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Effects of oral salt supplementation on physical performance during a half-ironman: A randomized controlled trial

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The aim of this study was to investigate the effectiveness of oral salt supplementation to improve exercise performance during a half-ironman triathlon. Twenty-six experienced triathletes were matched for age, anthropometric data, and training status, and randomly placed into the salt group (113 mmol Na^+ and 112 mmol Cl^-) or the control group (cellulose). The experimental treatments were ingested before and during a real half-ironman triathlon competition. Pre- and post-race body mass, maximal force during a whole-body isometric strength test, maximal height during a countermovement jump, were measured, and blood samples were obtained. Sweat samples were obtained during the running section. Total race time was lower in the salt group than in the control group ($P = 0.04$). After the race, whole-body isometric strength ($P = 0.17$) and jump height ($P = 0.49$) were similarly reduced in both groups. Sweat loss ($P = 0.98$) and sweat Na^+ concentration ($P = 0.72$) were similar between groups. However, body mass tended to be less reduced in the salt group than in the control group ($P = 0.09$) while post-race serum Na^+ ($P = 0.03$) and Cl^- ($P = 0.03$) concentrations were higher in the salt group than in the control group. Oral salt supplementation was effective to lessen body mass loss and increase serum electrolyte concentration during a real half-ironman.

Oral salt supplementation before or during competitions is a popular strategy used by endurance athletes aiming to replace the electrolytes lost by sweating. Sweat production during exercise is influenced by several factors including exercise intensity and duration, environmental conditions, clothing, and heat acclimatization, and it can vary from extremely low values to more than 3 L/h (Rehrer, 2001). The concentrations of the main sweat electrolytes (sodium, chloride, and potassium) vary greatly among individuals despite similar cardiorespiratory fitness (Hamouti et al., 2011) and it is not uncommon to find individuals with unusually salty sweat [< 80 mM for sweat sodium concentration (Brown et al., 2011)]. Despite the fact that sports drinks contain salt to replace the loss of electrolytes during exercise, the concentrations of sodium, chloride, and potassium contained in commercially available sports drinks are well below the values found in sweat (Coso et al., 2008). Thus, it might be necessary to use salt supplements (in addition to sports drinks) to compensate for the loss of electrolytes in endurance disciplines, especially in competitions in hot environments, athletes with unusually salty sweat or athletes that do not properly match fluid

intake and sweat loss (Montain et al., 2006). However, it is also necessary to evaluate the potential digestive side effects produced by the ingestion of salt supplements.

The main physiological goal of ingesting salt during prolonged exercise is to maintain serum electrolyte concentrations preserving intravascular osmotic pressure and plasma volume in a situation in which both fluid and electrolytes balances are challenged by sweating. The salt ingested during exercise enters into the intravascular spaces, leads to the maintenance of aldosterone and vasopressin production (Rehrer, 2001), increases the thirst stimulus, and reduces the amount of urine produced (Shirreffs & Maughan, 1998). These effects associated with the ingestion of salt enhance electrolyte balance and stimulate the maintenance of body water, ultimately reducing physical fatigue and medical problems associated with these homeostatic imbalances (Sawka & Montain, 2000; Speedy et al., 2002; Valentine, 2007) in endurance disciplines. In addition, maintaining electrolyte balance in extracellular and intracellular fluids might aid in preserving motor drive during muscular contractions (Coso et al., 2008) which in turn affects the retention of muscle strength. Despite these physiological benefits associated with oral salt supplementation, its effectiveness for endurance performance is unclear.

Several investigations have examined the effects of salt supplementations on various endurance exercise activities under well-controlled laboratory conditions (Barr et al., 1991; Vrijens & Rehrer, 1999; Sanders et al., 2001; Twerenbold et al., 2003; Sims et al., 2007a, b; Coso et al., 2008; Anastasiou et al., 2009; Hamouti et al., 2012). From this laboratory-based research, it can be concluded that the ingestion of salt before or during exercise might improve endurance because of an attenuated decrease in plasma volume, maintained serum sodium concentration, and improved thermoregulation, especially in the heat. However, in these studies, salt supplementation was always accompanied by a fluid intake regime in which fluid volume matched or exceeded sweat rate during exercise. This experimental setting imposes an artificial fluid overload that does not reflect common practice during real endurance competitions (Del Coso et al., 2012, 2013a, b, 2014b).

To our knowledge, only three investigations have determined the effectiveness of salt or sodium supplementation during field endurance protocols (Speedy et al., 2002; Hew-Butler et al., 2006; Cosgrove & Black, 2013). These investigations included *ad libitum* fluid intake regimes instead of matching fluid and sweat volumes. Interestingly, with this "ecological" setting, oral salt supplementation did not modify serum sodium concentration or body weight changes; it was also ineffective to increase performance. However, salt ingestion increased fluid intake and attenuated plasma volume reductions in comparison to a placebo (Cosgrove & Black, 2013) indicating that salt ingestion produced an osmotic stimulus during endurance exercise. While field investigations increased the applicability of salt intake during exercise, they failed to control variables which are known to influence endurance performance (e.g., cardiorespiratory fitness, training status, carbohydrate intake, etc.).

Thus, laboratory and field investigations present contradictory findings with respect to the effectiveness of salt supplementation to improve physical performance. The aim of this study was to determine the effectiveness of oral salt supplementation to improve performance in competitive triathletes during a half-ironman race. The experiment was set up with an ecologically valid context (real triathlon competition) with *ad libitum* water access controlling other factors that could influence endurance performance such as cardiorespiratory fitness, training status, experience, or carbohydrate intake during the race. We hypothesized that participants supplemented with salt would improve race time because of enhanced body water and electrolyte preservation.

Methods
Ethics statement

Participants were fully informed of the risks and discomforts associated with the experiments and signed a written consent form before taking part in this investigation. The study was approved by

Table 1. Morphological characteristics, training status, and previous best race time in the half-ironman distance for triathletes that ingested placebo (control) or salt capsules during a half-ironman triathlon race

	Control	Salt
n	13	13
Age (year)	37.4 ± 7.8 (32.7–42.1)	36.5 ± 5.9 (33.0–40.1)
Weight (kg)	73.4 ± 7.4 (69.0–77.8)	74.9 ± 7.7 (70.2–79.6)
Height (m)	175 ± 5 (172–178)	179 ± 7 (175–183)
Experience (year)	8.3 ± 3.0 (2.7–14.1)	7.2 ± 2.6 (3.6–10.7)
Swimming training (km/week)	8.4 ± 6.7 (3.7–13.2)	8.7 ± 4.3 (5.9–11.4)
Cycling training (km/week)	186 ± 78 (118–254)	170 ± 71 (118–222)
Running training (km/week)	36.5 ± 20.4 (21.1–55.8)	33.5 ± 15.9 (23.9–43.0)
Previous best race time (min)	301 ± 25 (288–314)	301 ± 33 (290–312)

Data are mean ± SD (95% confidence intervals). Swimming, cycling, and running training represent the mean distance covered per week during the practices in the month prior to the race. The comparison between groups was $P > 0.05$ for all the variables.

the Camilo Jose Cela Ethics Committee in accordance with the latest version of the Declaration of Helsinki. This study has been registered in ClinicalTrials.gov with the identifier number: NCT 02103491.

Participants

Twenty-six healthy and well-trained triathletes were recruited by email or through Internet announcements to participate in this study. The participant recruitment was carried out between May 1 and June 1, 2013. Before enrolling in the investigation, a questionnaire about their medical history, previous training, previous triathlon experience, and previous best race time in half-ironman triathlon races was filled out by each participant. All participants were males. Participants were matched (in pairs) for age, anthropometric data, training, and best race time; and an equal number of triathletes ($n = 13$) was randomly assigned to the control group or to the salt ingestion group using randomization software. Sample size was determined based on the standard deviation of triathletes' race times obtained in a previous publication (Del Coso et al., 2012). The main morphological variables, training status, and best performance time in the half-ironman distance of the finishers were similar between these groups ($P > 0.05$; Table 1). Once the participants had finished the triathlon race and completed the post-race measurements, their participation in the investigation was at an end (this study did not include a follow-up protocol).

Experimental protocol

A double-blind, placebo-controlled, parallel/randomized experimental design was used in this study. Participants were instructed to perform light exercise and to avoid pain-relieving strategies (e.g., analgesic medications, manual massage, ice, etc.) 2 days before the race. In addition, participants were instructed to avoid any sources of caffeine and alcohol during the 24 h before the onset of the race. Three hours before the race, participants arrived at an area close to the start line having drunk 500 mL of tap water 2 h before arrival. Participants had their habitual pre-competition

meal, which was not standardized among participants to avoid affecting their individual pre-competition routines. However, the pre-competition meals were analyzed afterwards and their content in carbohydrates, proteins, and salt was similar between groups.

On arrival, participants rested for 10 min in a recumbent chair and a 5 mL venous blood sample was drawn from an antecubital vein. The blood was allowed to clot and centrifuged at 5000 g to obtain serum. Participants then completed a 10-min standardized warm-up consisting of running, dynamic leg exercises, and practice jumps. After that, they performed two countermovement vertical jumps (CMJ) for maximal height on a force platform (Quattrojump, Kistler, Winterthur, Switzerland) to assess pre-race leg power output. On command, the participants flexed their knees and jumped as high as possible while maintaining their hands on their waist and landed with both feet. The highest values for jump height and the peak muscle leg power output during the concentric phase of the jump were used for statistical analysis. Participants were previously familiarized with the jump test.

Subsequently, whole-body isometric muscle strength was measured by means of a handheld pull gauge (Isocontrol Isométrico, EV-Pro, Madrid, Spain) set at a frequency of 1000 Hz. For this measurement, participants stood on a 50×50 cm iron base connected to a handle bar by a non-elastic cable. The isometric gauge was inserted within the cable and the height of the cable was individually set to provide a 135° knee flexion with the back and arms completely extended. Participants were instructed to perform a maximal pull for 3 s using their whole body (mainly legs and arms) while maintaining this position. Verbal motivation was provided during the test. An adjustable lumbar-back protector was used for support and protection during the execution. Maximal and mean isometric strength were obtained during the test. Participants were previously familiarized with this measurement.

Participants were then provided with three plastic bags each of which contained four white capsules (e.g., a total of 12 capsules). In the salt group, the capsules were filled with a commercially available product that contains buffered electrolyte salts (Saltstick caps, Saltstick, California, USA). The total amount of electrolytes provided in the salt group was 2580 mg of sodium (113 mmol), 3979 mg of chloride (112 mmol), 756 mg of potassium (19.3 mmol), and 132 mg of magnesium (5.4 mmol). This amount of salt was calculated to replace ~ 50% of the sodium lost in sweating by an average participant with a sweat sodium concentration of 40 mM, a sweat rate of 1.0 L/h and a race time of 325 min. In the control group, participants received the same number of capsules with the exact same appearance but filled with an isocaloric placebo (cellulose). All the participants were instructed to ingest the contents of the first bag during the transition between the swimming and cycling sections, the second bag around the middle of the cycling leg, and the third bag during the transition between the cycling and running sections. This schedule was used to facilitate ingestion and electrolyte absorption during the race. Participants received a sample of these capsules (filled with placebo) the week before the race to practice the ingestion protocol during the transition and the cycling sector. Participants were encouraged to ingest all the capsules according to the programmed schedule and to report any incidence during the capsule ingestion throughout the race.

Just 15 min before the race (and after their habitual warm-up), participants were weighed in their competition clothes (without wetsuit) and a segmental bioelectrical impedance analysis was performed (BC-418, Tanita, Tokyo, Japan) to predict pre- to post-race total body water changes. The race started at 12:00 h and consisted of 1.9 km of swimming, 75 km of cycling (1100 m net increase in altitude), and 21.1 km of running. Environment conditions were recorded at 30-min intervals and mean ± standard deviation (SD; range) dry temperature during the event was 22.5 ± 2.7 °C (18.8–26.6 °C) with a relative humidity of 36.8 ± 8.3% (32–45%). The swim section was performed in a natural lake with a water temperature of 17.5 ± 0.3 °C. All participants wore neoprene wetsuits during the swim section, drank, and consumed food *ad libitum*, and swam, cycled, and ran at their own pace with no instructions given by the experimenters (apart from those related to capsule ingestion).

During the second transition (between the cycling and running legs), two sweat patches (Tegaderm + Pad, 3M, St Paul, MN, USA) were placed on their forearms to collect sweat samples. For this purpose, participants went to an area located just outside the transition area and their forearm skin was cleaned with distilled water and alcohol and dried with clean gauze to eliminate any remains of previous sweat from the skin. The sweat patch was then firmly adhered to the skin and fastened by an elastic tubular net bandage (Elastofix, Insfarma, Zaragoza, Spain). This process took approximately 1 min and this time was subtracted from the final race time of each participant.

Within 1 min of the end of the race, participants went to a finish area and body mass and body bioelectrical impedance were immediately measured using the same apparatus as described previously. Participants were instructed to avoid drinking from the finish line until the post-race weighing and an experimenter assured compliance. Then, participants performed two CMJs and the whole-body isometric muscle strength test, as previously described. These tests were completed within 5 min of the end of the race. Participants then rested for 5 min and a venous blood sample was obtained. During this resting period, the sweat patches were removed using clean tweezers and placed in a sterile 10-mL tube. Sweat patches that were detached from the skin or presented a leak were discarded.

After these protocols, the subjects self-rated their perceived exertion during the race using the Borg scale (6 to 20 points) while perceived leg muscle soreness was self-rated using a visual analog scale (0 to 10 points). Participants also filled out a detailed questionnaire about fluid and food intake during the race. Data on this questionnaire were used to calculate fluid, calorie, and carbohydrate intake during the race. With this self-reported questionnaire, we also calculated electrolyte intake during the race (apart from the salt ingested with the capsule treatment). Finally, participants reported any incident during the intake of the capsules and the side effects derived from their ingestion.

Blood and sweat sample analysis

The blood was allowed to clot *in situ* and serum was separated by centrifugation (10 min at 5000 g) and frozen at −80 °C until the day of analysis. At a later date, the serum portion was analyzed for osmolality (1249, Advance 3MO, Norwood, MA, Spain), sodium, chloride, potassium, and magnesium concentrations (Nova 16, NovaBiomedical, Madrid, Spain). In addition, the serum creatine kinase concentration was measured as a blood marker of muscle damage by means of an autoanalyzer (AU5400, Beckman Coulter, Brea, CA, USA). The sweat was separated from the patches by centrifugation (10 min at 3000 g), transferred to 5-mL sealed tubes and refrigerated at 4 °C. At a later date (within 2 days of the race), sweat osmolality was measured with the same osmometer employed for the serum samples while sweat electrolyte concentration were measured using an ion selective electrode analyzer (Cobas 6000, Roche, Madrid, Spain).

Statistical analysis

The normality of each variable was initially tested with the Shapiro–Wilk test. All the variables presented a normal distribution. For the variables obtained once during the experiment (race time, body mass change, sweat electrolyte concentration, self-rated fatigue, and muscle soreness, etc.) the comparison between groups (salt vs control) was performed using Student's t-test for

Table 2. Performance, perceived exertion and leg muscle soreness for a group of triathletes that ingested placebo (control) or salt capsules during a half-ironman race

Variable (units)		Control	Salt	P-value
Swimming velocity (m/s)		0.75 ± 0.15	0.80 ± 0.08	= 0.14
Cycling velocity (m/s)		7.74 ± 0.81	8.26 ± 0.67	= 0.04
Running velocity (m/s)		3.08 ± 0.43	3.37 ± 0.50	= 0.06
Perceived exertion (points)		16 ± 3	17 ± 2	= 0.51
Perceived muscle soreness (mm)		6.46 ± 1.51	6.85 ± 1.21	= 0.48
Jump height (cm)	Pre	30.9 ± 5.3	30.1 ± 5.1	= 0.70
	Post	25.0 ± 5.4*	25.4 ± 4.4*	= 0.86
Jump height change (%)		−19.0 ± 7.5	−15.6 ± 7.3	= 0.49
Leg muscle power (W/kg)	Pre	27.0 ± 3.5	26.5 ± 4.3	= 0.75
	Post	24.5 ± 3.1*	24.0 ± 3.3*	= 0.74
Leg muscle power change (%)		−9.2 ± 8.2	−8.3 ± 11.6	= 0.84
Isometric strength (N)	Pre	1114 ± 285	1117 ± 322	= 0.98
	Post	935 ± 229*	1054 ± 238*	= 0.23
Isometric strength change (%)		−16.1 ± 7.7	−5.6 ± 5.7	= 0.17

*Different from pre in the same group at $P < 0.05$.

independent samples. For the variables obtained twice during the experiment (body mass, blood variables, jump performance, etc.), the comparison between groups was performed using a mixed model analysis of variance (time × treatment) with repeated measures for the variable time. The data were analyzed with the statistical package SPSS version 19.0 (SPSS Inc., Chicago, Illinois, USA). The significance level was set at $P < 0.05$. Data are presented as mean ± SD.

Results
Triathlon race time and sector times

The mean time taken to complete the half-ironman triathlon was $333 ± 40$ min for the participants that ingested the placebo capsules during the race (e.g., control group). The group of triathletes that ingested salt capsules during the race completed it in a significantly lower race time ($307 ± 32$ min; $P = 0.04$). The participants in the salt group presented a higher speed in the cycling leg than the participants in the control group and a tendency for a higher speed in the running leg (Table 2). However, the ratings of perceived exertion and leg muscle soreness were similar between groups at the end of the race (Table 2). It is of note that five participants from each group did not finish the race. The causes of the dropout during the race were different but mostly related to muscle pain/injuries, mechanical problems, and falls during the cycling leg.

Changes in the countermovement jump and maximal isometric strength

Before the race, mean jump height was similar between groups (Table 2). After the race, mean jump height was significantly reduced in both the control and the salt groups ($P < 0.05$) and the magnitude of change was very similar between groups ($P = 0.49$). From similar pre-race values, leg muscle power was also reduced in both groups after the race ($P < 0.05$) and the reduction was similar between groups (Table 2; $P = 0.84$). Whole-body isometric muscle strength was significantly reduced from pre- to post-race in both groups ($P < 0.05$) and the reduction in this variable was equivalent between groups ($P = 0.17$).

Sweat loss, rehydration, and body mass change during the race

The total amount of sweat lost during the race was $4.0 ± 1.1$ L in both groups (Table 3; $P = 0.98$). However, the amount of rehydration was ~ $0.4 ± 0.4$ L higher in the salt group than the control group ($P = 0.05$). This meant that body mass change during the race tended to be reduced in the salt group ($−2.8 ± 0.9\%$) when compared with the control group ($−3.4 ± 1.3\%$; $P = 0.09$). From similar pre-race values, bioelectrical impedance changes were smaller in the group of participants that ingested salt (Table 3). There were between-group differences in the pre- to post-race bioimpedance changes measured in the right leg ($P = 0.02$) and in the left leg ($P = 0.02$), and the differences between groups tended to be significant for the whole-body bioelectrical impedance ($P = 0.06$). Participants ingested similar amounts of energy ($775 ± 337$ and $888 ± 376$ kcal for the salt and control group, respectively; $P = 0.43$), carbohydrates ($177 ± 77$ and $206 ± 87$ g; $P = 0.39$), fat ($1.8 ± 0.9$ and $1.7 ± 1.0$ g; $P = 0.89$), and proteins ($0.1 ± 0.1$ and $0.1 ± 0.1$ g; $P = 0.73$) during the race.

Changes in blood osmolality and serum electrolyte concentrations

Pre and post-race values for the blood and serum variables are shown in Table 4. In the control group, blood osmolality increased from $290.9 ± 6.0$ to $300.1 ± 3.5$ mOsm/kg ($P < 0.05$) after the race. Blood osmolality also increased in the salt group after the race ($P < 0.05$) but post-race blood osmolality was

Table 3. Sweat loss, rehydration, and body mass change for a group of triathletes that ingested placebo (control) or salt capsules during a half-ironman race

Variable (units)		Control	Salt	P-value
Sweat loss (L)		4.0 ± 1.1	4.0 ± 1.1	= 0.98
Rehydration (L)		1.5 ± 0.6	1.9 ± 0.4	= 0.05
Body mass (kg)	Pre	73.4 ± 7.4	74.9 ± 7.7	= 0.64
	Post	70.9 ± 7.0	72.7 ± 7.4	= 0.26
Body mass change (%)		−3.4 ± 1.3	−2.8 ± 0.9	= 0.09
Whole-body impedance (Ω)	Pre	511 ± 51	543 ± 40	= 0.90
	Post	540 ± 45*	541 ± 34	= 0.11
Whole-body impedance change (%)		5.3 ± 2.2	−0.3 ± 2.1	= 0.06
Right leg impedance (Ω)	Pre	227 ± 24	234 ± 21	= 0.44
	Post	235 ± 25*	231 ± 17	= 0.33
Right leg impedance change (%)		3.2 ± 3.1	−0.7 ± 3.2	= 0.02
Left leg impedance (Ω)	Pre	227 ± 22	232 ± 20	= 0.61
	Post	235 ± 23*	228 ± 16	= 0.20
Left leg impedance change (%)		3.1 ± 2.7	−0.6 ± 3.2	= 0.02

*Different from pre in the same group at $P < 0.05$.

Table 4. Blood osmolality and serum electrolyte concentrations for a group of triathletes that ingested placebo (control) or salt capsules during a half-ironman race

Variable (units)		Control	Salt	P-value
Blood osmolality (mOsm/kg)	Pre	290.9 ± 6.0	291.2 ± 3.8	= 0.91
	Post	300.1 ± 3.5*	303.8 ± 5.3*	= 0.02
Sodium concentration (mM)	Pre	141.4 ± 1.3	141.8 ± 2.1	= 0.58
	Post	143.4 ± 2.2*	144.9 ± 1.8*	= 0.03
Chloride concentration (mM)	Pre	99.9 ± 1.4	99.8 ± 1.8	= 0.81
	Post	99.5 ± 2.2	101.7 ± 2.5*	= 0.03
Potassium concentration (mM)	Pre	4.1 ± 0.3	4.0 ± 0.2	= 0.64
	Post	4.7 ± 0.3*	4.7 ± 0.4*	= 0.78
Magnesium concentration (mM)	Pre	1.9 ± 0.1	1.9 ± 0.1	= 0.82
	Post	2.0 ± 0.2	1.9 ± 0.2	= 0.16
Creatine kinase concentration (U/L)	Pre	181.6 ± 89.7	164.2 ± 51.4	= 0.55
	Post	883.1 ± 546.2*	733.5 ± 463.0*	= 0.46

*Different from pre in the same group at $P < 0.05$.

significantly higher in the salt group than in the control group ($P = 0.02$). Similarly, serum sodium increased from pre- to post-race in both groups ($P < 0.05$) but post-race values were significantly higher in the salt group ($P = 0.03$). Serum chloride remained stable in the control group while it was increased just at the end of the race in the salt group. Post-race serum chloride concentration was higher in the salt group ($P = 0.03$) when compared with the control group. The magnitude of the change from pre- to post-race in serum potassium and magnesium concentrations was not affected by the salt ingestion ($P > 0.05$). A similar post-race value was found for creatine kinase concentrations between groups ($P > 0.05$).

Sweat osmolality and sweat electrolyte concentrations

Sweat osmolality was very similar in the control and salt groups (Table 5). Likewise, sweat sodium (46 ± 21 and 48 ± 16 mM, respectively; $P = 0.72$), chloride (36 ± 18 and 38 ± 14 mM, respectively; $P = 0.82$), potassium (6.8 ± 1.2 and 5.9 ± 0.9 mM, respectively; $P = 0.06$) and

Table 5. Sweat osmolality, sweat electrolyte losses, and oral electrolyte consumption for a group of triathletes that ingested placebo (control) or salt capsules during a half-ironman race

Variable (units)	Control	Salt	P-value
Sweat osmolality (mOsm/kg)	137.8 ± 46.6	123.8 ± 29.3	= 0.37
Sodium lost (mmol)	189 ± 116	191 ± 72	= 0.72
Sodium consumed (mmol)	25 ± 11	135 ± 11	= 0.02
Sodium balance (mmol)	−150 ± 122	−56 ± 71	= 0.01
Chloride lost (mmol)	152 ± 99	150 ± 62	= 0.82
Chloride consumed (mmol)	40 ± 20	145 ± 18	< 0.01
Chloride balance (mmol)	−100 ± 105	−6 ± 6	< 0.01
Potassium lost (mmol)	29 ± 10	24 ± 7	= 0.19
Potassium consumed (mmol)	1 ± 1	21 ± 2	< 0.01
Potassium balance (mmol)	28 ± 1	3 ± 8	< 0.01
Magnesium lost (mmol)	1.5 ± 2.3	0.6 ± 0.2	= 0.18
Magnesium consumed (mmol)	0.5 ± 0.5	5.9 ± 0.2	< 0.01
Magnesium balance (mmol)	−1.0 ± 2.2	−5.3 ± 0.2	< 0.01

The electrolyte balance after the race was calculated by subtracting total electrolyte sweat loss (sweat electrolyte concentration × sweat volume) from the electrolyte intake during the race (salt or placebo). The electrolyte intake included the treatment + the food and drinks ingested *ad libitum* during the race and self-reported in a questionnaire.

magnesium (0.4 ± 0.6 and 0.2 ± 0.1 mM, respectively; $P = 0.18$) were very similar in the control and salt groups. However, the body balances of all electrolytes measured in this investigation (sodium, chloride, potassium and magnesium) were enhanced in the group of participants that ingested salt during the race (all $P < 0.05$) as was expected from a higher intake of these electrolytes as part of the experimental treatment.

Side effects derived from the ingestion of capsules

The ingestion of the capsules filled with salt did not increase the prevalence of supragastric belching (54 vs 46% of participants with this phenomenon for the salt and control group, respectively), nausea (15 vs 8%), vomitus, (0 vs 0%), stomach discomfort (15 vs 23%), flatulence (23 vs 38%), urge to defecate during the race (8 vs 8%), or diarrhea (8% vs 8%) during or after the race ($P > 0.05$ for all these comparisons).

Discussion

Several investigations have been devoted to determining the effects of salt ingestion on endurance performance (Vrijens & Rehrer, 1999; Sanders et al., 2001; Speedy et al., 2002; Twerenbold et al., 2003; Hew-Butler et al., 2006; Coso et al., 2008; Anastasiou et al., 2009; Cosgrove & Black, 2013). Briefly, most laboratory-based investigations have found benefits of salt supplementation during endurance activities such as improved physical performance, attenuated decrease of serum sodium concentration and expanded plasma volume. These effects were even greater in investigations performed in hot environments. However, laboratory investigations have always accompanied the salt supplementation during exercise with a fluid ingestion regime that matched sweat losses, which probably facilitated the occurrence of these benefits. Field investigations regarding the effects of salt supplementation during endurance events (Speedy et al., 2002; Hew-Butler et al., 2006; Cosgrove & Black, 2013) have increased the applicability of the experimental setting by using *ad libitum* fluid intake regimes, as is the case during real competitions. Interestingly, they have failed to find positive effects of salt ingestion on performance although it has been suggested that these field investigations did not control participants' training status or the carbohydrate intake during the race.

The current investigation presents some novelties when compared with all these previous laboratory and field experiments. First, we determined the effectiveness of a commercially available salt supplement and then tested it during a real triathlon competition. Both settings were used to increase the ecological validity of the experiment and to improve the applicability of the results for exercise physiologists, nutritionists and triathletes. Second, participants drank and ate *ad libitum* during the race, but the amount of fluid and food was registered and analyzed afterwards to ensure that the groups tested in this investigation only differed in the amount of salt ingested during the race. Third, we compared two groups with similar physical and physiological characteristics (Table 1) reducing the interference of these variables on the outcomes of the investigation. With this experimental setting, we can suggest that the ingestion of commercially available salt capsules was effective to reduce race time and to enhance water and electrolyte balances during a real triathlon competition.

The mechanism or mechanisms responsible for the increased physical performance during the race with the oral salt supplement were related to an enhanced maintenance of water and electrolyte balances since muscle fatigue, as measured by maximal jumps and isometric muscle strength, was unaffected by the ingestion of salt. Triathletes in both groups presented similar amounts of sweat losses during the race (Table 3) but participants in the salt group replaced ~ 71% of the salt lost by sweat during the race, a value slightly higher than previously planned (e.g., 50%). Interestingly, participants in the salt group finalized the race with a lower body water reduction as indicated by body mass and segmental bioimpedance changes (Table 3).

Typically, blood osmolality increases during prolonged exercise because of the progressive reduction in the water content of blood induced by sweating and increased blood pressure. This increased blood osmolality drives the osmotic stimulus that activates thirst and thus the necessity of drinking during exercise to reduce dehydration (Maughan & Shirreffs, 2010). In this investigation, post-race blood osmolality was higher in the salt group than in the control group, but in this case, blood osmolality was "artificially" increased by the ingestion of salt during exercise. Interestingly, increased blood osmolality in the salt group was related to a $26 \pm 10\%$ rise in fluid intake, despite all participants drinking *ad libitum* during the race. This osmotic stimulus mediated by the ingestion of salt during exercise was likely responsible for the increased fluid intake in the salt group (Wemple et al., 1997; Speedy et al., 2002; Cosgrove & Black, 2013). In fact, the greater fluid intake during exercise may be one of the main causes for the increased performance found in this investigation.

A better maintenance of body water content during exercise by increased drinking has been repeatedly suggested as a long-standing strategy to reduce body core temperature and the cardiovascular stress of prolonged exercise, especially in the heat (Montain & Coyle, 1992). As previously indicated, the salt group presented an enhanced maintenance of body mass and water content. However, we did not measure thermoregulatory or cardiovascular variables to identify whether the maintenance of the water balance with the ingestion of salt was related to a lower body core temperature and/or heart rate. Previous investigations in the laboratory, with

pre-exercise salt supplementation plus water, have found that oral salt intake can present thermoregulatory and cardiovascular benefits during exercise (Sims et al., 2007a, b; Hamouti et al., 2012). Nevertheless, the confirmation that salt intake can benefit thermoregulation and cardiovascular response because of an increased fluid intake requires further investigations during real competitions.

As expected, the oral salt supplements taken during the race increased serum electrolyte concentrations (Na^+ and Cl^-) at the end of the race. This effect was present because salt ingestion did not affect the amount of sweat or the sweat electrolyte losses during the race while it greatly increased the intake of electrolytes when compared with the control group (Table 5). Previously, it has been suggested that there is a positive correlation between the maintenance of a sodium balance and the preservation of knee extensor muscle strength after prolonged exercise (Coso et al., 2008). In the present investigation, participants in the salt group did not present a better maintenance of jump performance or isometric muscle strength (Table 2) likely because of the fact that participants in the control group did not present excessively low serum sodium values. Muscle tissue and neurons are considered electric tissues of the body and they are activated by the electrolyte changes between the extracellular and intracellular fluids. An enhanced electrolyte balance caused by salt supplementation might aid in the maintenance of motor drive during muscular contractions (Coso et al., 2008), which in turn affects the preservation of strength and performance during the race. However, this mechanism was not evident in the current investigation.

The intention of this investigation was to examine the effects of salt ingestion in an ecologically valid context. For this reason, we used a commercially available salt product and tested its effects during a real competition in which participants' competition routines were minimally affected. Thus, the present investigation demonstrates how physical performance and the physiology of competitive triathletes are modified when oral salt supplementation is incorporated into their habitual routines, as would happen in a real competition. However, the experimental setting presents several limitations. First, food and fluid intake were not standardized during the race. Although the amount of calories and carbohydrate ingested during the race was similar between groups, participants in the salt group ingested 0.4 ± 0.4 L more fluid than the control group during the race, probably driven by an increased osmotic stimulus induced by the salt supplementation. With this experimental design, it is difficult to discriminate the influence of salt ingestion on performance from the increased voluntary fluid intake during the race (or to know whether it is necessary for both factors to be present to obtain an increased performance). A second limitation of this study is the lack of data on urinary volume and urinary electrolyte concentrations because it was impossible to collect urine samples during the race. Although participants did not report any stopping to urinate during the race, it is possible that part of the salt ingested during the race was excreted by the kidneys and remained in the bladder. Without urinary variables, it is speculative to conclude whether all or part of the amount of salt used for supplementation was responsible for the benefits obtained during the race. Third, the salt supplement was provided without individualization, and the percentage of electrolytes replaced (in comparison to the electrolyte losses) was not equal for all the triathletes in the experimental group. Finally, another limitation is related to the low statistical power provided by the sample size (13 individuals per group). Some of the tendencies found in this investigation could reach statistical significance with a higher sample size. Even with these limitations, the ingestion of salt during a half-ironman race presented several performance and physiological benefits for well-trained triathletes.

In summary, triathletes that ingested an oral salt supplement, containing 113 mmol of Na^+ and 112 mmol of Cl^-, were associated with lower finishing race times during a half-ironman triathlon than triathletes that ingested a placebo. These benefits were probably driven by a higher voluntary fluid intake during the race and higher serum electrolyte concentrations. Moreover, oral salt intake did not produce side effects when compared with a placebo. Thus, oral salt supplements might be an ergogenic aid for long-distance triathlon events.

Perspectives

The aim of endurance athletes during competitions in both thermoneutral and hot environments should be to minimize dehydration by limiting body mass losses through sweating to ~2% of body mass (Maughan, 2010). However, athletes typically encounter difficulties in matching fluid ingestion to sweat losses during real endurance events such as the triathlon because drinking so much fluid is sometimes intolerable. Other causes for the dehydration commonly found during endurance events include social customs that influence how much is consumed and the rate of fluid absorption from the gastrointestinal system that could influence the prevalence of gastrointestinal problems associated with rehydration (Greenleaf, 1992). In-competition nutrition should be focused on avoiding water and salt deficits in endurance athletes (Maughan & Shirreffs, 2010), especially those competing in hot environments and those with high sweat sodium concentrations (Montain et al., 2006). The use of salt capsules or salted supplements can help to reduce body mass loss and to lessen the electrolyte deficits found in endurance competitions. This investigation demonstrated that the ingestion of salt increased the

amount of fluid drunk and its retention through osmotic stimulus. These physiological effects were translated into increased overall performance during an endurance triathlon.

Key words: Sodium, hyponatremia, endurance exercise, hydration, sweat, thirst.

Author contribution

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[1]Formulated the research question; [2]designed the study; [3]carried it out; [4]analyzed the data; [5]wrote the article; [6]revised the article.

References

Anastasiou CA, Kavouras SA, Arnaoutis G, Gioxari A, Kollia M, Botoula E, Sidossis LS. Sodium replacement and plasma sodium drop during exercise in the heat when fluid intake matches fluid loss. J Athl Train 2009: 44: 117–123.

Barr SI, Costill DL, Fink WJ. Fluid replacement during prolonged exercise: effects of water, saline, or no fluid. Med Sci Sports Exerc 1991: 23: 811–817.

Beis LY, Wright-Whyte M, Fudge B, Noakes T, Pitsiladis YP. Drinking behaviors of elite male runners during marathon competition. Clin J Sport Med 2012: 22: 254–261.

Brown MB, Haack KK, Pollack BP, Millard-Stafford M, McCarty NA. Low abundance of sweat duct Cl- channel CFTR in both healthy and cystic fibrosis athletes with exceptionally salty sweat during exercise. Am J Physiol Regul Integr Comp Physiol 2011: 300: R605–R615.

Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC Jr, Sherman WM. American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 1996: 28: 1–7.

Cosgrove SD, Black KE. Sodium supplementation has no effect on endurance performance during a cycling time-trial in cool conditions: a randomised cross-over trial. J Int Soc Sports Nutr 2013: 10: 30.

Coso JD, Estevez E, Baquero RA, Mora-Rodriguez R. Anaerobic performance when rehydrating with water or commercially available sports drinks during prolonged exercise in the heat. Appl Physiol Nutr Metab 2008: 33: 290–298.

Cox GR, Snow RJ, Burke LM. Race-day carbohydrate intakes of elite triathletes contesting Olympic-distance triathlon events. Int J Sport Nutr Exerc Metab 2010: 20: 299–306.

Del Coso J, Areces F, Salinero JJ, Gonzalez-Millan C, Abian-Vicen J, Soriano L, Ruiz D, Gallo C, Lara B, Calleja-Gonzalez J. Compression stockings do not improve muscular performance during a half-ironman triathlon race. Eur J Appl Physiol 2014a: 114: 587–595.

Del Coso J, Fernandez D, Abian-Vicen J, Salinero JJ, Gonzalez-Millan C, Areces F, Ruiz D, Gallo C, Calleja-Gonzalez J, Perez-Gonzalez B. Running pace decrease during a marathon is positively related to blood markers of muscle damage. PLoS ONE 2013a: 8: e57602.

Del Coso J, Gonzalez C, Abian-Vicen J, Salinero Martin JJ, Soriano L, Areces F, Ruiz D, Gallo C, Lara B, Calleja-Gonzalez J. Relationship between physiological parameters and performance during a half-ironman triathlon in the heat. J Sports Sci 2014b: 32: 1680–1687.

Del Coso J, Gonzalez-Millan C, Salinero JJ, Abian-Vicen J, Soriano L, Garde S, Perez-Gonzalez B. Muscle damage and its relationship with muscle fatigue during a half-iron triathlon. PLoS ONE 2012: 7: e43280.

Del Coso J, Salinero JJ, Abian-Vicen J, Gonzalez-Millan C, Garde S, Vega P, Perez-Gonzalez B. Influence of body mass loss and myoglobinuria on the development of muscle fatigue after a marathon in a warm environment. Appl Physiol Nutr Metab 2013b: 38: 286–291.

Dolan SH, Houston M, Martin SB. Survey results of the training, nutrition, and mental preparation of triathletes: practical implications of findings. J Sports Sci 2011: 29: 1019–1028.

Greenleaf JE. Problem: thirst, drinking behavior, and involuntary dehydration. Med Sci Sports Exerc 1992: 24: 645–656.

Hamouti N, Del Coso J, Ortega JF, Mora-Rodriguez R. Sweat sodium concentration during exercise in the heat in aerobically trained and untrained humans. Eur J Appl Physiol 2011: 111: 2873–2881.

Hamouti N, Fernandez-Elias VE, Ortega JF, Mora-Rodriguez R. Ingestion of sodium plus water improves cardiovascular function and performance during dehydrating cycling in the heat. Scand J Med Sci Sports 2012: 24: 507–518.

Hew-Butler TD, Sharwood K, Collins M, Speedy D, Noakes T. Sodium supplementation is not required to maintain serum sodium concentrations during an Ironman triathlon. Br J Sports Med 2006: 40: 255–259.

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scand J Med Sci Sports 2010: 20 (Suppl. 3): 95–102.

Maughan RJ, Shirreffs SM. Dehydration and rehydration in competitive sport. Scand J Med Sci Sports 2010: 20 (Suppl. 3): 40–47.

Montain SJ, Cheuvront SN, Sawka MN. Exercise associated hyponatraemia: quantitative analysis to understand the aetiology. Br J Sports Med 2006: 40: 98–105.

Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. J Appl Physiol 1992: 73: 1340–1350.

Rehrer NJ. Fluid and electrolyte balance in ultra-endurance sport. Sports Med 2001: 31: 701–715.

Sanders B, Noakes TD, Dennis SC. Sodium replacement and fluid shifts during prolonged exercise in humans. Eur J Appl Physiol 2001: 84: 419–425.

Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 2007: 39: 377–390.

Sawka MN, Montain SJ. Fluid and electrolyte supplementation for exercise heat stress. Am J Clin Nutr 2000: 72: 564S–572S.

Shirreffs SM, Maughan RJ. Volume repletion after exercise-induced volume depletion in humans: replacement of water and sodium losses. Am J Physiol 1998: 274: F868–F875.

Sims ST, Rehrer NJ, Bell ML, Cotter JD. Preexercise sodium loading aids fluid balance and endurance for women exercising in the heat. J Appl Physiol 2007a: 103: 534–541.

Sims ST, van Vliet L, Cotter JD, Rehrer NJ. Sodium loading aids fluid balance and reduces physiological strain of trained men exercising in the heat. Med Sci Sports Exerc 2007b: 39: 123–130.

Speedy DB, Thompson JM, Rodgers I, Collins M, Sharwood K, Noakes TD. Oral salt supplementation during ultradistance exercise. Clin J Sport Med 2002: 12: 279–284.

Twerenbold R, Knechtle B, Kakebeeke TH, Eser P, Muller G, von Arx P, Knecht H. Effects of different sodium concentrations in replacement fluids during prolonged exercise in women. Br J Sports Med 2003: 37: 300–303; discussion 303.

Valentine V. The importance of salt in the athlete's diet. Curr Sports Med Rep 2007: 6: 237–240.

Vrijens DM, Rehrer NJ. Sodium-free fluid ingestion decreases plasma sodium during exercise in the heat. J Appl Physiol 1999: 86: 1847–1851.

Wemple RD, Morocco TS, Mack GW. Influence of sodium replacement on fluid ingestion following exercise-induced dehydration. Int J Sport Nutr 1997: 7: 104–116.