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Translated from *Archivos de Medicina del Deporte* 2008;XXV(1):29-38



123

Volumen XXV (1)

Enero
Febrero
2008

Archivos de medicina del deporte

Órgano de expresión de la Federación Española de Medicina del Deporte
y de la Confederación Iberoamericana de Medicina del Deporte



Comparative study of different procedures of hydration during an exercise of long duration

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COMPARATIVE STUDY OF DIFFERENT PROCEDURES OF HYDRATION DURING AN EXERCISE OF LONG DURATION*

ESTUDIO COMPARATIVO DE DIFERENTES PROCEDIMIENTOS DE HIDRATACIÓN DURANTE UN EJERCICIO DE LARGA DURACIÓN

SUMMARY

Introduction: Dehydration plays an important part in performance deterioration for sportsmen. When considering rehydration strategies during physical exercise, it is important to bear in mind that the gastric emptying of ingested liquids is fast and absorption into the duodenum as fast as possible.

Objectives: To assess the capacity for adequate hydration, under conditions of heat and high humidity, with regard to various strategies based on the ingestion of different types of drinks with different flavours and palate conditions.

Method: An open, single-centre, crossed study of nutritional measures which was randomized with respect to the order in which the drinks selected for the study were ingested. 26 male long-distance runners were randomly selected. Each individual performed four ergometric endurance tests on a continuous belt.

In the first test the ergometric strain for the following ones was determined. In test number 2 (with constant load), only water was consumed; during number 3, flavored drinks, chosen from an assortment of 5 drinks in addition to one selected by the individual, were ingested. The fourth test consisted in consuming "ad libitum" any one of the five previous flavored drinks, the drink selected by the individual in the study, and also water.

Statistical analysis: Initially a descriptive statistical analysis was carried out; with regard to the quantitative variables, the average plus typical deviation were calculated, and with respect to the qualitative variables, both the absolute and relative frequency. In order to compare the different variables ANOVA was performed for repeated measures with two intrasubject factors (time: before and after the test; test: test 1, test 2, test 3).

Results: During test 2, each individual consumed only water at an average quantity of 487 mL. When the volunteer had an assortment of drinks available (test 3), the average consumption increased to 642 mL, a 31.8% increase on the previous one, and this increase was statistically significant ($p < 0.021$). During the carrying-out of the test for event 4 in which the subject

RESUMEN

Introducción: La deshidratación es un factor importante en el descenso del rendimiento deportivo. En las estrategias de rehidratación durante el ejercicio debe tenerse en cuenta que el vaciado gástrico de los líquidos ingeridos sea rápido y la absorción en duodeno lo más rápida posible.

Objetivos: Valorar la capacidad de hidratarse adecuadamente, en condiciones de calor y humedad alta, en función de diversas estrategias basadas en ingerir distintos tipos de bebidas con diferentes sabores y condiciones de palatabilidad.

Método: Estudio cruzado de intervención nutricional, unicéntrico, abierto, aleatorizado en la secuencia de ingesta de las bebidas del estudio. Se seleccionaron al azar a 26 corredores de fondo varones. Cada individuo realizó 4 pruebas de esfuerzo en ergómetro de cinta continua. En la primera prueba se determinó la carga del ergómetro de las siguientes. En la prueba nº 2 (con carga constante) se consumió agua exclusivamente; en la nº 3 se ingirieron bebidas con sabor elegidas entre un conjunto de 5 bebidas y una bebida elegida por el individuo. La prueba nº 4 consistió en tomar "ad libitum" cualquiera de las 5 bebidas con sabor anteriores, la bebida elegida por el individuo a estudio y agua.

Análisis estadístico: Inicialmente se realizó estadística descriptiva; a las variables cuantitativas se les calculó media y desviación típica y a las variables cualitativas frecuencia absoluta y relativa. Para la comparación de las distintas variables se realizó ANOVA para medidas repetidas con dos factores intrasujeto (tiempo: antes y después de la prueba; prueba: prueba 1, prueba 2, prueba 3).

Resultados: Durante la realización de la prueba 2, el individuo consumió únicamente agua en una cantidad media de 487 mL. Cuando el voluntario tuvo a su disposición un conjunto de bebidas (prueba 3), el consumo medio se incrementó hasta 642 mL, un 31,8% con respecto al inicial y este incremento fue estadísticamente significativo ($p < 0,021$). Durante la realización de la prueba de esfuerzo 4 en la que el sujeto podía consumir cualquiera de las be-

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*This study has been sponsored by the Observatory of Hydration and Health (OHS)

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Accepted: 15-12-2007 / Original nº 535 / Translated from *Archivos de Medicina del Deporte* 2008;XXV(1):29-38

was able to consume any of the existent drinks from test 3 or water (drink diversity), liquid consumption was increased to 729 mL, an increase of 49.7% with respect to the first, and this difference was also statistically significant ($p < 0.005$). The difference observed in the consumption of liquids between tests 3 and 4, did not turn out to be significantly different. From all of this it is possible to deduce that the subjects in the study consumed a greater quantity of liquids during those events in which they had a greater diversity in the assortment of drinks available, which meant that weight loss caused by dehydration diminished and at the same time the consumption of liquids during the 24 hours posterior to the endurance test carried out in the laboratory also diminished.

Key words: Drinks. Hydration. Dehydration. Thermoregulation. Physical exercise.

bidat existentes en la prueba 3 o agua (diversidad de bebidas), se incrementó el consumo de líquidos hasta 729 mL, un 49,7% con respecto al inicial y esta diferencia también fue estadísticamente significativa ($p < 0,005$). La diferencia observada en el consumo de líquidos entre las pruebas 3 y en la 4, no resultó estadísticamente significativa. De todo ello se deduce que los sujetos estudiados consumieron mayor cantidad de líquidos en aquellas pruebas en las que disponían de un conjunto de bebidas con mayor diversidad, lo que hizo disminuir la pérdida de peso provocada por la deshidratación al tiempo que también disminuyó el consumo de líquidos en las 24 horas posteriores a la prueba de esfuerzo realizada en el laboratorio.

Palabras clave: Bebidas. Hidratación. Deshidratación. Termorregulación. Ejercicio físico.

INTRODUCTION

Dehydration brought on by physical exercise

Dehydration is an important factor in the reduction of athletic performance. There is a group of factors that may occur singly or in combination; for example, reduced gastric emptying¹ and higher incidence of gastrointestinal pain²; an increase in the plasmatic levels of angiotensin and vasopressin³; reduction in plasmatic volume and increase in the osmolality and viscosity of the blood⁴. There is also a reduction of central venous pressure together with a rise in the temperature where sweating begins, compromising its thermoregulatory effect by reducing sweat production and periphery blood circulation in an effort to maintain central venous pressure⁵. Finally, when hypohydration is coupled with food restrictions, muscular glycogen drops to 45%, representing an important challenge to the process of muscular contraction⁶.

Hydration during physical stress

In any strategy for rehydration during exercise both the ambient temperature and the intensity, duration and type of exercise must be taken into account. It is important to realize that most stu-

dies on fluid replacement run into the problem of ingestion during the practice of a sport. In this sense, it is very important that the gastric emptying be fast and the duodenal absorption the fastest possible⁷⁻⁹. As to osmolality, the barrier is plasmatic osmolality, the position of the E.U. Scientific Committee on Food (SCF) being between 270 and 330 mOsm/kg¹⁰.

Finally, the type of CHO may not be very important, even though it may influence palatability which is, on the other hand, the greatest determiner in the consumption of a drink. According to the SCF, in situations of high muscular fatigue, especially for athletes, the drink should contain between 80 and 340 Kcal (335-1470 KJ) provided by the CHOs for every 1000 ml of solution, and between 20 and 50 mmol/L (460-1150 mg/l) of Na⁺ (SCF, 2006)¹⁰. The drink's ideal temperature when taken in large quantities should be approximately between 15°C-22°C (59°F and 72°F), it should be sweetened and have an agreeable flavor (ACSM, 1997)¹¹.

OBJECTIVES

Evaluate the ability to maintain adequate hydration under conditions of high heat and humidity, using different strategies based on consumption

of different types of drink with different flavors and levels of palatability.

MATERIALS AND METHOD

Type of study

A unicentric, open nutritional cross-study using randomly-ordered consumption of the different drinks included in the study.

Study subjects

26 male long-distance runners were selected at random. The average relative oxygen consumption of the group was 51.03 ± 6.2 ml/Kg/min and the average age was 34.5 ± 7.5 .

Prior to the study each of them underwent a sports-medical checkup. Each athlete was informed orally and in writing of the methodology of the study, as well as of the possible negative effects that might appear as a consequence of the different tests that were going to be carried out (exercise stress tests and blood tests). They were also informed of the voluntary nature of the project, both as refers to their participation in the project and the possibility of abandoning it at any time. All of them signed an informed consent form to participate in the project and an informed consent form for each of the exercise stress tests undergone.

Study site

The exercise stress tests were carried out in the Army Physiology Laboratory of the Catholic University of San Antonio in Murcia. This center

has the installations, the material and the health personnel necessary for the execution of said tests.

Methodology

Each individual did 4 exercise stress tests on a treadmill ergometer. They were required to come to each test with appropriate clothing and shoes, and without having made any intense physical or psychological efforts in the 48 hours prior to the stress test.

1st Test

Triangular maximal progressive stress test on a treadmill, with an initial speed of 7 km/h, increasing 1 km/h each minute, maintaining a constant grade of 1%. After taking this test the participants had to make a note of any liquid consumed the day before and the day after the next three tests and they were asked about what drinks they preferred to ingest during or after physical activity.

The next three tests that the athletes did differed only in the type of liquid that they could consume, as follows:

- Test 1, water: *ad libitum* consumption of water only.
- Test 2, flavored drinks: *ad libitum* consumption from a selection of 5 flavored drinks and one drink chosen by the individual.
- Test 3, variety of drinks: *ad libitum* consumption from a selection of the 5 previous drinks, the drink chosen by the participant in the study, and water (Table 1).

	Energy (KCAL)	Carb. (GR)	Lipids (GR)	Proteins (GR)	Flavor	Gas
Drink 1	45	10.4	0	0.1	Orange	No
Drink 2	32	8.5	0	0	Lemon	No
Drink 3	26	6.3	0	0	Lemon	No
Drink 4	37	8.9	0	0	Quinine	Yes
Drink 5	0	0	0	0	Cola	Yes

TABLE 1.
Information and organoleptic characteristics of the drinks employed [100 ml]

Being a cross-study, and to minimize the bias of the individual's learning curve during the execution of the different tests, the group of volunteers was divided into three groups at random, in such a way that each group did the tests in a different order. This structure is summarized in Table 2.

2nd Test

The second test was held one week after the first. All the tests were held in the morning. One hour before the tests were begun, laboratory conditions for their execution were created using a vaporizer and heat pump to bring the temperature and humidity to 30°C and 60%, respectively.

The individuals did a rectangular stress test on a treadmill, with a limited charge of 11 km/hour, with a constant grade of 1%. The test lasted for

50 minutes and the consumption of liquids during the same was *ad libitum*. The liquids were put into identical, transparent, numbered plastic bottles, with the drink at an initial temperature of 8°C. Prior to doing the test the runner sampled the different drinks at his disposal.

During the test all drink consumption was noted: the drink, the quantity and the time. At minute 30 of the test the temperature and ambient humidity were registered. Finally, at the end of the test the total amount of liquids consumed was added up.

3rd and 4th Tests

The third and fourth tests were carried out a week after the second test. Their methodology and the establishment of the different variables were exactly the same as in the prior rectangular test;

TABLE 2.
Order of tests
carried out

Runner	Day 1	Day 2	Day 3
1	Water	Flavored drinks	Flavored drinks + Water
2	Water	Flavored drinks	Flavored drinks + Water
3	Water	Flavored drinks	Flavored drinks + Water
4	Water	Flavored drinks	Flavored drinks + Water
5	Water	Flavored drinks	Flavored drinks + Water
6	Water	Flavored drinks	Flavored drinks + Water
7	Water	Flavored drinks	Flavored drinks + Water
8	Water	Flavored drinks	Flavored drinks + Water
9	Flavored Drinks	Flavored drinks + Water	Water
10	Flavored Drinks	Flavored drinks + Water	Water
11	Flavored Drinks	Flavored drinks + Water	Water
12	Flavored Drinks	Flavored drinks + Water	Water
13	Flavored Drinks	Flavored drinks + Water	Water

Runner	Day 1	Day 2	Day 3
14	Flavored drinks	Flavored drinks + Water	Water
15	Flavored drinks	Flavored drinks + Water	Water
16	Flavored drinks	Flavored drinks + Water	Water
17	Flavored drinks	Flavored drinks + Water	Water
18	Flavored drinks + Water	Water	Flavored drinks
19	Flavored drinks + Water	Water	Flavored drinks
20	Flavored drinks + Water	Water	Flavored drinks
21	Flavored drinks + Water	Water	Flavored drinks
22	Flavored drinks + Water	Water	Flavored drinks
23	Flavored drinks + Water	Water	Flavored drinks
24	Flavored drinks + Water	Water	Flavored drinks
25	Flavored drinks + Water	Water	Flavored drinks
26	Flavored drinks + Water	Water	Flavored drinks

the only difference was the type of liquid available for consumption.

STATISTICAL ANALYSIS

Initially a descriptive statistical analysis was made: with regard to the quantitative variables the average plus standard deviations were calculated, and for the qualitative variables both the absolute and relative frequencies. In order to compare the different variables, ANOVA was done for repeated measures with two between-subject factors (time: before and after the test; test: test 1, test 2, test 3).

RESULTS

The results of the application of descriptive statistics to all the variables (average and standard deviation for the quantitative variables and relative frequency for the qualitative variables) in the study are shown on Tables 3, 4, 5 and 6.

Laboratory ambient conditions

The ambient conditions in the laboratory remained constant during the execution of all of the exercise stress tests, with no significant differences in the ambient temperature or humidity being observed when the tests were compared (Table 7).

			Liq. PR	Liq. 24h	Weight
Water	Pre-test	Average		2534.2	72.4
		Std. dev.		599.3	7.1
	Post-test	Average	487.0	2972.6	71.5
		Std. dev.	223.4	676.1	7.0
Flavored drinks	Pre-test	Average		2440.0	72.5
		Std. dev.		606.5	7.1
	Post-test	Average	642.8	2702.5	72.0
		Std. dev.	228.9	897.7	7.01
Various drinks	Pre-test	Average		2600.0	72.8
		Std. dev.		454.6	4.1
	Post-test	Average	729.0	2625.0	72.2
		Std. dev.	223.5	713.6	4.0

TABLE 3.
Weight and
consumption
of water

LIQ. PR: liquid intake during the tests (mL); LIQ 24H: liquid intake in the 24 hours prior to and after the tests (mL); WEIGHT: weight of the athlete just before and after the tests (Kg).

			HB	HCTO	PV
Water	Pre-test	Average	14.3	42.0	58.0
		Std. dev.	0.8	2.5	2.5
	Post-test	Average	14.5	42.5	56.8
		Std. dev.	0.9	2.6	3.8
Flavored drinks	Pre-test	Average	14.5	42.0	57.9
		Std. dev.	0.9	2.5	2.5
	Post-test	Average	13.7	42.6	56.3
		Std. dev.	0.4	2.5	3.2
Various drinks	Pre-test	Average	14.3	40.4	59.6
		Std. dev.	0.9	1.7	1.7
	Post-test	Average	14.3	42.1	55.7
		Std. dev.	0.9	2.6	4.4

TABLE 4.
Hematologic
variables

HB: hemoglobin (gr/100mL); HCTO: hematocrit (%); PV: plasmatic volume (%)

TABLE 5.
Serum and
urinary
variables

			Sodium	OSM PL	DEN URI	OSM URI
Water	Pre-test	Average	138.9	287	1020	722
		Std. dev.	2.5	6	7	231
	Post-test	Average	140.3	289	1021	716
		Std. dev.	2.6	6	7	201
Flavored drinks	Pre-test	Average	138.2	283	1021	771
		Std. dev.	3.2	20	6	249
	Post-test	Average	139.6	286	1024	778
		Std. dev.	3.8	15	5	188
Various drinks	Pre-test	Average	139.0	285	1015	750
		Std. dev.	3.4	6	5	131
	Post-test	Average	139.9	289	1018	791
		Std. dev.	3.0	9	7	90

SODIUM: natremia (mEq/L); PL OSM: plasmatic osmolarity (mosm/L); DEN URI: urine density (gr/L); OSM URI: urine osmolarity (mosm/L)

TABLE 6.
Vital constants

			CF	SAP	DAP	TEMP
Water	Pre-test	Average	60.9	118.3	73.4	36.0
		Std. dev.	10.8	11.7	10.1	0.4
	Post-test	Average	86.9	107.8	72.5	36.5
		Std. dev.	13.4	10.4	6.5	0.4
Flavored drinks	Pre-test	Average	60.3	113.5	70.2	36.0
		Std. dev.	10.0	9.9	7.8	0.3
	Post-test	Average	89.1	108.7	73.0	36.5
		Std. dev.	14.6	7.9	6.7	0.4
Various drinks	Pre-test	Average	63.6	111.0	71.0	35.7
		Std. dev.	11.3	5.5	8.9	0.2
	Post-test	Average	98.2	99.8	70.0	36.7
		Std. dev.	15.2	9.8	7.1	0.2

CF: Cardiac frequency (lpm); SAP: systolic arterial pressure (mm of Hg); DAP: diastolic arterial pressure (mm of Hg); TEMP: body temperature (°C)

TABLE 7.
Ambient
conditions

		AMB. TEMP.	REL. HUM.
Water	Average	27.4	61.5
	Std. dev.	0.5	7.3
Flavored drinks	Average	27.5	65.0
	Std. dev.	0.5	4.3
Various drinks	Average	27.2	65.8
	Std. dev.	0.4	3.2

AMB. TEMP.: ambient temperature (°C); REL. HUM.: relative humidity (%)

Consumption of liquids

During the execution of Test 1, the individual only consumed water of an average amount of 487 mL. When the volunteer had a selection of drinks at his disposal (Test 2) the average con-

sumption rose to 642 mL, 31.8% higher than the first test, and this increase was statistically significant ($p < 0.021$). When exercise stress test 3 was carried out, where the subject could ingest any of the drinks available in Test 2 or water (various drinks), liquid consumption increased to 729 mL, 49.7% higher than the first test, and this difference was also statistically significant ($p < 0.021$). The difference observed in the consumption of liquids between tests 2 and 3 was not statistically significant (Figure 1).

The increase in the consumption of liquids in tests 2 and 3 with respect to test 1 is not homogeneous throughout the test. If we show the average consumption of liquids throughout the tests on

a graph (by which the liquid consumed by the individual during a test up to a set moment can be seen), we can observe various features:

- The consumption of liquids intensifies in the second half of the test, being less in the first half hour. Undoubtedly the subject begins to ingest liquids when the thirst reflex appears and this mechanism starts up when the individual has lost approximately 1% of his weight as a consequence of the dehydration caused by perspiring.
- Until the halfway point of the test, the consumption of liquids is absolutely equivalent (in the first half hour they ingest the same quantity of liquid in the three tests and even through minute 45 liquid consumption is identical in tests 1 and 2). The increase in the ingestion of liquids which occurs in tests 2 and 3 takes place in the second half of the tests (Figure 2).

If we analyze the number of drinks utilized by the subjects in tests 2 and 3, we obtain the following data:

- Test 2: the average percentage of drinks utilized by the individual was 51.4 ± 9.5 .
- Test 3: the average percentage of drinks utilized by the individual was 57.4 ± 10.7 .

This indicates that if the individual has a variety of drinks available for his consumption, he makes use of it.

Upon evaluating the consumption of each of the drinks separately, we can observe that drinks 4 and 5 were very seldom used by the athletes; therefore, if we exclude those two drinks from the previous calculations, the conclusions reached would be more incontrovertible (Figure 3).

Upon analyzing the consumption of liquids that took place in the 24 hours prior to and after each of the tests carried out, we can also see differences. In all types of tests there is an increase in this consumption in the 24 hours after the test

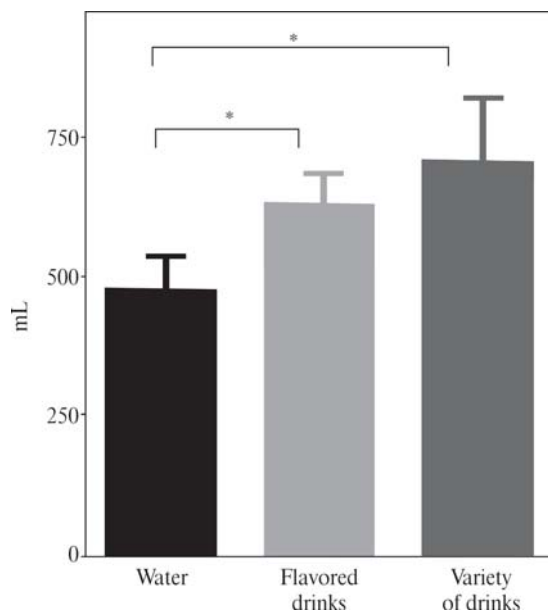


FIGURE 1. Consumption of water during the execution of the rectangular stress tests. Average values \pm EEM [(*) Pure statistically significant differences $p < 0.05$]

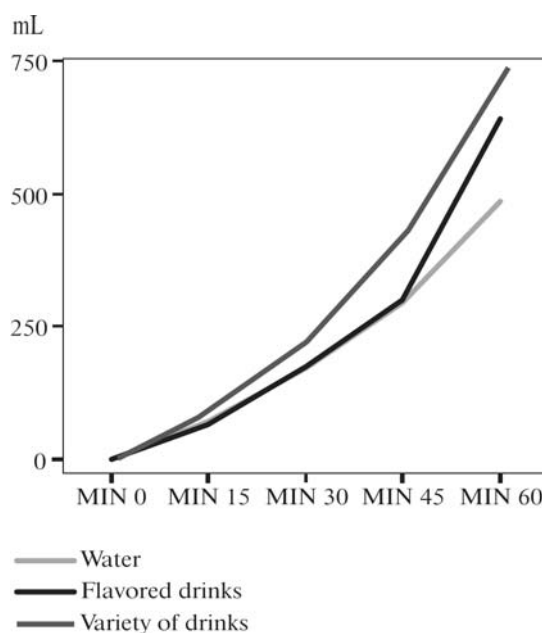
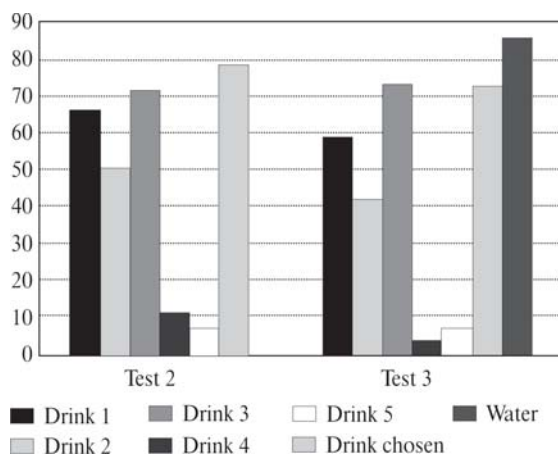
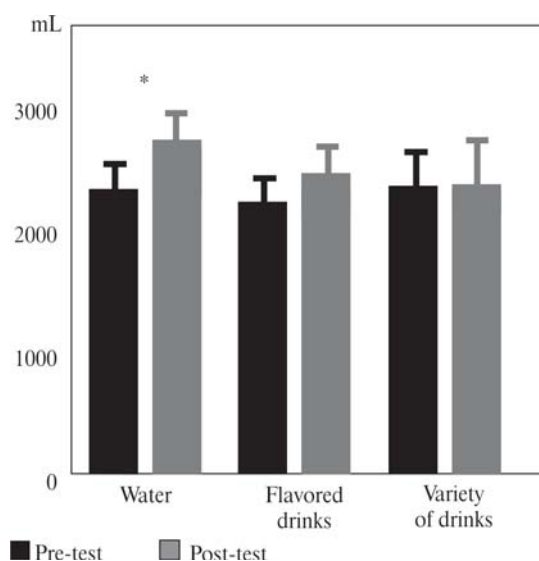
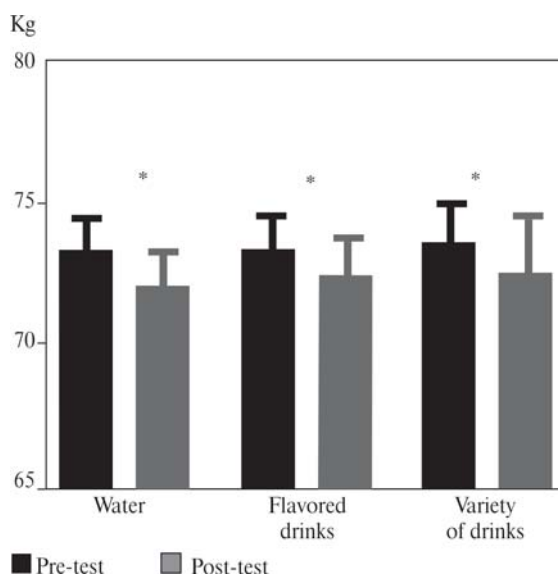


FIGURE 2. Average accumulated consumption of liquids in each of the stress tests completed by the athlete

with respect to that of the day before, but while they did tests 2 and 3, said increase is minimal and without statistical significance, whereas when they did test 1 said difference acquires statistical significance. Therefore, probably, the lower hydric consumption during test 1 provoked a greater consumption of liquids during the 24

FIGURE 3.
Percentage of use
of each of the
drinks in each of
the stress tests**FIGURE 4.**
Consumption of
liquids in the 24
hours prior to and
after the execution
of the rectangular
stress test. Average
values +/- EEM [(*)
statistically
significant
differences for
 $p < 0.05$]**FIGURE 5.**
Volunteer weight
obtained imme-
diately before and
immediately after
the execution of
the rectangular
stress test. Average
values +/- EEM
[(*) statistically
significant
differences for
 $p < 0.05$]

hours afterward to recuperate basal conditions (Figure 4).

Weight

Individual weight loss can be observed after each of the stress tests, secondary to hydric loss through sweating ($p < 0.001$). This weight loss does not have the same magnitude in the different tests. When the subject consumes only water, the average weight loss he experiences is 990 gr; when he has a selection of drinks at his disposal the average weight loss is 760 gr and when he can ingest a variety of drinks the average weight loss he experiences is 620 gr. In a statistical comparison of these losses, we can observe significant differences between tests 1 and 2 ($p < 0.018$) and between tests 1 and 3 ($p < 0.035$) (Figure 5).

Hematological variables and plasmatic volume

The concentration of hemoglobin, hematocrit and plasmatic volume present a completely parallel evolution. The first two undergo a significant value increase during the execution of all the stress tests ($p < 0.001$ both) while the plasmatic volume is diminished, also significantly ($p < 0.001$). These variations do not change depending on the test carried out, in other words, the possibility of drinking water or of choosing among a selection of flavored drinks or of choosing a drink from group 3, does not modify the evolution of these variables. The consumption of liquids does not, in any case, manage to avoid the consequences that dehydration produces on these variables, although it probably minimizes them, but equally in all three tests.

Serum variables

Natremia

Dehydration, a consequence of the execution of rectangular exercise stress tests under complicated thermoregulatory conditions, is not compensated by the consumption of liquids,

which causes a hemoconcentration with its corresponding increase in levels of serum sodium. This significant increase ($p < 0.043$) occurs equally in the three stress tests carried out by the individual.

Plasmatic osmolarity

This presents the same variations as the previous variable and for the same reasons. A significant increase can be observed in all the rectangular stress tests ($p < 0.001$). Alterations of said increase depending on the type of consumption that was made in each test have not been noted.

Urinary variables

Osmolarity and density of the urine collected before and after the tests do not present significant differences. This statistically significant absence is produced in the three rectangular tests carried out by the subject; in other words, the possibility of consumption of a greater or lesser quantity of flavors or diversity of liquids does not produce any modification of these variables. It is probable that the lack of any control of hydric consumption in the time leading up to the stress tests may have influenced the result of these variables.

Vital constants. Cardiac frequency

A significant increase ($p < 0.001$) can be observed in cardiac frequency obtained after 10 minutes' rest between the moments prior to the test and the moments after it. This increase of 29.7 bpm on average does not present differences when the different tests are compared, in other words, the changes observed in this parameter are the same, without regard to the consumption of drinks.

Vital constants. Arterial pressure

The two components of arterial pressure display different behavior. Systolic arterial pressure continues to display the same variability as the rest of the parameters analyzed above; in other words, a decrease can be observed when compared with the value obtained before and after the stress test

($p < 0.001$) and this decrease shows no change when the different tests completed by the individual are compared. Diastolic arterial pressure does display different behavior depending on the availability of liquids. In the first and third stress tests this variable undergoes an identical significant decrease, while in the second this variable displays an increase when compared to pre- and post-test levels. These variations do not display statistical significance.

Vital constants. Temperature

Body temperature also experiences an average increase of 0.62°C after the execution of the rectangular stress test ($p < 0.001$) and this increase is not dependent on the category of hydration employed.

CONCLUSIONS

- The consumption of liquids by an individual over time follows an exponential curve.
- Individuals consume a greater quantity of liquids in those tests in which the subject has a selection of different-flavored drinks at his disposal.
- Individuals consume a greater quantity of liquids in those tests in which the subject has a selection of drinks of greater diversity at his disposal (in this case, he consumes a significant number of them).
- The increase in consumption of liquids in the tests in which the individual has a variety of drinks at his disposal decreases the weight loss occasioned by dehydration.
- In the tests in which flavored drinks and a variety of drinks are ingested, the consumption of liquids in the 24 hours after the stress test is less, since a greater amount of liquids was consumed during the tests due to the variety and diversity of the drinks, and the subjects therefore display an adequate state of hydration and are satiated.

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