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Original Research

Is body fluid status affected by different electrolyte solutions during endurance cycling?

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Abstract

Fatigue development in endurance sports has several causes; among these, dehydration can impair performance. Both water and electrolytes are lost during exercise, in particular, when exercising in hot environments. These losses must be replaced, with carbohydrate-electrolyte solutions, in different forms. This study aimed to evaluate the effects of different hydrating solutions on body fluid status. Nine male recreational cyclists performed three experimental trials on separate days: trials consisted of a two-hour endurance ride, with three different hydration solutions, consumed in a randomized order (water, water+powder, water+gel).
Body weight was measured, and bioimpedance vector analysis was performed both before and after each trial. Changes from pre- to post-training in the impedance vector, phase angle, total body water and extracellular water were then compared between the three conditions, using MANOVA for repeated measures. A time × treatment effect was shown for the total body water (p=0.05) and impedance vector (p=0.032), with both the powder and gel differing from the water-only condition. Powder and gel solutions have been shown to be equally effective in limiting the negative effects of dehydration, preventing the loss of total body water. However, gels may represent a practical advantage for endurance athletes, especially those who take part in long-distance races.

Keywords: Cycling, energy drinks, endurance training, sports performance, water–electrolyte imbalance

Introduction

Endurance sports continue to gain in popularity, with more and more people taking part in running, cycling and triathlon races, lasting from 30 minutes to over 10 hours [1]. Fatigue during such events is often associated with reduced blood glucose concentrations and muscle glycogen depletion; in addition to glycogen depletion, dehydration can impair endurance performance [2].

Athletes begin such competitions when normally hydrated and develop fluid loss throughout the event. Physiological factors contributing to performance decrements that are linked to dehydration include increased cardiovascular strain, altered central nervous system functioning and increased heat strain. Several studies demonstrated that dehydration >2% reduced endurance performance both in a temperate and hot environment when exercise lasted over 90 minutes [3].

In addition to water, sweat contains electrolytes that are also lost. The conventional approach during races is to advise riders to adopt a 'drink to thirst' approach to hydration, where fluid intake (a mixture of both water and electrolyte solutions) can vary between 350 to 800 ml per hour depending on ambient conditions [4]. Electrolyte solutions can be in the form of powder (and dissolved into the water bottle) or gels. It is also generally agreed that carbohydrates added to fluid replacement beverages can be beneficial during long-term exercise; recommendations for exercise lasting over one hour include ingesting 600–1200 ml per hour of solution, containing 4–8% carbohydrate and 0.5–0.7 g of sodium per litre of water consumed [5].

If both fluid replacement and carbohydrate delivery are to be met with a single beverage, the carbohydrate concentration should not exceed 8%, or even be slightly less, as highly concentrated carbohydrate beverages reduce gastric emptying [6].

Ebert *et al.* [7] reported that, during professional tours, riders finished the race mildly dehydrated despite consuming fluid in accordance with guidelines; interestingly, the authors highlighted that more successful riders experienced a higher level of dehydration (up to 4% body mass). Body weight is a critical factor in cycling, especially during hill-climbing: a dehydration-induced reduction in body mass may positively affect performance, improving the power-to-weight ratio and possibly reducing the energy cost, although to date no data support this hypothesis. Research documenting the actual fluid intake of professional cyclists during competition is scarce, and recommendations are based mainly on laboratory trials that do not consider opportunities to drink, environmental and terrain conditions, increased heat-loss potential, roles within a cycling team, race tactics or changing exercise intensity [7].

There is still an incomplete picture regarding how different electrolyte-based beverages could affect body fluid status, and by which measure they could prevent the negative effects of dehydration. This study aimed to evaluate, in an outdoor setting, the effects of two different electrolyte-based solutions on body fluid status during endurance cycling training sessions.

Materials and methods

Participants

Nine male subjects were enrolled to participate in this study. All of the subjects were amateur cyclists who trained for at least 6 hours per week in the 4 weeks before the beginning of the study. Inclusion criteria were: to be aware of individualized training zones (heart rate and/or power), previously defined by laboratory testing, and to possess medical permission for competitive activity. Exclusion criteria were: age

<18 or >55 years old and the taking of medication. Subjects were instructed to avoid exercise in the 48 hours prior to the experimental trials and to refrain from consuming alcohol and caffeine for at least 24 hours. Participant characteristics are reported in **Table 1**.

Table 1 Participant characteristics

	Mean ± Standard Deviation
Age (years)	11.4 ± 39.3
Height (m)	0.07 ± 1.76
Weight (kg)	4.6 ± 66.4
BMI (kg/m^2)	1.2 ± 21.4

Procedures

On a first meeting in the laboratory, participants were informed about the experimental procedures and written informed consent was given by every subject. Height and baseline body weight were measured. Bioimpedance vector analysis (BIVA) was performed to assess body fluid status (BIA 101 Anniversary, Akern, Italy). BIVA measures resistance (R) and reactance (Xc) values.

R represents the opposition to the flow of an alternating current through intra- and extracellular ionic solution, whereas Xc represents the capacitive component of tissue interfaces, cell membranes and organelles. Both R and Xc yield the impedance vector (Z; geometric relationship = arc tangent of Xc/R expressed in degrees), the length of which (square root of $R^2 + Xc^2$) is inversely related to total body water (TBW). The phase angle or PA (arc tangent [(Xc/R)(180°/π)]), on the contrary, is suggested to be an indicator of cellular function [8].

Body weight was measured, and BIVA was performed before and immediately after each experimental trial; measurements were taken with the subjects only wearing underclothes. The experimental trial consisted of a 2-hour ride around endurance pace, corresponding to the aerobic threshold of the subjects; the course was the same, and the environmental conditions were similar between the trials, which were separated by 48 hours' rest. Data regarding the experimental trial conditions are reported in **Table 2.**

Table 2 Experimental trial conditions

	Trial 1	Trial 2	Trial 3
Distance (km)	60.2	61.4	61.9
Ascent (m)	499	501	526
Time (min)	123	124	128
Mean temperature (°C)	17.6	16.1	16.3

Each subject performed the 3 different trials in a randomized order. On 1 trial, subjects were given 2 500 ml bottles of water. On a second experimental session, subjects were given the same 2 bottles, with a hypotonic, energy- and electrolyte-rich powder (20 g per bottle) dissolved in the water (Ke Sali, Ke Forma, San Marino). On the third trial, subjects were given the 2 bottles of water and 2 electrolyte gel packs (50 ml) (Hydrorace Gel, Ke Forma, San Marino). The nutritional composition of the powder and gel is reported in **Table 3**.

The study was carried out in compliance with the ethical standards reported in the Declaration of Helsinki (1975).

Table 3 Powder vs gel nutritional composition

	Gel (50 ml)	Powder (20 g)
Energy	-	66.4 kcal
Fat	-	<0.1 g
Carbohydrates	-	14 g
of which sugar	-	2.2 g
Protein	-	<0.1 g
Salt	-	0.835 g
Zinc	-	10 mg
Sodium	250 mg	334 mg
Calcium	122 mg	-
Phosphorus	155 mg	-
Chloride	279 mg	-
Potassium	300 mg	335 mg
Magnesium	113 mg	338 mg
Vitamin C	-	117 mg
Vitamin E	-	12 mg
Thiamine	-	2.1 mg

Statistical analyses

The rate of fluid consumption (ml/kg/min) was calculated as the total fluid consumed during the training session (1000 ml), divided by the pre-exercise body mass (kg) and then by the total exercise time (min).

The hypohydration level was computed as the delta percentage change in body mass from pre- to post-exercise.

Multivariate analysis of variance for repeated measures was performed to test differences with respect to time (pre- vs post-training) and treatments (water, water+powder, water+gel), both as within factors, for the dependent variables considered (body weight, Z, PA, TBW and extracellular water (ECW)). Partial eta squared (η^2) was calculated as the effect size measure.

Data were analyzed using Microsoft Excel and IBM SPSS Statistics 26.0; significance was set at a standard alpha value of 0.05.

Results

All of the subjects completed the three experimental sessions. The rate of fluid consumption was 0.12 ± 0.01 ml/kg/min, and dehydration (as the percentage variation in body weight between pre- and post-training) was between 0.0 and 2.1%, in all conditions. Body weight changed in the post-training measurement in all conditions [$F_{(1,8)}$=7.617, η^2=0.488, *p*=0.025].

Z did not change over time (*p*>0.05), but a time × treatment effect was seen in the water+powder condition, with respect to the control [F(1,8)=6.769, η^2=0.458, *p*=0.032].
The PA was not affected either by time or treatment. A time × treatment effect was observed for the TBW in the water+powder condition, with respect to the control [$F_{(1,8)}$=5.188, η^2=0.393, *p*=0.05] (see **Fig. 1**).

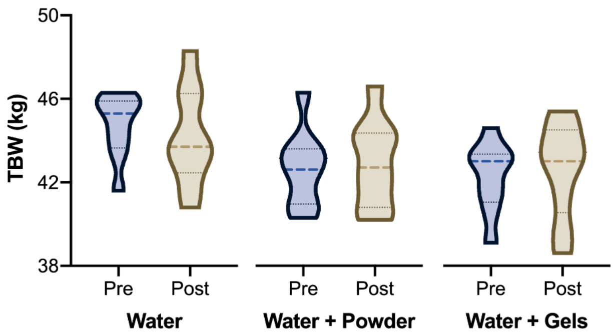

Figure 1 Violin plots of total body water (TBW) values, pre- and post-training, in the three experimental conditions

No effects of time or treatment were observed for the ECW. No differences between the two experimental treatments (powder or gel) were observed for any of the variables measured. All data are shown in **Table 4**.

Table 4 Body weight and body fluid status variables in the three experimental conditions, pre- and post-training

	Water (Control Group)		Water + Powder		Water + Gels	
	Pre	Post	Pre	Post	Pre	Post
Weight (kg)	66.4 ± 4.6	65.8 ± 4.2	66.5 ± 4.5	66.1 ± 4.2	65.7 ± 4.7	65.2 ± 4.7
Z (Ω/m)	454.7 ± 46.1	461.9 ± 38.3	492.3 ± 46.2	486.7 ± 43.8*	495.9 ± 42.6	488.9 ± 48.7
PA (°)	7.54 ± 0.93	7.43 ± 0.69	7.16 ± 0.75	7.24 ± 0.79	7.32 ± 0.82	7.08 ± 0.73
TBW (kg)	44.7 ± 1.5	44.2 ± 2.3	42.6 ± 1.8	42.9 ± 2.1*	42.3 ± 1.7	42.6 ± 2.3
ECW (kg)	17.8 ± 1.8	17.7 ± 1.8	17.5 ± 1.5	17.5 ± 1.7	17.1 ± 1.6	17.6 ± 1.5

Z = impedance vector; **PA** = phase angle; T**BW** = total body water; **ECW** = extracellular water.
**p*<0.05 (time □ treatment effect vs control)

Discussion

This study aimed to compare, in a real-world setting, the different effects of two electrolyte-based solutions on body fluid status during endurance cycling training sessions.

The two formulations had a similar composition with respect to the electrolyte content but differed in their consumption method: one was in the form of a powder and the other in the form of a gel. The main results of this study are that there were no differences between the two formulations in terms of changes in Z length and the TBW. Indeed, the training session produced a reduction in TBW only in the water/control group, while this remained stable or slightly increased in the powder and gel groups post-training. Similar results were observed for the Z length, with an increment in the water/control group and a trend towards a reduction in the two treatment groups. In this regard, the TBW and the Z length are reported to be inversely related [8].

The PA, which has been considered an indicator of cellular function, muscular strength and endurance [9], was unaffected by the exercise.

This implies that the ratio between intra- and extracellular water (ICW/ECW) remained unchanged since the PA and the ICW/ECW ratio are directly proportional [10]. These results are in accordance with those reported by Gatterer *et al.* [11], who described an increase in Z length and a reduction in the TBW after a dehydration exercise session in the heat. Campa *et al.* [12] compared the effects of a cycling exercise performed in hydrated (subjects drank one litre of water during the trial) and dehydrated conditions: they found an increase in Z length only in the dehydrated conditions, while no changes were reported for the PA.

In addition to containing water, sweat contains electrolytes that are lost; therefore, the composition of the fluids consumed is of fundamental importance. It is recommended that 'sports beverages' contain ~20–30 mEq/l of sodium, ~2–5 mEq/l of potassium and ~5–10% carbohydrate [6]. The requirement for different components depends on the specific exercise task (that is, duration and intensity) and on the weather conditions. These carbohydrate-electrolyte solutions commonly exist in the form of a powder that is dissolved with water into the bottle. Of note, these components can also be consumed by a non-fluid mechanism, such as the use of gels. In cycling and other endurance disciplines (such as running and triathlons) opportunities to drink may be limited, due to environmental and terrain conditions, race tactics and because weight is a limiting factor in terms of performance. Powder solutions could be problematic and awkward to carry but gels are undoubtedly lighter and more easily carried, in particular, in long-distance races where feed zones are far apart and limited in number (for example, ultraraces). For an athlete, having the possibility of taking gels may represent an advantage since nutritional needs could be met without carrying unnecessary weight.

Conclusions

Dehydration may impair endurance performance; therefore, carbohydrate and electrolyte-based beverages should be consumed by athletes, depending on the exercise performed and the weather conditions. Powder and gel solutions have been shown to be equally effective in limiting the negative effects of dehydration, preventing the loss of TBW. However, gels may represent a practical advantage to endurance athletes who take part in long-distance races.

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Conflict of Interest

The author Alexander Bertuccioli provides external consulting services for the company AQUA VIVA Srl, owner of the brand KEFORMA.

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