Title: Coconut water does not improve markers of hydration during sub-maximal exercise and performance in a subsequent time trial compared to water alone

Running title: Coconut water and hydration during exercise

Authors: Daniel J. Peart[1, 2*], Andy Hensby[1], Matthew P. Shaw[1]

[1] Sport and Biosciences, University Centre, North Lindsey College, Scunthorpe, UK

[2] Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle upon Tyne, UK

[*]Correspondence:

Dr Daniel J. Peart

Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle upon Tyne, UK

Email: Daniel.peart@northumbria.ac.uk

Abstract

The purpose of this study was to compare markers of hydration during sub-maximal exercise and subsequent time trial performance when consuming water (PW) or coconut water (CW). There was also a secondary aim to assess the palatability of CW during exercise and voluntary intake during intense exercise. 10 males (age 27.9 ± 4.9 years, body mass 78.1 ± 10.1kg, average max minute power 300.2 ± 28.2W) completed 60-min of sub-maximal cycling followed by a 10-km time trial on two occasions. During these trials participants consumed either PW or CW in a randomised manner, drinking a 250 ml of the assigned drink between 10-15 min, 25-30 min and 40-45 min, and then drinking *ad libitum* from 55-min until the end of the time trial. Body mass and urine osmolality were recorded pre-exercise and then after 30-min, 60-min, and post time trial. Blood glucose, lactate, heart rate, rate of perceived exertion (RPE; 6-20) and ratings of thirst, sweetness, nausea, fullness and stomach upset (1 =very low/none, 5= very high) were recorded during each drink period. CW did not significantly improve time trial performance compared to PW (971.4 ± 50.5 and 966.6 ± 44.8 seconds respectively; P=0.698) and there was also no significant differences between trials for any of the physiological variables measured. However there were subjective differences between the beverages for taste, resulting in a significantly reduced volume of voluntary intake in the CW trial (115 ± 95.41 ml and 208.7 ± 86.22 ml; p < 0.001).

Keywords: Palatability, glucose, urine osmolality, perceived exertion

Introduction

There is a growing body of research investigating the use of natural food products for improving sports performance and/or enhancing recovery. Such examples include beetroot juice (Cermark et al., 2012), peppermint oil (Meamarbashi and Rajabi, 2013) and raisins (Rietschier et al., 2011) to improve performance, and milk (Karp et al., 2006), montmorency cherries (Bell et al., 2014), blueberries (McLeay et al., 2012) and spices (Mashhadi et al., 2013) for recovery.

Coconut water (CW), which is marketed as a general use soft drink, has attracted attention as a possible sport drink replacement due to its natural composition of carbohydrates and electrolytes. A number of studies have used exercise protocols to dehydrate participants and compare the rehydrating potential of coconut water compared to water and a commercial sports drink (Ismail et al., 2007, Kalman et al., 2012, Pérez-Idárraga and Aragón-Vargas, 2014, Saat et al., 2002). Ismail et al. (2007) reported enhanced rehydration with CW compared to PW, as assessed by plasma osmolality and plasma volume changes, but no difference compared to a commercial sports drink. However the authors concluded that CW was more palatable than the sports drink and resulted in less nausea, and therefore would be the superior choice. Pérez-Idárraga and Aragón-Vargas (2014) and Saat et al. (2002) failed to report enhanced rehydration with CW compared to PW, although they did suggest that it would still be a reasonable option due to its high palatability and its ability to maintain blood glucose levels. None of these studies investigated the effects of consuming CW on subsequent exercise performance. Kalman et al. (2012) had participants complete a ramp exercise to fatigue 3-hours after the rehydration period but found no significant differences between groups. Laitano et al. (2014) utilised a slightly different experimental design whereby participants were not dehydrated prior to consuming CW, but rather consumed CW prior to a time to exhaustion exercise test in the heat. It was reported that CW was more effective than PW for subsequent exercise in hot conditions. Of note is that neither of the tests employed by Kalman et al. (2012) nor Laitano et al. (2014) measured performance *per se*, but rather exercise capacity.

None of these authors have given CW to participants during exercise, so no study to date has actually investigated the potential of the carbohydrates and electrolytes found in coconut water for exercise performance, or whether the improved palatability promotes voluntary fluid intake during exercise. This in particular may be of interest as it has been suggested that the palatability of a drink is a crucial factor to promote *ad libitum* fluid intake during exercise to reduce the risk of hypohydration (Burdon et al., 2012).

The primary aim of this study was to observe the effects of coconut water on hydration during sub-maximal exercise and subsequent time trial performance compared to water. A secondary aim was to assess palatability of the drink during exercise and voluntary intake during intense exercise.

Methods

Subjects

Ten non-smoking, recreationally active males volunteered to take part in the study (age 27.9 ± 4.9 years, body mass 78.1 ± 10.1kg, average max minute power 300.2 ± 28.2W). All trial protocols received approval from the institution ethics board and written informed consent was obtained from each participant. Subjects were handled with due consideration of the Declaration of Helsinki.

Experimental Design

Participants were instructed to report to the laboratory on three separate occasions with a week between each visit. Testing took place at the same time of day for each participant following a 4-hour fast in order to control for circadian variations. Participants were asked to complete a 24 hour food and drink diary prior to their first visit and instructed to consume a similar diet in the 24 hour period before subsequent visits. The initial visit included a max minute power (MMP) test followed by instruction and familiarisation of the trial protocol for the other visits. Visits two and three were the CW (bottled, Vita Coco®) and PW (tap water) trials which were completed in a randomised cross-over design (the composition of each drink is presented in Table 1).

Max Minute Power (MMP) Test

The MMP test, completed on a cycle ergometer (Wattbike, Nottingham, UK), consisted of a ramp protocol with an initial prescribed power output of 100W which increased by 25W each minute until exhaustion. The MMP sustained for a full minute was used to determine the workload for the experimental trials.

Experimental Trials

Before beginning the experimental trials body mass, urine osmolality (Osmocheck, Vitech Scientific, UK), capillary blood lactate (Lactate Pro, KDK Corporation, Japan), glucose (Accutrend, Roche Diagnostics, Switzerland) and heart rate (F11 Polar Electro, Finland) were measured. Both the blood lactate (Baldari et al., 2009) and blood glucose (Solnica and Naskalski, 2005) monitors used have been reported to have good reliability elsewhere. The trials required participants to cycle for 60 minutes on the Wattbike; 30 minutes at a relatively low intensity 45% MMP and then 30 minutes at a higher intensity 65% MMP (Cermark et al., 2012). Average power output was recorded after 30 and 60 minutes. Although the Wattbike does not control power output, the difference in average watts between trials was negligible (on average 1.5 W differences). In the final minute of each 15 minute period measurements of blood lactate, glucose and heart rate were taken and participants were asked to rate perceived exertion using a 6-20 scale (Borg, 1982) and thirst, sweetness, nausea, fullness and stomach upset using a scale from one (very low/none) to five (very high) (Ismail et al., 2007). In the first three measurement periods participants were instructed to consume 250ml of their assigned drink. In the final measurement period participants were given 250ml of fluid to sustain them until the end of the 10km time trial. Subjects were told they could drink as much or as little as they desired of the final drink, or to in fact drink more than 250 ml if desired. The purpose of this was to examine voluntary fluid intake.

Following the 60-minute controlled power output trial, body mass and urine osmolality were measured again before participants were instructed to cycle 10km (TT) as quickly as possible. Participants were blinded to all information other than remaining distance during the TT. Upon completion the time trial result and volume of liquid consumed were recorded before body mass and urine osmolality were recorded for a final time.

Statistical Analysis

All statistical analyses were completed using IBM SPSS Statistics 23 (SPSS Inc., Chicago, IL). Central tendency and dispersion of the sample data are represented as the mean ± SD. 10-km TT performance, voluntary fluid intake and sweat rate (L/hour) in PW and CW trials were compared using a paired samples t-test. Sweat rate was calculated as change in body mass plus volume of drink consumed, divided by total trial time. The change in all other variables across condition and time were analysed using linear mixed models. Post hoc tests with Sidakadjusted p values were used to locate significant paired differences, with two-tailed statistical significance accepted at $p < 0.05$.

Results

Blood Glucose and Blood Lactate

Blood glucose did not change significantly during the exercise ($F = 1.517$, $p = 0.208$), and nor was there any difference between conditions ($F = 1.767$, $p = 0.193$). The blood lactate response was comparable between conditions ($F = 0.224$, $p = 0.640$) with a significant main effect for time ($F = 17.608$, $p < 0.001$) whereby it increased during the 65% intensity compared to the 45% intensity ($p \leq 0.015$) (Table 2).

Hydration

Participants on average lost approximately 0.9% of their body mass during each testing trial but this was not statistically significant ($F = 5.17$, $p = 0.400$) (Fig 1A), and there was no difference between conditions ($F = 0.244$, $p = 0.629$). Urine osmolality did not change during the exercise ($F = 2.5$, $p = 0.102$), and nor was there any difference between conditions ($F = 0.564$, $p = 0.459$) (Fig 1B). Sweat rate was not significantly different between PW and CW (1.19 ± 0.26 and 1.31 ± 0.90 L/hour respectively; $t = 2.26$, $p = 0.675$).

Heart rate and RPE

Heart rate and RPE was comparable between conditions ($F = 0.004$, $p = 0.952$ and $F = 1.537$, $p = 0.222$ respectively) (Fig 2 A and B). In both HR was significantly higher during the 65% section (45 and 60-min) compared to the 45% section (15 and 30-min) ($p \leq 0.001$), and RPE was progressively higher at each time point ($p \leq 0.001$).

Beverage perception and voluntary consumption

The ratings of thirst, nausea, fullness and stomach upset were comparable between beverages ($p \geq 0.083$), however sweetness was rated significantly higher in CW ($p = 0.006$) (Fig 3). Voluntary consumption of CW (115 ± 95.41ml) was significantly lower than that of PW (208.7 ± 86.22ml; $p < 0.001$).

Time trial performance

Participants on average completed the 10-km TT 5 seconds faster in the PW compared to CW condition (966.6 ± 44.8 and 971.4 ± 50.5 seconds respectively). However the performance was not significantly different between conditions ($t = -0.4$, $p = 0.698$).

Discussion

Coconut water has been proposed as a method of rehydration superior to PW due to the natural composition of electrolytes and carbohydrates (Ismail et al., 2007), and whilst there is evidence to the contrary most authors suggest it may be a preferred option due to its high palatability (Ismail et al., 2007, Pérez-Idárraga and Aragón-Vargas, 2014, Saat et al., 2002). The novelty of the current study is that it investigated whether consuming coconut water during exercise would maintain the participants' hydration status closer to resting values and have any positive effect on subsequent time trial performance. However the measures of hydration observed in this study were not significantly different between PW and CW, with body mass decreasing comparably between conditions by approximately 0.9%, and urine osmolality remaining statistically unchanged throughout the trial. It should be considered that sweat rates of 1.19 ± 0.26 and 1.31 ± 0.90 L/hour for PW and CW trials may not have been high enough for the additional electrolytes present in CW (Table 1) to have a worthwhile effect. Attention must also be drawn to the fact that whilst electrolyte content of CW was higher than PW, this was predominantly due to higher potassium levels as sodium was actually lower (Table 1). Nevertheless the results of this study suggest that CW is no more effective than PW for maintaining hydration during 1-hour submaximal cycling, supporting the findings from Pérez-Idárraga and Aragón-Vargas (2014).

In addition to measures of hydration blood glucose also did not change significantly between conditions. This is despite the naturally greater carbohydrate concentration in the CW (5% concentration, Table 1). El-Sayed et al. (1997) similarly reported no significant differences in blood glucose during 1-hour of cycling when consuming a carbohydrate beverage compared to PW. However these authors attributed this to missing the peak blood glucose response due to timing issues (55-min period between beverage and mid-exercise blood measurement). One study that had timings between carbohydrate beverage consumption and blood measurements similar to the current demonstrated significant differences in blood glucose compared to a PW control during exercise (Siegler et al., 2012). Of note is that Siegler et al. (2012) employed a much more intense 1-hour time trial so it may be the case that the lower intensity employed in this study resulted in an insulin-mediated reduction of blood glucose between measurements which was missed due to the fact that blood measurement was taken prior to consuming the drink each time (speculation as this study did not measure insulin). However Ismail et al. (2007) and Saat et al. (2002) reported significant increases in blood glucose when consuming CW compared to PW at rest 30-minute post consumption, therefore the 10-min between beverage consumption and blood glucose measurement is unlikely to be the reason for a lack of difference.

As with blood glucose, CW had no effect upon blood lactate, heart rate and RPE during the submaximal ride. The absence of physiological differences between the conditions may well explain the insignificant effect of CW on subsequent TT performance. Kalman et al. (2012) published the only other study investigating CW and exercise performance in normothermic conditions, reporting no significant difference between a PW and CW condition. However in this previous study participants completed a step time to exhaustion protocol on a treadmill 3-hour after a dehydrating exercise protocol. The design implemented did not necessarily allow the past authors to investigate the effect of CW upon performance as the nature of the exercise may not be expected to change markedly (more exercise capacity than performance), and the participants did not consume any CW in the preceding 2-hour prior to the exercise test, hence the novelty of the current study. Laitano et al. (2014) did however observe improvement in exercise capacity following the consumption of CW compared with PW when exercising in the heat (34°C, ~55% relative humidity). It may be the case that CW has more potential benefit under heat stress, but the results of the current study combined with those from Kalman et al. (2012) suggest that CW has no apparent ergogenic benefit when consumed either during or post exercise in normothermic conditions.

It cannot be discounted that limitations to the exercise protocol employed here may have contributed to the absence of a performance improvement with CW. Although some studies have reported significant effects of carbohydrate ingestion on exercise durations of 60-90 minutes they have been at an intensity greater than the current study (Jeukendrup, 2011, Siegler et al., 2012), and carbohydrate intake is typically considered to be more beneficial for exercise durations >120 minutes (Jeukendrup, 2014). Moreover the amount of carbohydrate ingested may not have been adequate to see an effect. If participants had consumed the full 1000 ml of CW at 5% concentration they would have ingested 50 g of carbohydrate in the first hour which is close to the recommended 60 g/hour (Burke et al., 2011, Jeukendrup and Jentjens, 2000). However due to the *ad libitum* nature of the consumption at the end of the trial participants ingested on average 43 g carbohydrate over the combined sub-maximal and time trial exercises at an approximate rate of only 34 g/hour. This may in fact not be a limitation though as it has been proposed that a rate of ~30 g/hour may be sufficient for shorter exercise durations as the mechanism of ergogenicity is likely not to be related to metabolic factors (Jeukendrup, 2011, Jeukendrup, 2014). Future work should endeavour to increase either the exercise duration or intensity to further examine any potential effects of CW on exercise performance. Another limitation to the current study was the inability to ensure environmental conditions matched for each trial, which may have had an effect on the results. However, the absence of any significant differences between sweat rates as described earlier in the paper may suggest that this has had limited influence on the study.

Interestingly during the time trial participants voluntarily drank significantly less CW than PW (~93 ml difference, $p < 0.001$). This is despite comparable ratings of thirst and fullness at the end of the sub maximal cycle. A reason for this is perhaps due to the significantly higher rating of sweetness for CW than PW, and anecdotal evidence that all participants preferred to consume PW than CW. This is despite past work stating that CW was more palatable than PW (Ismail et al., 2007, Pérez-Idárraga and Aragón-Vargas, 2014, Saat et al., 2002). Of note is the fact that the majority of this past work took place in tropical regions where CW is more traditionally consumed in the day-to-day diet (Ganguly, 2013), and the only other study in which participants preferred PW similar to this study was conducted in a Western country (USA). This raises an interesting consideration in Sport and Exercise nutrition whereby the cultural palate may have a role in athlete choices and adherence to particular interventions. This is particularly pertinent as the palatability of a drink may be a crucial factor in promoting *ad libitum* fluid intake during exercise (Burdon et al., 2012). Whilst the relatively small ~100 ml difference in fluid intake has had little practical effect in this study, it must be considered that the *ad libitum* component of the study was short and if continued over a longer period could equate to a difference of ~300-400 $ml.hour^{-1}$.

In conclusion the blood and hydration parameters measured during sub-maximal exercise were comparable whether participants consumed CW or PW, and the CW offered no ergogenic benefit for a subsequent TT. However there were subjective differences between the beverages for taste, resulting in a significantly reduced volume of voluntary intake in the CW trial.

Novelty Statement

Current literature surrounding coconut water has focused upon its potential rehydrating properties for after exercise. This is the first study to examine its use during exercise, and provides evidence that it may likely be no more beneficial than plain water, and is not necessarily as palatable as previously reported.

Practical Application Statement

There is conflicting evidence with regard to the benefits of coconut water over plain water for rehydration after exercise; however it is generally recommended that coconut water may be more favourable due to its high palatability. The findings of this study suggest that coconut has no ergogenic benefit when consumed during exercise, and that practitioners need to consider their athlete's palate and preferences when applying research findings to the field. It cannot be discounted that the bottled coconut water may have a different taste to the fresh coconut water used in some studies, and those wishing to include coconut water in their nutrition plan should consider trialling different products.

Acknowledgments

The authors wish to thank those that volunteered to take part in the research. This study was funded by a Student Research Internship Grant awarded to AH by the University Centre at North Lindsey College.

References

Baldari, C., Bonavolontà, V., Emerenziani, G P., Gallotta, M C., Silva, A J. & Guidetti, L. (2009). Accuracy, reliability, linearity of Accutrend and Lactate Pro versus EBIO plus analyzer. *European Journal of Applied Physiology*, *107*, 105-111.

Bell, P G., Walshe, I H., Davison, G W., Stevenson, E. & Howatson, G. (2014). Montmorency cherries reduce the oxidative stress and inflammatory responses to repeated days high-intensity stochastic cycling. *Nutrients*, *6*, 829-843.

Burdon, C A., Johnson, N A., Chapman, P G. & O'Connor, H T. (2012). Influence of beverage temperature on palatability and fluid ingestion during endurance exercise: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism*, *22*, 199-211.

Burke, L M., Hawley, J A., Wong, S H. & Jeukendrup, A E. (2011) Carbohydrates for training and competition. *Journal of sports sciences*, *29*, S17-S27.

Cermark, N M., Gibala, M J. & van Loon, L J C. (2012) Nitrate Supplementation's Improvement of 10-km Time-Trial Performance in Trained Cyclists. *International Journal of Sport Nutrition and Exercise Metabolism. 22*, 64-71

Ganguly, S. (2013). Health benefits of coconut in the Asian cuisines: A Review. *Journal of Biological and Chemical Research*, *30*, 517-21.

El-Sayed, M S., Balmer, J. & Rattu, A J M. (1997) Carbohydrate ingestion improves endurance performance during a 1h simulated cycling time trial. *Journal of Sports Sciences*, *15*, 223-230.

Ismail, I., Singh, R. & Sirisinghe, R G. (2007) Rehydration with sodium-enriched coconut water after exercise-induced dehydration. *Southeast Asian Journal of Tropical Medicine and Public Health*, *38*, 769-785

Jeukendrup, A E. (2011) Nutrition for endurance sports: marathon, triathlon, and road cycling. *Journal of Sports Sciences*, *29*, S91-S99.

Jeukendrup, A. (2014) A step towards personalized sports nutrition: carbohydrate intake during exercise. *Sports Medicine*, *44*, 25-33.

Jeukendrup, A E. & Jentjens, R. (2000) Oxidation of carbohydrate feedings during prolonged exercise. *Sports Medicine*, *29*, 407-424.

Kalman, D S., Feldman, S., Krieger, D R. & Bloomer, R J. (2012) Comparison of coconut water and a carbohydrate-electrolyte sport drink on measures of hydration and physical performance in exercise-trained men. *Journal of the International Society of Sports Nutrition*, *9*, 1-10.

Karp, J R., Johnston, J D., Tecklenburg, S., Mickleborough, T D., Fly, A D. & Stager, J M. (2006) Chocolate milk as a post-exercise recovery aid. *International Journal of Sport Nutrition and Exercise Metabolism*, *16*, 78-91

Laitano, O., Trangmar, S J., Marins, D D M., Menezes, E S. & Reis, G D S. (2014) Improved exercise capacity in the heat followed by coconut water consumption. *Motriz: Revista de Educação Física*, *20*, 107-111.

Mashhadi, N S., Ghiasvand, R., Askari, G., Feizi, A., Hariri, M., Darvishi, L., Barani, A., Taghiyar, M., Shiranian, A. & Hajishafiee, M. (2013). Influence of ginger and cinnamon intake on inflammation and muscle soreness endued by exercise in Iranian female athletes. *International Journal of Preventative Medicine, 4*, 11-15.

Meamarbashi, A. & Rajabi, A. (2013). The effects of peppermint on exercise performance. *Journal of the International Society of Sports Nutrition, 10*.

McLeay, Y., Barnes, M J., Mundel, T., Hurst, S M., Hurst, R D. & Stannard, S R. (2012). Effect of New Zealand blueberry consumption on recovery from eccentric exercise-induced muscle damage. *Journal of the International Society of Sports Nutrition*, *9*, 19.

Pérez-Idárraga, A. & Aragón-Vargas, L F. (2014). Postexercise rehydration: potassium-rich drinks versus water and a sports drink. *Applied Physiology, Nutrition, and Metabolism*, *39*, 1167-1174.

Rietschier, H L., Henagan, T M., Earnest, C P., Baker, B L., Cortez, C C. & Stewart, L K. (2011). Sun-dried raisins are a cost-effective alternative to sports jelly beans in prolonged cycling. *Journal of Strength and Conditioning Research, 25*, 3150-3156.

Saat, M., Singh, R., Sirisinghe, R., G. & Nawawi, M. (2002). Rehydration after exercise with fresh young coconut water, carbohydrate-electrolyte beverage and plain water. *Journal of Physiological Anthropology and Applied Human Science*, *21*, 93-104.

Siegler, J., Howell, K., Vince, R., Bray, J., Towlson, C., Peart, D., Mellor, D. & Atkin, S. (2012). Aspartame in conjunction with carbohydrate reduces insulin levels during endurance exercise. *Journal of the International Society of Sports Nutrition*, *9*, 1-4.

Solnica, B. & Naskalski, J W. (2005). Quality control of SMBG in clinical practice. *Scandinavian Journal of Clinical and Laboratory Investigation*, *65*, 80-85.

Figure 1 – Average hydration as assessed by percentage change in body mass (A) and urine osmolality (B) pre-exercise, post submaximal exercise and post time trial.

Figure 2 – Average heart rate (A) and rate of perceived exertion (B) throughout the submaximal exercise. * indicates significant difference to other time points ($p \leq 0.001$). Rate of perceived exertion was progressively higher at each time point ($p \leq 0.001$).

Figure 3 – Average beverage perception rated a 1-5 scale (0 = not at all, 5 = very). * indicates significant difference between conditions ($p = 0.006$).

Table 1. Composition of PW and CW per 100 ml (Data from United Kingdom Drinking Water Inspectorate and www.vitacoco.com respectively).

	PW	CW
Energy (kJ)	0	72
Carbohydrates (g)	0	5
Potassium (mg)	0	195
Sodium (mg)	4	0.02

Table 2. Blood glucose and blood lactate pre-exercise and during the 60-min submaximal ride

		Pre-exercise	15-min	30-min	45-min	60-min
Glucose	PW	4.66 ± 1.01	4.24 ± 0.63	4.06 ± 1.06	3.92 ± 1.35	4.61 ± 0.80
(mmol/L)	CW	5.14 ± 1.23	4.29 ± 0.96	4.48 ± 1.20	4.68 ± 1.31	4.76 ± 1.16
Lactate	PW	1.63 ± 1.22	1.99 ± 0.81	2.21 ± 1.43	4.48 ± 1.78*†‡	5.53 ± 1.68 *†‡
(mmol/L)	CW	1.10 ± 0.37	2.84 ± 1.91	2.46 ± 1.87	4.29 ± 1.49 *†‡	6.14 ± 4.89 *†‡

*significantly different to pre-exercise ($p<0.05$), †significantly different to 15-min ($p<0.05$),

‡significantly different to 30-min ($p<0.05$)