^{b}	0.50 (-1.00 – 2.00)^{b}	-0.25 (-2.50 – 1.75)^{b}
Water (W)	0.00 (-35.00 – 40.00)^{b}	-0.50 (-2.50 – 1.00)^{b}	0.00 (-1.50 – 1.00)^{b}	-0.50 (-2.50 – 1.50)^{b}
Isotonic (Y)	35.00 (15.00 – 55.00)^{a}	1.50 (0.00 – 3.50)^{a}	1.50 (0.00 – 3.00)^{a}	1.50 (0.00 – 3.25)^{a}
King coconut (KC)	15.00 (-5.00 – 50.00)^{ab}	1.50 (0.00 – 3.00)^{a}	2.00 (0.00 – 3.00)^{a}	1.75 (0.00 – 3.00)^{a}
Friedman $\chi^2(3)$	13.57, p = .004	19.02, p < .001	12.59, p = .006	18.87, p < .001

Δ (delta) = post-exercise minus pre-exercise. Different superscript letters within a column denote significant pairwise differences at $p < .008$. For vertical jump, the Isotonic drink (Y) produced a significantly greater improvement than Jeevani (p = .010) and Water (p = .002).

Reaction time

Repeated-measures ANOVA indicated a large beverage-condition influence on the reaction-time ($F = 4.96$, $p = 0.012$, partial $\eta^2 = 0.18$). King Coconut water showed a statistically significant difference in reaction time compared to plain water indicating moderate effect size (Table 5).

Table 5: Reaction time change (seconds) across beverage conditions (mean ± SD)

Beverage condition	Δ Reaction time (s)
Jeevani (J)	-0.033 ± 0.047^{ab}
Water (W)	-0.002 ± 0.053^{a}
Isotonic (Y)	-0.028 ± 0.052^{ab}
King Coconut (KC)	-0.042 ± 0.032^{b}
RM ANOVA	$F(1.94, 42.60) = 4.96$, p = .012, $\eta p^2 = .18$

Δ (delta) = post-exercise - pre-exercise (negative values indicate faster reaction time). Different superscript letters denote significant pairwise differences ($p < 0.05$, Bonferroni-adjusted). Sphericity was violated (Mauchly's W = .365, p = .001).

Cardiovascular recovery

There were no statistically significant differences in the recovery of heart rate or blood pressure during the recovery process in beverage conditions (all $p > 0.05$), which showed that the type of beverage had no significant effect on short-term cardiovascular recovery (Table 6).

Table 6: Cardiovascular recovery measures across beverage conditions

Measure	Beverage condition	Statistic (Mean ± SD or Median ± IQR)	Test Result
HR recovery (bpm decrease)	J, W, Y, KC	38.1 ± 18.6, 32.6 ± 14.5, 40.0 ± 28.1, 36.1 ± 21.4	F = 1.15, p = .324, ηp^2 = .05
SBP recovery (mm Hg decrease)	J, W, Y, KC	46.0 (28.0-60.0), 38.0 (15.0-52.0), 33.0 (20.0-47.0), 31.0 (18.0-45.0)	$\chi^2(3)$ = 6.26, p = .100
DBP recovery (mm Hg decrease)	J, W, Y, KC	7.0 (-5.0-18.0), 0.5 (-12.0-14.0), 2.0 (-8.0-17.0), 5.0 (-2.0-12.0)	$\chi^2(3)$ = 3.86, p = .277

Subjective responses

The perception of thirst was found to significantly differ across conditions (p=0.001) with the highest thirst ratings being recorded with plain water. The analysis of the symptoms showed that plain water condition had more fatigue and discomfort in comparison to the beverages containing electrolytes (Table 7).

Table 7: Subjective perceptions (thirst perceptions) across beverage conditions

A. Thirst perception (1-10 scale)	Median (IQR)	Significant post-hoc comparisons (p<0.0083)
Jeevani (J)	3.5 (2.0 – 5.0)^{ab}	No significant differences Vs. other conditions
Water (W)	5.0 (4.0 – 7.0)^{a}	> Y (p = .001), > KC (p = .001)
Isotonic (Y)	2.0 (1.0 – 3.0)^{b}	< W (p = .001)
King coconut (KC)	2.0 (1.0 – 4.0)^{b}	< W (p=.001)
Friedman test	$\chi^2(3)$ = 17.62, p = .001	

Water was associated with significantly higher thirst ratings.

Table 8: Subjective perceptions (symptom perceptions) across beverage conditions

A. Symptom	% Reporting 'Yes'				
	Jeevani (J)	Water (W)	Isotonic (Y)	King Coconut (KC)	Cochran's Q Test
Dry mouth	43.5%	43.5%	39.1%	26.1%	Q(3)=4.16, p=.245
Headache	0%	8.7%	0%	4.3%	Q(3)=4.00, p=.261
Dizziness	0%	0%	0%	4.3%	Q(3)=3.00, p=.392
Fatigue	61%	65%	39%	43%	Q(3)=8.67, p=.034
Nausea	0%	0%	0%	13%	Q(3)=9.00, p=.029
Muscle cramp	8.7%	21.7%	8.7%	8.7%	Q(3)=5.40, p=.145
Confusion	0%	0%	0%	0%	-
N	13%	13%	35%	35%	Q(3)=8.33, p=.040

Significant differences were found in the incidence of fatigue, nausea and No symptoms with Water and Jeevani generally associated with higher fatigue, and isotonic and king coconut with higher reports of No symptoms (Table 8).

Altogether, electrolyte-containing drinks and especially the isotonic beverage demonstrated a better ability to maintain hydration, improve endurance and neuromuscular performances, and subjective recovery compared to simple water, which met the main aims of the study.

Discussion

The hypothesis at the beginning was that: beverages with electrolytes would provide better hydration, performance, and perceptual effects when compared to plain water in athletic cohorts of adolescents. This hypothesis is largely supported by empirical data in terms of the measures of hydration state, endurance performance, neuromuscular activity, reaction time and perceived thirst. On the other hand, immediate cardiovascular recovery was not realized as expected and should be an anticipated benefit; it showed a domain-specific pattern of support of electrolyte-based interventions.

This high performance of the isotonic sports drink is consistent with the carbohydrate-electrolytes hydration paradigm. The intake of carbohydrates during exercise maintains the intact glycogen stores within the body, and the workload (Jeukendrup, 2014), sodium enhances the absorption of intestinal fluids and retention of plasma volume (Maughan & Shirreffs, 2008). The significant portion of effect size in the results of endurance outcomes suggests that the composition of beverages significantly affected aerobic performance as opposed to being an insignificant statistical artifact. The results align with the recommendations that have been made by the American College of Sports Medicine (Sawka et al., 2007) that promotes the use of sodium-carbohydrate solutions during prolonged exercises.

King coconut water resulted in significant improvements in fluid retention and reaction time. Previous research (Saat et al., 2002) reported comparable rehydration effectiveness of coconut water and traditional carbohydrate-electrolyte sports drinks in moderately dehydrated adults. However, hydration responses between adults and adolescents may vary due to differences in body composition, sweat rate, and fluid regulation mechanisms. The present study extends existing evidence by investigating adolescents and suggests that coconut water-based hydration strategies may also contribute to cognitive benefits. The presence of electrolytes, carbohydrates, and naturally occurring bioactive compounds in coconut water may support physiological processes related to cognitive function and exercise performance. Although the underlying mechanisms were not directly assessed in the present study, these factors may provide a possible explanation for the observed psychomotor improvements.

However, subjective symptom data revealed a higher incidence of nausea (13%) and a notable prevalence of fatigue (43%) during king coconut water consumption. Although these symptoms were generally lower compared with plain water, the findings highlight the importance of individual tolerance and gastrointestinal comfort when recommending king coconut water as a hydration strategy, particularly before competition or high-intensity exercise.

Autonomic recovery in well-trained adolescents is typically robust, which may mask plasma volume–related effects. This observation is consistent with findings showing rapid parasympathetic reactivation and strong heart rate recovery kinetics in trained youth (Buchheit et al, 2007; Coote, 2010). Accordingly, cardiovascular recovery, particularly during the first minute, might not be sensitive enough to capture the effects of beverages in such a population.

Pure water was always found to have lower hydration parameters and greater thirst sensation. The speedy loss of plasma osmolality after the intake of water inhibits the discharge of antidiuretic hormone, hence resulting in diuresis and preventing fluid retention (Shirreffs, 2003). Similar findings have been reported in tropical South Asian studies, where plain water ingestion alone was insufficient to maintain hydration status during prolonged exercise compared to electrolyte-containing fluids. The implications of the perceptual results have practical implications; high levels of thirst even with fluid intake can lead to incomplete voluntary recovery of fluids in the actual training in the real world.

There are several constraints that are worth considering. To begin with, the crossover design addressed the inter-individual variability, but a rather small sample size could limit the generalizability. Second, the biochemical markers (e.g., plasma osmolality, sodium concentration, oxidative-stress measures) were not directly measured and limited the ability to interpret the results mechanistically. Third, the large number of outcome variables increases the chances of type I error, even when Bonferroni is applied. Precision of measurements may be low especially in bioelectrical impedance analysis, which is acutely sensitive to changes in fluids (Sawka et al., 2007). In addition, testing was performed in controlled indoor conditions; results can vary when hot and humid conditions are observed when thermoregulatory strain increases.

Despite these limitations, internal validity was supported by standardized protocols and environmental control as well as randomization and washout periods. Effect sizes identify meaningful practical differences, in particular, endurance performance and reaction time. The results provide new information by comparing commercial, traditional and natural hydration interventions in an adolescent sporting setting an underrepresented population in hydration studies.

In a practical way, the data support a task-specific as opposed to a universal hydration approach. Isotonic drinks seem to be the most effective in endurance and explosive athleticism, but king coconut water could have synaptic and hydrating effects. However, the higher incidence of nausea reported under the king coconut condition suggests that athlete-specific tolerance should be considered when using it as a hydration alternative. The simple water does not work after prolonged exercise.

Overall, the article supports a strategic, evidence-based treatment of hydration among adolescent athletes. Commercial and natural drinks containing electrolytes show benefits as compared to pure water, although there are different impacts across domains of physiological activity. Future studies must include biochemical biomarkers, prolong recovery response, use sport-specific field experiment and heat-stress conditions to define mechanisms and increase ecological validity.

Conclusions

The study shows that hydration strategy is a performance related determinant that is modifiable in adolescent athletes when they train in tropical climates. The results confirm that beverages containing electrolytes have significant physiological and performance benefits compared to pure water, in maintaining fluid balance, endurance capacity, and neuromuscular and psychomotor functioning. These results confirm the effects of hydration on aerobic work and even on explosive strength and cognitive reactivity, which is typically understated in the traditional hydration parameters.

The commercial isotonic beverage was the most effective one of the assessed interventions in terms of hydration and performance, which implies that a moderate carbohydrate to electrolyte ratio is the most appropriate to ensure effects during the sustained and moderate-to-vigorous-intensity exercise in the warm environment. King coconut water also offered similar hydration effects and distinct psychomotor effects, highlighting the potential of the beverage as a culturally appealing, psychomotor supportive, natural substitute in scenarios where commercially prepared products are unavailable or unwanted. On the other hand, pure water did not support performance related results in experimental environment.

Notably, there were no significant differences in short-term cardiovascular recovery, which indicated that beverage composition has a stronger effect on endurance, neuromuscular and perceptual aspects compared to instant autonomic recovery in healthy, trained adolescents. This pattern aligns with findings from both adult and adolescent hydration research, where cardiovascular recovery responses are often less sensitive to acute hydration interventions compared to performance outcomes.

The conclusion of these results is the urgent need of evidence-based hydration planning based on the duration of the exercise, the environmental factors of stress, and individual tolerance. To coaches, sport programmes and athletic institutions that especially run their activities in the tropical regions which include Sri Lanka, the adoption of well controlled and electrolyte-based hydration interventions are bound to improve the stability of performance and the health of the athletes.

Future studies must reach heterogeneous populations, longer adaption times, and sport-specific situations to narrow the line of application of the practical hydration suggestions. Additionally, future research should further compare adolescent and adult responses directly to better understand age-related differences in hydration physiology and performance outcomes.

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The authors declare no conflict of interest.

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