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HYDRATION IN EXERCISE: IS IT NECESSARY TO REPLACE ALL LOST BODY MASS?

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ABSTRACT
RODRIGUES, A. P. S.; CASTRO, M. S.; SHIGUEMOTO, G. E.; LINO, A. D. S.; PRESTES, J. Hydration in exercise: is it necessary to replace all lost body mass? Brazilian Journal of Biomotricity, v. 3, n. 4, p. 302-314, 2009. Currently, there is a debate about which percentage of body mass loss can compromise performance and lead to complications to athletes’ health. Most of the drinking guidelines for exercise recommend replacing all the body mass lost during exercise and drinking as much as tolerable to avoid body mass loss over 2%. A greater dehydration can compromise aerobic exercise and cognitive/mental performance in warm-hot environments and increase the risk for heat stroke, heat exhaustion and cramps. A “cardiovascular model of thermoregulation” is used to explain the thermal regulation during exercise, which proposes that sweating reduces body water content, reducing blood flow and increasing the cardiovascular strain. However, this model has been criticized by many authors, who state that sweating response is regulated by neural mechanisms that are not dependant of the cardiovascular response to the exercise. The aim of this study was to review the recommendations for fluid replacement during exercise and detail the real necessity to replace all body mass lost during exercise for better performance. We searched the following electronic databases with no data limitation: national and international articles related to the subject, in the scientific portals of Capes, Scielo, PubMed, Science Direct, Highwire and randomized control trails, in English and Portuguese. The inclusion criteria was considered human studies, papers on dehydration and performance, recommendations on hydration and exercise, ingestion of electrolytic beverages in exercise and the effects of hydration status and thermoregulation. The exclusion criteria were: experimental articles and general recommendation for non athletes.

Key words: hydration, dehydration, performance, exercise, thermoregulation.
RESUMO
RODRIGUES, A. P. S.; CASTRO, M. S.; SHIGUEMOTO, G. E.; LINO, A. D. S.; PRESTES, J. Hydration in exercise: is it necessary to replace all lost body mass? Brazilian Journal of Biomotricity, v. 3, n. 4, p. 302-314, 2009. Atualmente, há um debate sobre qual o percentual de perda de massa corporal pode comprometer o desempenho e levar a complicações para a saúde dos atletas. A maioria das recomendações sobre reposição de líquidos no exercício recomenda que toda a massa corporal perdida durante o exercício deva ser reposta com a ingestão máxima tolerada de líquidos para evitar a perda de massa corporal superior a 2%. A desidratação pode comprometer o exercício aeróbio e o desempenho cognitivo/mental em ambientes quentes e aumentar o risco de internação, exaustão pelo calor e cãibras. O "modelo de termo-regulação cardiovascular" é usado para explicar a regulação térmica durante o exercício, que propõe que a transpiração reduz o teor de água no organismo, reduzindo a circulação sanguínea e aumentando a tensão cardiovascular. Porém, este modelo tem sido criticado por muitos autores, que afirmam que a resposta da transpiração é regulada por mecanismos neurais que não dependem da resposta cardiovascular ao exercício. O objetivo deste estudo foi rever as recomendações de reposição de líquidos durante o exercício e detalhar a real necessidade de repor toda a massa corporal perdida durante o exercício para se obter um melhor desempenho. Foram pesquisados artigos nacionais e internacionais nos portais científicos Capes, Scielo, PubMed, Science Direct, Highwire e trilhas de controle randomizados, em Inglês e Português. Critérios de inclusão, estudos com humanos, artigos sobre desidratação e desempenho, recomendações sobre hidratação, ingestão de bebidas eletrólitas em exercício e efeitos do estado de hidratação e regulação térmica. Os critérios de exclusão foram: artigos experimentais e recomendações gerais para não atletas.

Palavras-chave: hidratação, desidratação, desempenho, exercício, termorregulação.

INTRODUCTION
When physical exercise is being performed under different environmental conditions such as temperature, humidity, exposure to sun and wind, the exercise may cause a rise in body temperature (central and skin) leading to physiological responses to eliminate the heat by increasing the secretion of perspiration and through the processes of conduction, convection, radiation, evaporation of sweat from the skin surface and blood flow to the skin. Sweat evaporation provides the primary avenue of heat loss during vigorous exercise in warm hot weather (AMERICAN COLLEGE OF SPORTS MEDICINE, 2007, ACSM; LIM et al., 2008).

In its most recent consensus, the ACSM (2007) proposed that dehydration with the loss of body mass exceeding 2% compromises the aerobic and cognitive/mental performance in a temperate and hot environment, and increases the risk of heat stroke, exhaustion and cramps. Consequently, athletes are warned that dehydration during exercise prejudices both health and performance (SAWKA et al., 2001). Nevertheless, a potential benefit of the reduction of body mass attributed to the loss of liquids has important effect on the reduction of energy spent on movement (COYLE, 2004; EBERT et al., 2007).

The “cardiovascular model of thermoregulation”, used by the majority of consensuses on hydration in exercise to explain temperature regulation, predicts that sweating reduces the body water content, causing reduction in the circulating blood volume (NOAKES & SPEEDY, 2006). The increased cardiovascular effort due to the reduction in filling of the heart leads to an increase in heart rate and cardiac output, associated with a reduction in blood flow to the skin, limiting heat transference. Therefore, because of causing harm to cardiovascular function, dehydration becomes the main determinant of body temperature in exercise (NOAKES & SPEEDY, 2006). However, this model is criticized by some authors, who affirm that transpiration is regulated by neural mechanisms that are not dependant on the cardiovascular response to exercise. In human, the body temperature is regulated by the hypothalamus region of the brain, which regulates body temperature to function within ±1°C of resting temperature over a 24 h cycle (SHIBASAKI et al., 2003; LIM 2008).
Excessive liquid ingestion could compromise performance and health. The majority of consensuses about the replacement of liquids during exercise recommend that all the weight lost during the exercise should be replaced with the maximum tolerated volume of liquid ingestion to improve performance and prevent dehydration (NOAKES, 2003b; NOAKES & SPEEDY, 2006).

In view of above mentioned, the aim of this study was to make a review of the recommendations about liquid ingestion during exercise, and whether it really is necessary to replace the body mass lost during exercise in order to obtain better performance.

We searched the following electronic databases with no data limitation: national and international articles related to the subject, in the scientific portals of Capes, Scielo, PubMed, Science Direct, Highwire and randomized control trails, in English and Portuguese. The inclusion criteria was considered human studies, papers about dehydration and performance, recommendations on hydration in exercise, ingestion of electrolytic beverages in exercise and effects of hydration status and thermoregulation. The exclusion criteria were experimental articles and general recommendation to not trained athletes.

**Dehydration and performance in exercise**

There is a great deal of discussion about what percentage of dehydration (in relation to body mass) can compromise physical performance and/or lead to health complications in athletes. At present the recommendation is that dehydration should not exceed a reduction of 2% in body mass. Physiological stress generated by dehydration is measured by the central temperature, cardiac frequency and the perceived responses of effort during exercise in hot environments (ACSM, 2007). Consequently, the majority of consensuses about fluid replacement recommend that athletes replace all the fluid lost during the exercise, in order to increase performance, prevent hypohydration and complications arising from the increase in central temperature (ACSM, 2007; CASA et al., 2000).

To Wyndham & Strydom (1969), this recommendation to athletes of the ingest large quantities of liquids during prolonged exercise to prevent heat stroke had been demonstrated by studies conducted the authors mentioned above, showing a relationship between the degree of dehydration that occurred during exercise and the increase in rectal temperature. Studies conducted afterwards by other authors, including Dr. Robert Cade, the inventor of Gatorade, led to the creation of a “cardiovascular model of thermoregulation”, previously mentioned, in which dehydration would harm cardiovascular function, effecting the control of body temperature in exercise. Thus, dehydration would become prejudicial to athlete’s health and performance, because it would lead to an increase in body temperature, causing heat illness, the most severe of them being heat stroke (NOAKES, 2003a; NOAKES & SPEEDY, 2006).

Sawka et al. (2001) mentions that hypohydration increases the central temperature in a temperate and hot climate. A deficit of only 1% in body mass is sufficient to lead to temperature increase during physical exercise, and this increase ranges from 0.1° to 0.25°C for each percentage of body mass lost.

In the study of Ebert et al. (2007) with eight well trained men cyclists, a sub maximum test was performed on a cycloergometer with duration of 2 hours, followed by exercise until exhaustion, simulating riding up a mountain. The increase in central temperature was higher in the group that made use of lower hydration (reduction of ~2.5% body mass) compared with that indicated by the consensus of the ACSM (1996) and lasted after the end of the simulated ride up the mountain. Furthermore, the performance of the group with lower hydration was significantly worse than that of the higher-hydration group.
Nevertheless, the authors mentioned that the research model did not allow one to deduce whether dehydration, hyperthermia or a combination of the two contributed to the drop in performance. However, the data suggest that a modest dehydration provides no advantage performance of mountain biking, and that the cardiovascular and thermal compromises are important (EBERT et al., 2007).

The “cardiovascular model of thermoregulation” has been criticized, due to the fact that transpiration is regulated by neural mechanisms that are not dependant on the cardiovascular response to exercise, therefore, this would not limit the production of sweat as has been affirmed. Consequently, the neural mechanism would be the main determinant of sweating, and not the cardiovascular reaction (NOAKES, 2007; SHIBASAKI et al., 2003).

It is known that the increase body temperature, during the exercise, is related to the intensity of the activity. When the steady state is achieved, the temperature is maintained high and the usual interpretation of this response would be that the increased body temperature accelerates all the physiological processes, with an advantage in performance, which can be of greater relevance than water-saving (NOAKES, 2007).

Laursen et al. (2006) conducted a study with well trained triathletes during a 226 km ironman triathlon. The results found demonstrated that a loss of body mass of approximately 3% lead to an increase of approximately 1°C only (~38.1±0.3°C) above the normal central temperature at rest. Although the volunteers had performed an exercise of moderate-high intensity (~83±6% of maximum heart rate) for 10 hours at a temperature of 23.3±1.2°C and relative humidity of the air of 60±14%, adequate thermoregulation of the athletes were observed during the competition. Therefore, no evidence was found that a reduction in body mass of 3% in the ironman competition could lead to hyperthermia.

Sharwood et al. (2004) evaluated the participants of the Ironman held in South Africa in 2000 and 2001. The athletes were divided into three groups according to the percentage of body mass lost during the tests, with one group of athletes experiencing a body mass loss greater than 5% (reaching 10.7%), another with a body mass loss between 3.5 to 4.5% and a last group ranging between a body mass loss of 3% and body mass gain of 3%. No differences in the rectal temperature, systolic and diastolic arterial pressure or medical complications were observed among the groups. These data suggested that the absolute loss of body mass that each athlete would present depended on individual factors and environmental condition, not significantly influencing the above-mentioned variables.

Shirreffs (2009) showed that a body mass reduction of 2% is tolerable under ≤22°C temperature, but this alteration impairs absolute power production and predisposes athletes to heat illness under ambient temperatures >30°C. The recommendation of the author is that Na⁺ should be included in fluids consumed during exercise if the exercise lasts >2 h and also in any event which a >3 – 4g of Na⁺ is lost in sweat.

**Recommendations on hydration in exercise**

There are consensuses about liquid replacement in exercise that should be highlighted. The most used internationally are those of the ACSM, the most recent being published at the beginning of 2007. The consensus of the NATA (CASA et al., 2000) and the consensus of the IOC (COYLE, 2004), as a chapter of the Consensus on Sports Nutrition published by this entity. It also can be detached the consensus of the IMMDA, which is also adopted by the United States of America Track and Field (USATF) for liquid replacement in marathons (NOAKES, 2007).

Therefore, the main recommendations of the above-mentioned consensuses are...
summarized as follows. Although there is a ACSM consensus published in 2007, because it is very recent, it is also necessary to analyze the consensus of 1996, since this is the reference in the majority of the studies conducted in the years previous to 2007.

The international recommendations for hydration before and during the exercise are similar, but there are some slight differences between them (table I). The most divergence is on the amount of liquids that should be ingested, maximum tolerated, ad libitum or mL per kg of body mass. After exercise the recommendation is consensual to what has been cited in the present study.

The ACSM (1996):

This consensus and recommendations are on the fact that the most severe effect of the dehydration caused by incomplete replacement of the liquids lost during exercise is inefficiency in dissipating heat, capable of elevating the central body temperature to high and dangerous levels. Complete replacement of the liquid deficit cannot occur without electrolytic replacement (primarily of sodium) coming from foods or beverages.

The consensus recommends the ingestion of 400 to 600 mL of water 2 hours before the exercise. During the exercise, individuals should be encouraged to consume the maximum quantity of liquids tolerated, without the occurrence of gastrointestinal discomfort, at a rate equal to that of losses by sweating. Consumption should be frequent and moderate (150 to 350 mL every 15-20 minutes). The requirements of liquids and carbohydrates can be attained simultaneously by the ingestion of 600 to 1.200 mL/h of solutions with 4 to 8% of carbohydrates.

The ACSM (2007)

The most recent consensus, published in 2007, is broader in scope, and in addition to the recommendations about hydration before, during and after exercise, it also approaches the need for fluids and electrolytes, evaluation of the hydration status, physiological effects, and provides information about the performance of hydration and modifiable factors as regards hydration, such as sex, age and diet.

By hydrating several hours prior to exercise there is sufficient time for urine output to return towards normal before starting the event. Consuming beverages with sodium (20–50 mEq.L⁻¹) and/or small amounts of salted snacks or sodium-containing foods at meals will help to stimulate thirst and retain the consumed fluids.

Before exercise, the recommendation is to begin pre-hydration about 4 hours before the activity to be performed, with the ingestion of a quantity of beverages from 5 to 7 mL per kg of body mass. If the individual does not produce urine, or it has a dark color or is very concentrated, more liquids must be ingested (approximately 3 to 5 mL.kg⁻¹.body mass) 2 hours before the exercise.

During exercise, the recommendation is to prevent excessive dehydration, that is, higher than 2% loss of body mass. The liquid replacement program must be determined individually, as it is very difficult to make a specific recommendation for the replacement of liquids and electrolytes, due to the different types of exercise and factors involved, such as: metabolic requirements, duration, type of clothing, environmental conditions, among others. The consensus recommends that individuals monitor the changes in body mass before and after training/competition, to estimate losses by sweat and to determine the liquid replacement program. For a marathoner, a possible starting point would be the ingestion of liquids ad libitum from 0.4 to 0.8 L/h, the higher rates being for the heavier and faster individuals competing in temperate environments, and the lower rates for the lighter and slower individuals competing in cooler environments.
After the exercise, the guidelines recommend the replacement of all the liquid and electrolytes lost, by consuming normal meals and beverages.

NATA (2000)

The consensus of NATA (2000) presents similar recommendations to those of the ACSM consensus of 1996, based on the premise that one must replace all the liquid lost during the exercise. The recommendation is to ingest from 500 to 600 mL of water or sports drinks from 2-3 hours before the exercise and from 200 to 300 mL of water or sports drinks 10-20 minutes before the exercise. During the exercise it is necessary to drink from 200 to 300 mL, every 10-20 minutes, to maintain hydration with a loss lower than 2% of body mass. The specific individual recommendations must be calculated based on the sweat rate, dynamics of the sports and individual tolerance. After the exercise, the aim of hydration must be to correct the loss of liquids that occurred, with a beverage containing water to restore the hydration status, carbohydrates to replace the glycogen and electrolytes stores to accelerate re-hydration (CASA et al., 2000).

IOC (2004)

The consensus of the IOC (2004) presents small differences in comparison with the liquid replacement recommendations of the North American consensus of 1996. The consensus recommends that whenever possible, the quantity of liquids ingested must be close to the amount produced by the sweat rate. When this is not possible, some athletes may tolerate a quantity of body water loss of 2% of body mass without risking wellbeing and performance in cold (5-10°C) or temperate (21-22°C) environments, however, in hot environments (>30°C) performance may be compromised and there may be predisposition to heat illness (COYLE, 2004).

Liquids should not be ingested in an amount higher than sweat rate, therefore, body mass does not increase during the exercise, a factor that could decrease the running economy and endurance performance (COYLE, 2004).

IMMDA (NOAKES, 2007)

The consensus of the IMMDA (NOAKES, 2007) criticizes the present paradigm that athletes must ingest the “maximum amount of liquids tolerated” during endurance exercises, such as marathons, and warns against this paradigm, since evidence has been shown that athletes, particularly the slower ones, can ingest large quantities of liquids that could cause fatal consequences, such as hyponatremia associated with exercise. Thereby, the recommendation is that liquids should not be ingested in the maximum quantity tolerated, but individuals should be instructed to ingest liquids ad libitum (according to the sensation of thirst), no more than 400-800 mL per hour, the rate being higher for faster and heavier runners competing in a temperate environment, and a lower rate for slower runners in more amenable environments (NOAKES, 2003a).

All the above-mentioned consensuses, except that of IMMDA (NOAKES, 2007), and the ACSM (2007) defend the point that all the body mass lost during the exercise must be replaced with the ingestion of the maximum tolerated volume of liquids to improve performance and prevent dehydration. The dehydration would be responsible for the increase in central temperature, capable of causing serious damage to health. Nevertheless, the excessive ingestion of liquids could also cause risks, as has been related in the scientific literature, with around seven cases of fatalities having been observed, and over 250 cases of exercise-associated hyponatremic encephalopathy (EAH) in athletes due to this recommendation (NOAKES, 2003a; NOAKES, 2003b).

Therefore, there continues to be a great controversy around the real benefits versus harm
of the recommendation that involves ingestion of high quantities of liquids.

Noakes (2003a) affirms that the ACSM consensus of 1996 is based more on laboratory than clinical evidences, and that the majority of studies conducted in laboratories use temperature/humidity conditions that exceed the climatic conditions under which the majority of marathons are performed. In addition not have an adequate cooling by convection, which is an important differential in exercise performed in laboratory, in comparison with exercise outdoor. Saunders et al. (2005) in a study with cyclists that performed exercise in various wind speeds, showed that a higher wind speed, as experienced when exercises are performed out of doors, results in a lower rectal temperature and a longer time to reach exhaustion in the exercise. Differently, in studies in which laboratory conditions were inadequate for cooling by convection and evaporation, there was an increase in heat storage and central temperature.

For Noakes (2003b) the consensuses about liquid replacement in exercise makes four suppositions. The first supposition is that all the body mass loss during exercise must be replaced to preserve health and improve performance; the second is that the sensations of thirst underestimates the real need for liquids during exercise, thus, athletes must be counseled about the quantity of liquids to ingest; the third is that the needs for liquids are always equal and that a universal recommendation is possible; and the fourth is that high rates of liquid ingestions are harmless, therefore, athletes may be advised to replace all the water lost by sweat and consume the maximum tolerated, 600-1200 mL per hour (NOAKES, 2003b). On the other hand, in the recent consensus of the ACSM (2007) a change in the recommendations of liquid replacement during exercise can be observed, in which these four suppositions no longer appear and have been replaced by recommendations that warn about the difference there may be among the types of exercise (metabolic requirements, duration, clothing, and equipment used), environmental conditions and other factors that could have an influence on sweating.

Thus, the ACSM (2007) consensus does not make the recommendations of ingesting the maximum quantity of liquids tolerated, and replacing all the body mass lost during exercise, but recommends that the aim of liquid ingestion during exercise must be to prevent excessive dehydration; that is, greater than 2% reduction in body mass by water deficit, and avoid large changes in the electrolytic balance. Among the changes there is also the recommendation to ingest liquids ad libitum during exercise, in quantities of 0.4 to 0.8 L per hour, which has the consensus of the IMMDA as reference (NOAKES, 2003a). Furthermore, recommendations are made about the development of individual liquid replacement programs, due to the great variability among the types of exercise and environmental conditions, admitting that there is no universal recommendation for liquid replacement (ACSM, 2007). These alterations in the recommendations indicate an important change in the “present paradigm” of dehydration.

**Replacement of all the weight lost during the exercise**

Cheuvront *et al.* (2003) reviewed 13 important studies about the effects of dehydration on performance and they demonstrated that the non ingestion of liquids during exercise probably harms performance, particularly during more prolonged exercises in a hot environment. It was also demonstrated that the benefits of ingesting liquids increase with the duration of the exercise are less apparent in exercises of short duration. Nevertheless, the question is whether there is a real additional benefit in the ingestion of the “maximum volume tolerated of liquids” or “replace the losses by sweat” compared with the ingestion of “some” quantity of liquids during exercise (NOAKES, 2003a; NOAKES, 2007).

Noakes (2007) questions whether there was adequate control in longitudinal clinical trials
that prove that the entire body mass lost during exercise is beneficial to athletes who compete outdoors, since the consensus is usually applied to athletes who train and compete on those conditions. However, no studies were found that showed evidence that the ingestion of liquids in the “maximum tolerated quantity” improves performance and prevents medical consequences. Contrary to what is proposed, the best marathoners and cyclists in the world, apparently have low rates of liquid ingestion during exercises with a duration from 1-3 hours, which do not nearly approach the quantities recommended by the ACSM consensus of 1996, of 1.200 mL/h. Winning athletes, or those that finish endurance tests close to those in the first places generally are the ones that present the highest levels of dehydration; in the case of ironman athletes this can reach 8-10% loss of body mass (NOAKES, 2003b; NOAKES, 2007; SHARWOOD et al., 2004).

The fastest marathon runners tend to present levels of dehydration at the end of the test, ranging from 2 to 8% loss of body mass (COYLE, 2004).

In a study with 224 km ironman triathletes, in that the reduction in body mass was analyzed, the results demonstrated a weak, but significant inverse relationship between the percentage of body mass lost and the final time of the test; that is, the athletes that lost most body mass during the test tended to finish with the best times (SHARWOOD et al., 2004).

In the study of Laursen et al. (2006) previously mentioned, with 226 km ironman triathletes, the athletes ingested foods and liquids *ad libitum* during the test. In addition to not presenting significant increase in central temperature, the plasmatic concentration of sodium and specific gravity of urine also presented no significant modifications, demonstrating that the athletes finished the test in a normal state of hydration of the extracellular liquid. Moreover, there was a reduction in body mass of approximately 3%.

From the results obtained, the authors inferred that recommendations such as, “ingestion of maximum volume tolerated of liquids during exercise” and that “a reduction of only 1% of body mass increases the central temperature during exercise” are not applicable to exercise situations such as an ironman, and researches must be conducted to re-evaluate these aggressive hydration strategies recommended by many consensuses. Therefore, a disparity has been shown between the results of classical laboratory studies on which the consensuses are based, and the new findings of field studies, as regards the relationship between hypohydration and central temperature, since the laboratory studies were performed in climatized chambers with inadequate air speed, limiting the dissipation of heat, when compared with the conditions in the field where the airspeed is greater (LAURSEN, 2006).

Noakes (2007) compared six researches in which the effects on performance in exercise when the ingestion of “some” quantity of liquid are compared with ingestion for complete liquid replacement, and it was observed that in none of the studies complete liquid replacement presented a superior result to that of *ad libitum* ingestion. Therefore, it appears that the *ad libitum* ingestion of liquids is at least as effective as ingestion to replace all the liquid lost.

McConell et al. (1997) compared the ingestion of liquids to replace 50% or 100% of the body mass lost during the exercise with the non-ingestion of liquids in well trained cyclists/triathletes, who performed 2 h of cycling at 69±1% of the VO$_{2peak}$ followed by exercise pedaling until exhaustion at 90% of the VO$_{2peak}$ at a temperature of 21°C. The results demonstrated that there was no difference in performance between the groups that replaced 50 and 100% of lost body mass. However, the group that did not ingest liquids had a reduced performance in comparison with the group that replaced 100% of the lost
In another study, McConell et al. (1999) compared the ingestion of liquids to replace 50% or 100% of the body mass lost during exercise with the non-ingestion of liquids in well trained cyclists/triathletes, who performed 1 h of intense exercise (45 min on a cycloergometer at 80% of the \( VO_{2\text{peak}} \) followed by 15 minutes pedaling under maximum load achieved) in an amenable environment (21°C). The results demonstrated that there was no significant difference in the heart rate, body temperature, plasma volume and electrolytes or performance, suggesting that there is a little benefit from ingesting liquids during intense exercise with the duration of 1 hour in an amenable environment.

A study conducted with women runners by Cheuvront & Haymes (2001) tested the \textit{ad libitum} ingestion of liquids by the athletes in a 30 km treadmill run with a mean intensity of 71±7% of the \( VO_{2\text{max}} \) under three environmental conditions: hot, moderate and cool temperatures. The results showed a replacement of 60-70% of sweat losses, being sufficient to maintain dehydration below approximately 3% of body mass and rectal temperature below 39°C. Once again, it was observed that the athletes did not need to replace 100% of the sweat losses to maintain thermal homeostasis, since that heat elimination is not limited by the environment.

Daries et al. (2000) examined the effects of higher than \textit{ad libitum} liquid ingestion in long distance runners who performed the 2 hour exercise (90 minutes running at 65% of the \( VO_{2\text{peak}} \), followed by 30 minutes of running the maximum possible distance at an ambient temperature of 25°C). A solution with carbohydrates and electrolytes was administered \textit{ad libitum} in determined volumes of 150 or 350 mL/70 kg of body mass every 15-20 minutes. The results demonstrated that higher volumes of liquid ingestion (~0.9 L/h in the 350 mL/70 kg group) when compared with the lower volume (~0.4 L/h in the \textit{ad libitum} and 150 mL/70 kg groups) presented no significant differences in volume and plasma osmolality, and there was no improvement in performance in the 2 hour run at 25°C.

Based on the evidences that demonstrated that the \textit{ad libitum} ingestion of “some” quantity of liquid during the exercise appears to be at least as effective as “ingesting the maximum tolerate volume”, Noakes (2007) suggested a hypothesis: it is not the level of dehydration that determined the extent to which performance is influenced by the ingestion or non-ingestion of liquids, but that performance can be improved irrespective of the quantity of dehydration that occurred, since that sufficient liquids are ingested to prevent the development of the sensation of thirst during the exercise. Should this hypothesis be true, this mechanism would explain why it is possible for elite athletes to present optimum performance while they ingest small quantities of liquids during exercise; the fastest marathon runners are among the most dehydrated, as demonstrated in classical and modern studies; and the athletes that lose around 10% of body mass are among the finalists in 226 km ironman triathlons (NOAKES, 2007).
**Ingestion of electrolytic beverages in exercise**

The goal of drinking during exercise is to prevent excessive dehydration (2% body weight loss from water deficit) and excessive changes in electrolyte balance to avert compromised exercise performance (ACSM, 2007).

The consensuses of the ACSM (2007); NATA (CASA et al., 2000); IOC (COYLE, 2004) recommend the ingestion of sodium during exercise for various reasons, among them to prevent hyponatremia, improve the palatability of the beverage to increase the consumption of liquids and stimulate the sensation of thirst. The inclusion of sodium in re-hydrating beverages or diet allows the volume of liquids to be better conserved and the desire to ingest liquids increases. According to the ACSM (2007); NOAKES (2007) after exercise, beverages containing sodium, such as the sports drinks may be useful, but many foods can provide the electrolyte requirements.

The recommendation of the ACSM (2007) is that these types of fluid replacement beverages should contain ~20–30 meq.L⁻¹ sodium (chloride as the anion), ~2–5 meq.L⁻¹ potassium and ~5–10% carbohydrate. The need for these different components (carbohydrate and electrolytes) will depend on the specific exercise task (e.g., intensity and duration) and weather conditions. The sodium and potassium favor the replacement of sweat electrolyte losses, while sodium also helps to stimulate thirst, and carbohydrate provides energy supply.

The IOC guidelines (COYLE, 2004) affirm that there is no documented need for the inclusion of sodium in replacement beverages ingested during exercise, unless in terms of the absorption of liquids and sugar in the body.

As previously mentioned, there is great concern about the recommendation of ingesting a high quantity of liquids and the consequences of this procedure, such as: the development of exercise associated hyponatremia (EAH). Evidences have been presented that these conditions are caused by the insufficiency of the kidneys in eliminating water when there is excessive ingestion of water, due to the “syndrome of inappropriate anti-diuretic hormone secretion – SIADH) in which there is an inadequate secretion of ADH and renal sodium excretion is increased, and water excretion is inhibited. Therefore, what really determines the plasma sodium concentration during exercise does not appear to be the quantity of sweat or urine loss, or the quantity of sports drinks poor in electrolytes ingested.

A large sweat loss of sodium is not the main factor for the development of EAH, and the athletes who gain most weight during exercise have greater probability of finishing the test with the lowest plasma sodium concentrations. This weight gain is correlated with excessive liquid ingestion and the prevention of this high ingestion could avoid EAH (ALMOND et al., 2005; NOAKES et al., 2005; NOAKES & SPEEDY, 2006).

Thus, it is not clear how the ingestion of beverages with low sodium concentration could minimize hyponatremia. To the contrary, it has been demonstrated that the ingestion of sports drinks with electrolytes, instead of water, was incapable of preventing hyponatremia in psychiatric patients with polydypsia. In studies with athletes, it has been demonstrated that the ingestion of electrolytic sports drinks compared with water did not significantly alter the plasma sodium concentrations (REEVES, 2004).

Marins et al. (2003) conducted a study with 15 cyclists that exercised for 2 hours at 65% of the VO₂ max in a cycloergometer. In this study, four hydration procedures were compared: water *ad libitum*, programmed water (3 mL of water /kg of body mass every 15 min), Type 1 carbohydrate solution with 22 mg/100 mL of sodium, and Type 2 carbohydrate solution...
with 40 mg/100 mL of sodium, with the quantity of carbohydrate beverages also being 3 mL of liquid/ kg of body mass every 15 minutes. The athletes' degree of dehydration at the end of the tests was lower than 2% loss of body mass, presenting no significant difference among the treatments, and the results demonstrated that the four procedures adopted did not significantly alter the plasma sodium response in a period of 2 hours of exercise.

Carvalho & Marins (2007) evaluated the ingestion of water versus a carbohydrate and electrolytic drink containing 45 mg/100 mL of sodium in soldiers that marched 16 km under moderate environmental conditions. With the ingestion of 200-250 mL of liquid every 15 minutes, the soldiers presented a low level of dehydration (<1% loss of body mass). The plasma sodium concentration values presented a significant reduction when compared with the values before the test. Nevertheless, there was no significant difference among the groups, demonstrating that the carbohydrate and electrolytic solution was incapable of maintaining the balance of sodium concentrations in the body.

CONCLUSIONS
In this review, we identified that dehydration has a relationship with performance and increase in central temperature in laboratory studies, but, field studies contradict these results, thus one cannot affirm what percentage of dehydration in relation to body mass would lead to an increase in central temperature and/or compromise performance;

Further studies are necessary to evaluate the effects of dehydration on performance in exercise, especially studies that are conducted under environmental conditions that are closer to the conditions experienced by athletes in races;

The non-ingestion of liquids during exercise probably compromise performance, particularly during more prolonged exercises in a hot environment. The benefits of ingesting liquids increase with the duration of the exercise and are less apparent in exercises of short duration;

The *ad libitum* ingestion of liquids appears to be as effective as the “ingestion to replace all the lost body mass” or “in maximum tolerated quantity”.

Thus, we suggest that the amount of fluid administered to an athlete should be under consideration the individuality of the athlete, the training period, duration, intensity, climatic conditions of training and competition.

REFERENCES


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