

Effects of Hypotonic and Isotonic Sports Drinks on Endurance Performance and Physiology

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Isotonic sports drinks containing carbohydrate and electrolytes are often consumed for endurance performance, but hypotonic drinks may be superior. The purpose of this study was to compare effects on performance and related physiology of a new sports drink, Mizone Rapid (hypotonic; containing carbohydrate and electrolytes) with three other drinks: Mizone (hypotonic; carbohydrate only), Powerade (isotonic; carbohydrate and electrolytes), and a water placebo. **Methods:** Sixteen well-trained cyclists were randomized in balanced double-blind crossover fashion to consume each of the four drinks on separate days at a rate of 250 ml every 15 min during a 2-h steady ride at constant power, followed by a continuous incremental test to peak power. Tests were performed on a cycle ergometer at room temperature (18-22°C) and were separated by 3-7 d. **Results** and **Discussion:** Peak power with Mizone Rapid was substantially higher than that with water and Mizone (4.3% and 3.2% respectively) but similar to that with Powerade (0.2%) (90% confidence limits for differences, $\pm 2.6\%$). Analysis of urine composition and volume after the performance test provided evidence that Mizone Rapid was excreted and therefore probably absorbed more rapidly than the other drinks: it produced both the lowest urine osmolarity and the highest urine volume. There were no clear differences between the effects of the drinks in the steady ride on tympanic temperature, heart rate, blood glucose and blood lactate that were consistent with the effects on subsequent performance. **Conclusion:** Consumption of a hypotonic drink aimed at optimizing fluid absorption has an effect on endurance performance similar to that of an isotonic drink and may have beneficial effects on endurance performance relative to water and a hypotonic drink lacking sodium. **KEYWORDS:** cycling, ergogenic, hydration, Mizone, Powerade.

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In comparison with plain water, drinks containing carbohydrate and salt can enhance performance when consumed before or during high-intensity exercise lasting at least an hour (e.g., Coyle, 2004). The carbohydrate contributes to the performance enhancement by offsetting the depletion of the body's stores of carbohydrate, the main fuel for intense endurance exercise. The sodium in the drinks contributes either by accelerating the uptake of carbohydrate from the gut or by offsetting the reduction in circulating fluid volume that occurs through sweating or shift of fluid into active muscle. Stimulation of carbohydrate receptors in the mouth may also have an ergogenic effect (Carter et al., 2004; Chambers et al., 2009).

Optimizing the concentrations of carbohydrate and salt for performance is a concern for sport nutritionists and drink manufacturers (Coombes and Hamilton, 2000). Higher concentrations provide more carbohydrate and salt but reduce the rate of gastric emptying and can therefore slow the rate of delivery of fluid, while hypertonic drinks can even impair performance by drawing fluid from the circulation into the gut (Maughan and Leiper, 1999). Manufacturers have opted generally for isotonic formulations, but these are not necessarily optimal. Only two studies focusing on performance have included hypotonic drinks, and the issue of their efficacy is still unresolved. Maughan and colleagues (1996) compared the

effects of non-blinded consumption of water, an isotonic and a hypotonic glucose-electrolyte solution after an overnight fast. The subjects were 12 males of unstated fitness who consumed the drinks during a time-to-exhaustion test at room temperature (21 °C) and lasting ~100 min. Median or mean endurance times were longer by 9-18% for either solution vs water, but the comparison of the two solutions was unclear: median times were longer by 2.8% for the hypotonic solution, mean times were longer by 8.1% for the isotonic solution, and neither comparison was statistically significant. Subjects in the other study (Galloway and Maughan, 2000) were six fit but not specifically competitive males who performed a similar time-to-exhaustion test in a hot environment (31 °C) after an overnight fast. Here there was a clear increase in median performance time of 40% when the drink was a hypotonic glucose-electrolyte solution compared with a slightly hypertonic sucrose-electrolyte solution. However, the difference in performance could not be ascribed simply to the difference in tonicity or type of carbohydrate, because the hypotonic drink was consumed at approximately twice the rate of the other drink.

When we were approached by a drink manufacturer to investigate the efficacy of their two hypotonic drinks, we designed a study in which the subjects were competitive athletes performing the exercise tests at room temperature in a more realistic non-fasted state. We included an isotonic drink and non-caloric colored flavored water in a double-blind manner to eliminate placebo effects, and we used a progressive approach in the analysis to make probabilistic inferences about magnitudes of effects (Hopkins et al., 2009).

Methods

Study Design

This study employed a double-blind randomized crossover controlled design. The cyclists first performed an incremental test to peak power, followed on a separate day by a familiarization trial of the exercise test, which consisted of a 2-h pre-load at fixed intensity followed 10 min later by a maximal exercise test. They were then randomized in balanced crossover fashion to consume each of four different drinks (Table 1) during the pre-load of the exercise test. The tests were separated by 3-7 d.

Table 1. Composition of the drinks.

	Placebo (water)	Mizone Rapid	Mizone	Powerade
Simple sugars (g.100 ml ⁻¹)	0	3.9	2.8	6.0
Glucose polymer (g.100 ml ⁻¹)	0	0	0	1.6
Sodium chloride (mmol.L ⁻¹)	0	10	0	12
Vitamins B3, B5, B6 (mg.L ⁻¹)	0	4, 2, 5	4, 2, 5	0
Vitamins B12 (µg.L ⁻¹)	0	6	6	0
Osmolarity (mosmol.L ⁻¹)	10	233	188	303

Subjects

Seventeen well-trained, competitive endurance cyclists and triathletes were recruited from the greater Auckland area. One subject did not complete all tests and was excluded from the analysis. The characteristics of the remaining 16 subjects (mean ± standard deviation) were as follows: age, 34 ± 6 y; body mass, 82.0 ± 8.8 kg; peak power, 344 ± 36 W; maximum oxygen consumption, 4.3 ± 0.5 L.min⁻¹. All subjects gave their written informed consent in accordance with AUT University's ethics committee.

During the study all subjects were in a peri-

od of high mileage/endurance development, with the majority of subjects competing in endurance races of 2-3 hours duration each weekend. The subjects maintained their normal diet during the course of the intervention. They were instructed to have an easy day of training prior to each testing session and to consume 500 ml of water one hour prior to each session.

Exercise Performance Tests

All physiological and performance tests were conducted in a temperature-controlled laboratory (19-21 °C) using an electro-magnetically braked cycle ergometer (Velotron, Racermate,

Seattle, Washington). Prior to the first test, the ergometer was set up to replicate the subject's road bike as closely as possible. The settings were recorded and used for each subsequent testing session.

Each cyclist initially performed an incremental exercise test to determine peak power, which was used to set the intensity of exercise for the five subsequent performance tests. The incremental step test commenced at a workload of 150-180 W, depending on fitness, and increased by 30 W every 3 min until volitional exhaustion. At the end of each 3-min stage, capillary blood was sampled from an earlobe for measurement of blood lactate using a hand-held analyser (Lactate Pro, Arkray, Japan). Oxygen uptake was measured continuously using a breath-by-breath metabolic system (Metamax 3b, Cortex, Leipzig, Germany). Heart rate was recorded continuously at 5-s intervals using a short-range telemetry device (Polar A1, Polar Electro, Kempele, Finland). Maximum oxygen uptake was determined as the highest 30-s value obtained during the test.

Each experimental ride consisted of a 2-h pre-load bout of exercise at the same fixed workload (55-60% of peak power) followed by a maximal cycle test. During the 2-h pre-load the cyclists were required to maintain a consistent cadence and were given a 5-min rest after the first hour. The maximal exercise test commenced 10 min after the 2-h pre-load at a workload of 180 W and increased by 1 W every 2 s until volitional exhaustion. The cyclists were not given feedback on elapsed time or power output during the maximal exercise test. Each cyclist performed a familiarisation ride of the experimental procedure on one occasion while consuming their usual drink, one week before the first experimental ride. In each of the four experimental rides the cyclist consumed a different drink. The cyclist consumed the same volume of each drink (250 ml) at 15-min intervals during the ride.

Prior to the start of and immediately following the 2-h pre-load, capillary blood (1.5 ml) was drawn from a finger puncture and collected into tubes with lithium-heparin anti-coagulant. Osmolarity was determined from this sample by an independent commercial laboratory (Lab Plus, Auckland, NZ). Urine was also collected immediately after the blood samples and volume recorded. Volume of any urine voided

during the 5-min rest period after the first hour of the pre-load was also recorded. A 50-ml sample from each collection period was sent to the independent laboratory for determination of osmolarity.

Prior to the start of, after one hour, and immediately following the 2-h pre-load, body mass was determined in minimal clothing using digital scales (Model HW-G, A&D Mercury, Thebarton, Australia). Sweat volume was then inferred from change in body mass, taking account of fluid consumption and urine production.

Statistics

Data were analyzed using mixed linear models in the Statistical Analysis System (Version 9, SAS Institute, Cary NC). In addition to the fixed nominal effect for the different drinks, the models included a fixed nominal effect for the order of the drink trials and covariates to adjust for the effect of within-subject between-trial changes in ambient temperature and pre-test urine osmolarity (with pre-test serum osmolarity replacing pre-test urine osmolarity in the analysis of serum osmolarity). These covariates were analyzed by setting each subject's mean to zero, and their magnitudes were evaluated as the effect of two within-subject standard deviations (the square root of the mean within-subject variance). All models included a random effect for subject identity and a random effect to account for additional error on the first trial. The models for analysis of data from the pre-load included a random effect for within-subject between-trial variation, and the residual was the within-subject within-trial error of measurement. The residual in the models for the analysis of data from the maximum test was the within-subject between-trial error of measurement.

We used the magnitude-based approach to inferences: clinical for performance and mechanistic for the physiological variables (Hopkins et al., 2009). With clinical inferences, an effect with possible benefit (>25% chance) was clear if harm was very unlikely (odds ratio of benefit/harm >66) and unclear otherwise; other effects were clearly not beneficial. With mechanistic inferences, an effect was deemed unclear if its 90% confidence interval overlapped thresholds for substantiveness (that is, if the effect could be substantially positive and negative); other effects were clear. The thresholds

for the mechanistic variables were the usual standardized differences, using the average between-subject standard deviation derived from the mixed model. The thresholds for the performance test were derived using the following novel rationale: the individualized preload was assumed to bring the subjects to a state of fatigue similar to that of cyclists in the first peloton of a road race near the end of the race; performance in the incremental test was assumed to simulate the physical demands of an extended sprint to the finish in a road race; an individual subject's percent variation in performance from trial to trial was assumed to be similar to the percent variation that the cyclists in the first peloton would experience between competitions; the threshold for smallest important change in performance was therefore given by 0.3 of the within-subject variation from trial to trial, while those for moderate and large effects were given by 0.9 and 1.6 of the within-subject variation ([Hopkins et al., 2009](#)).

Results

Performance in the incremental test following the 2-h steady ride and physiological measures taken at the end of the test are shown in Table 2 for each of the four drinks. Table 3 shows the comparison of the means of these measures between Mizone Rapid and each of the other drinks.

The error of measurement of peak power derived from the linear model was 4.1% (90% confidence limits $\times/\div 1.26$), and the resulting thresholds for small, moderate and large changes in performance were 1.2%, 3.7% and 6.6% respectively. The highest peak power in the incremental test occurred with Mizone Rapid and Powerade; the observed difference between these drinks was possibly trivial, but there was too much uncertainty for the comparison to be clear. On the other hand, peak power with Mizone Rapid was very likely higher (98% chance) than that with water, and the difference was possibly moderate (68% chance). The difference in peak power between Mizone Rapid and Mizone was likely to have been substantial but small (87% chance).

Peak heart rate and lactate following the incremental test were also highest in the trials conducted with Mizone Rapid and Powerade, and peak glucose was highest with Powerade. There was a clear reduction in blood osmolarity with water relative to the other drinks after the

performance test, but differences between Mizone Rapid, Mizone and Powerade were unclear. Mizone Rapid produced the lowest urine osmolarity and the greatest urine volume after the performance test compared to the other drinks.

The effects of 2 SD of covariates in the analysis of the incremental test were either trivial or unclear, with the following exceptions: a 1.3 °C increase in ambient temperature was associated with a small increase in peak lactate of 18% (90% confidence limits $\pm 14\%$); a 2.8% increase in pre-test serum osmolarity tracked almost perfectly into a 2.7% increase in post-test serum osmolarity ($\pm 1.0\%$); and a 3.1-fold increase in pre-test urine osmolarity was associated with a small reduction in urine volume, by a factor of 0.69 (0.53 to 0.88) and a small 14% increase in sweat volume ($\pm 11\%$).

Mean values of measures taken during the steady ride are shown in Figure 1. There were no obvious consistent differences between drinks in the changes in tympanic temperature and heart rate during the ride. Differences in the mean tympanic temperature were trivial (up to 0.11 °C) but unclear (90% confidence limits $\sim \pm 0.18$; threshold for small 0.12 °C). Mean heart rate with Mizone Rapid was 1.0-1.3 min^{-1} less than with any other drink, but this difference was probably trivial (90% confidence limits ± 2.2 ; threshold for small 2.6 min^{-1}). Mean blood glucose was highest for Powerade, by a clear moderate-large amount (0.56-0.79; ± 0.58 ; threshold for small 0.12 mmol.L^{-1}), but the differences between Mizone Rapid and water or Mizone were small or trivial respectively. Lactate concentration was also highest with Powerade (1.65 mmol.L^{-1}), and lowest for Mizone Rapid (1.47 mmol.L^{-1}), this difference being only small (confidence limits and threshold for small, ± 0.15 and 0.10 mmol.L^{-1}).

Not apparent in Figure 1 is the effect of the ambient temperature as a covariate on the mean value of each variable. An increase of two standard deviations in ambient temperature (1.3 °C) was associated with a clear small increase in tympanic temperature (0.18°C; 90% confidence limits $\pm 0.07^\circ\text{C}$) and a trivial-small increase in heart rate (2.5; $\pm 0.6 \text{ min}^{-1}$). Effects of this covariate on blood glucose and blood lactate and effects of pre-exercise urine osmolarity as a covariate on all four variables were not noteworthy.

Table 2. Measures taken at the end of the incremental exercise test following a 2-h ride, during each of which one of the drinks was consumed. Data shown for each drink are back-transformed least-squares means of log-transformed raw values. The standard deviation is the typical variation between subjects derived from a linear model, averaged over the four drinks for the log-transformed measure and back-transformed to approximate raw units.

	Water	Mizone Rapid	Mizone	Powerade	Standard deviation
Peak power (W)	364	380	369	378	48
Peak heart rate (min ⁻¹)	175	180	175	178	17
Peak lactate (mmol.L ⁻¹)	5.4	6.8	5.9	7.1	2.3
Peak glucose (mmol.L ⁻¹)	4.3	4.3	4.6	5.1	0.7
Blood osmolarity (mosmol.L ⁻¹)	280.4	284.8	283.2	286.5	5.9
Urine osmolarity (mosmol.L ⁻¹)	445	270	358	370	280
Urine volume (ml)	220	300	210	270	270
Sweat volume (ml)	1380	1400	1510	1520	370

Table 3. Differences (%) between Mizone Rapid and the other drinks at the end of the incremental exercise test, and qualitative outcomes^a representing magnitude of the confidence limits.

	Mizone Rapid–Water	Mizone Rapid–Mizone	Mizone Rapid–Powerade	90% conf. limits	Threshold for small ^b
Peak power	4.4 small-large	3.0 trivial-mod.	0.5 unclear	±2.6	1.2
Peak heart rate	2.6 small-trivial	2.6 small-trivial	1.4 trivial-small	±2.5	2.1
Peak lactate	28 small-mod.	15 small-mod.	-3 unclear	±17	8
Peak glucose	1 unclear	-7 unclear	-15 small-large	±10	3.1
Blood osmolarity	1.6 trivial-large	0.6 unclear	-0.6 unclear	±1.3	0.4
Urine osmolarity	-39 mod.-trivial	-29 trivial-mod.	-27 trivial-mod.	±25	16
Urine volume	34 trivial-mod.	46 trivial-mod.	12 unclear	±50	21
Sweat volume	1 unclear	-8 unclear	-8 unclear	±14	5.3

^aAn effect is shown as unclear if the confidence interval spans substantial positive and negative values; otherwise the two descriptors represent the magnitude of the confidence limits, with order chosen so that the first descriptor is closer to the magnitude of the observed value. Examples: "4.4 small-large" implies the true value could be between small and large (i.e., moderate), but closer to small than large.

^bFor peak power, 0.3 of the error of measurement; for other measures, 0.2 of the between-subject standard deviation in Table 2, adjusted for small-sample bias.

Discussion

In this study consumption of a hypotonic carbohydrate-electrolyte drink may have produced a moderate enhancement of endurance

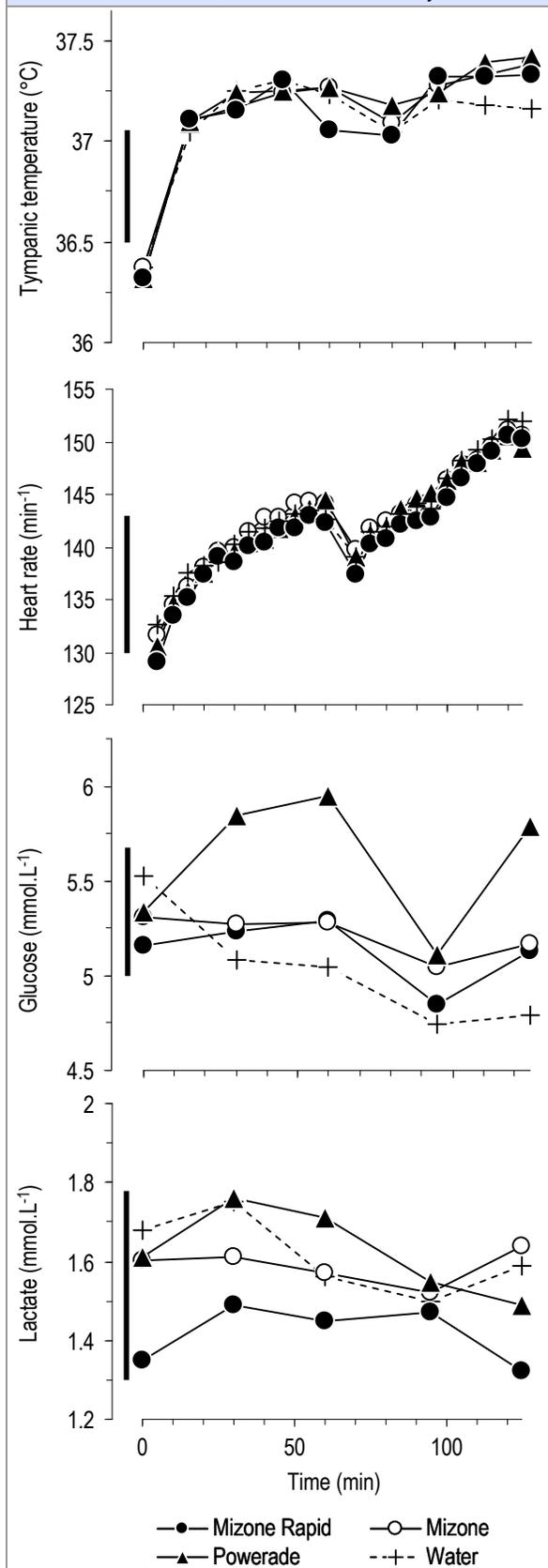
performance in comparison with a water placebo. A small benefit was also likely in comparison with a hypotonic drink containing only

carbohydrate, but performance was possibly similar to that with an isotonic carbohydrate-electrolyte drink. The incremental test we used following a pre-load should represent a good simulation of the energy demands in the closing stages of a cycle road race lasting several hours. Our quantitative inferences are based on the assumption that the variability in performance cyclists showed between trials in the test would be similar to that in such races. Irrespective of this assumption, it seems reasonable that the effects of ~2-4% we observed here would be important, considering that effects of ~1% are important in endurance time trials (Hopkins et al., 1999).

Test protocols can have profound effects on performance outcomes and errors of measurement (Hopkins et al., 2001), making it difficult to compare magnitudes of performance effects in different studies. Here we used a submaximal pre-load of fixed duration and intensity, which amplifies effects in a subsequent performance test (Hopkins et al., 2001). We also opted for an incremental test rather than the more usual time trial following the pre-load, because we wanted to eliminate noise and bias arising from difficulty subjects might have in choosing an appropriate pace following a pre-load. The resulting error of measurement of ~4% in the test is about three-fold more than the ~1-2% usually observed for peak power in incremental tests when there is no pre-load (Hopkins et al., 2001). It seems reasonable to assume that the pre-load caused a similar amplification of effects on peak power, and if we also assume that performance in an incremental test reflects performance in a time trial (an assumption the reviewer of this article challenged), we can infer that the two glucose-electrolyte solutions would have enhanced performance in an aerobic time trial by ~1-2% relative to water. The effects we observed are therefore comparable with the 2.3% effect on mean power for a glucose-electrolyte drink relative to a water placebo in a 1-h time trial (Jeukendrup et al., 1997). The 9-18% effects on times to exhaustion lasting ~100 min in the study of Maughan et al. (1996) are also of similar magnitude, when these are divided by 10-15 to convert them to effects in a time trial (Hopkins et al., 2001).

Our findings are consistent with other evidence of the importance of both carbohydrate

Figure 1. Measures from the 2-h steady ride for each drink. Data are means; bars are between-subject SD.



and sodium for the absorption of drinks from the gut (e.g., Brouns and Kovacs, 1997). While we did not measure carbohydrate or fluid absorption directly, some of our results provide indirect evidence for faster water absorption of Mizone Rapid: it produced the lowest urine osmolality and the greatest urine volume after the performance test, suggesting earlier excretion and therefore earlier absorption than the other drinks. Blood osmolality at the end of each test did not provide clear evidence of differences in absorption and excretion of water and osmolytes in the drinks: the lowest osmolality with water could be due to the fact that the water was finally being absorbed by the end of the test but was not yet filtered out by the kidneys.

Our finding of substantially higher peak lactates following the incremental test in the trials conducted with Mizone Rapid and Powerade could be a consequence of greater uptake of exogenous carbohydrate from these drinks than with Mizone and of course water during the pre-load. If the exogenous carbohydrate led to sparing of muscle glycogen, lactate could reach a greater peak in the incremental test (Maughan and Poole, 1981) through the athletes being able to push harder. This explanation could also account for the greater peak heart rates and peak power with Mizone Rapid and Powerade.

The physiological measures taken during the pre-load did not shed any additional light on the possible explanations for the differences in performance between the drinks. Tympanic temperature and heart rate turned out to be extraordinarily sensitive to ambient temperature, so lack of any substantial effect of the drinks on these variables is unlikely to be due to problems with measurement.

The reviewer requested some discussion of the issue that double blinding is difficult to achieve successfully with commercial products, because they can have different tastes, consistencies, colors and smells. At the time of the study we did not ask the subjects to guess which drink they were consuming, because our own sampling of the drinks led us to believe that the success of the blinding was not an issue. Of course there were subtle differences in taste, but how would these subjects know which drink they were getting unless they were familiar with the different tastes of the drinks? Even if some subjects had guessed they were on one

of the sports drinks, why would they think that it was any better or worse than the other drinks? However, given the recent evidence that carbohydrate receptors in the mouth can enhance performance (Carter et al., 2004; Chambers et al., 2009), we cannot exclude the possibility that the different performance outcomes with the drinks were due to taste or stimulation of other receptors rather than to metabolic or circulatory effects of carbohydrate and salt content.

We also agreed with the inclusion of the following caution from the reviewer about dilution of sports drinks. "It is possible that in the low range of carbohydrate intakes it is difficult to see differences in performance. Recent studies have suggested that larger intakes, in particular of glucose:fructose mixtures, can result in greater improvements in performance (Currell and Jeukendrup, 2008; Jeukendrup, 2010; Smith et al., 2010; Triplett et al., 2010). In endurance competitions (cycling events, Ironman 70.3, Ironman races, with the exception of marathon) we have found that athletes tend to have carbohydrate intakes between 60 and 80 grams per hour (Pfeiffer et al., unpublished). Such intakes cannot be achieved by low carbohydrate drinks alone, and any use of diluted sports drinks is usually in conjunction with gels or solid carbohydrate sources, at least for longer events (Pfeiffer et al., unpublished). It is impossible to conclude from the current study that low carbohydrate drinks are preferred in all conditions."

In conclusion, it is clear that a hypotonic sports drink with much less carbohydrate than the usual isotonic drinks can be an effective ergogenic aid for endurance performance of an hour or so, provided the drink includes some salt. It seems likely that water from the hypotonic drink is absorbed more rapidly than the isotonic drink, but more evidence from a tracer study is needed to resolve this issue.

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