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The Role of Alcohol, Sports Drinks, and Caffeinated Beverages in Preventing Heat-Related Illness

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With the increase in frequency of extreme heat events,[1] people are increasingly suffering from heat-related illness. This can present with acute symptoms of weakness, headache, dizziness, and muscle cramps. Prolonged exposure can result in adverse cardiovascular and kidney outcomes. When severe, prolonged heat exposure can lead to death. Heat-related illness is more prevalent in outdoor workers, including those who work in the agriculture and construction industries.[2]

In an effort to protect workers from heat-related illness, the US Occupational Safety and Health Administration has recently proposed a heat standard for workers employed in conditions that put them at risk.[3] The proposed 2024 OSHA Heat Standard advises "water, rest, and shade"[4] but is not specific in recommendations regarding the types of beverages that would replenish fluids and help workers maintain adequate hydration. Current messaging that is available on the internet, and even fact sheets from reputable sources, commonly advise workers, athletes, and the public to avoid coffee, sports drinks, and alcohol; these recommendations are not conclusively supported by scientific literature or an understanding of homeostatic mechanisms that conserve hydration. As the climate warms and this public health challenge grows, it is critical to provide accurate information to mitigate the adverse effects of heat on human health.

METHODS

Using key words in PubMed and following relevant references, we reviewed the physiological mechanisms of salt and water homeostasis and the scientific literature on commonly imbibed beverages (caffeinated beverages, coffee, sugary beverages, fructose containing drinks, diet drinks, ethanol). The goal was to examine their role in hydration and to clarify best practice recommendations for preventing heat-related illness among workers and the public.

MECHANISMS OF FLUID HOMEOSTASIS

The human body needs to maintain fluid homeostasis to ensure appropriate cell function. The kidney is the primary organ that regulates the intracellular and extracellular fluid compartments through the absorption and excretion of water and various electrolytes. Sodium (Na+) reabsorption occurs primarily in the proximal tubule and secondarily along the Loop of Henle and collecting tubule. When there is low effective arterial blood volume, which is sensed by baroreceptors, the renin-angiotensin-aldosterone system is upregulated, resulting in aldosterone release from the adrenal glands. Aldosterone increases renal sodium reabsorption via stimulation of basolateral sodium-potassium ATPase while increasing the opening frequency of the epithelial sodium channels in the principal cells of the collecting tubules. These responses lead to increased sodium reabsorption from the filtrate.

Water reabsorption also occurs in the collecting ducts as induced by antidiuretic hormone (ADH), also known as arginine vasopressin. Osmoreceptors in the hypothalamus sense increased plasma osmolarity while baroreceptors in the carotid body, right atrium, and aorta sense decreased perfusion pressure. Both stimuli cause a release of preformed ADH from the posterior pituitary. ADH acts on the vasopressin type 2 receptors in the collecting ducts and causes an increased density of aquaporin channels leading to augmented water reabsorption and increased urinary concentration. With this physiology in mind, recommendations for maintaining adequate hydration must account for their effects on total body sodium and total body water retention and repletion.

EFFECTS OF BEVERAGES ON HYDRATION

Ethanol

Ethanol, contained in alcoholic beverages, increases plasma osmolarity, but because it freely traverses cell membranes, it does not affect serum tonicity. Therefore, it does not induce ADH secretion. Instead, the earliest work in this field showed that alcohol causes diuresis by inhibiting ADH.[5] Another early study showed that for every 10 grams of alcohol ingested, there would be an additional 100 mL of urine output.[6] Some thought that alcohol-induced diuresis was due to a loss of solutes, but Roberts[7] proved that alcohol causes a diuresis even with concurrent ingestion of sodium chloride. A later study[8] measured ADH levels after alcohol intoxication, and it did not show a correlation between alcohol and ADH levels; this study suggested there might be a direct toxic effect of alcohol on the renal tubules, though alcohol as an inhibitor of ADH is still the prevalent theory.[9] Interestingly, ethanol has no effect on the renin angiotensin-aldosterone-system, as it has been shown to have no effect on aldosterone levels.[10]

Later research has shown that the diuretic effect of alcohol depends on several other factors. The higher the concentration of alcohol, the greater the diuresis.[6] In addition, in chronic alcoholics, the diuretic effect of alcohol is reduced. This is probably multifactorial, due both to low solute intake and to tolerance to the diuretic effect. One study[11] showed that after exercise induced dehydration, alcohol will cause an increased urine output with augmented water losses as compared to a nonalcoholic beverage. Though the mechanism may not be fully understood, there is a measurable diuretic effect of ethanol on the kidneys, therefore ethanol would not be preferred as a beverage of choice to replete salt and water losses.

Sugary Drinks and Zero Sugar Sports Drinks

Sports drinks are another option to prevent dehydration. These beverages are

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designed to be consumed during sports activities or exercise. They typically contain sugars and electrolytes, including sodium, potassium, and magnesium. In a study of 400 farm workers in California, Moyce[12] found that the workers drank 0.2 oz/kg of sugary drinks during their workday. Animal studies[13] have shown acute kidney injury (AKI) associated with sugary beverages because the enzyme fructokinase is activated, leading to an inflammatory cascade, which causes tubulointerstitial kidney injury. In another mouse model, frequent dehydration led to hyperosmolarity, which triggered the endogenous production of fructose, which when metabolized by phosphofructokinase, led to kidney injury.[14] If this mechanism were conserved in humans, it would militate against adding more fructose via supplements, however, in humans, multiple studies have not demonstrated that fructose induces AKI.[15] One of these studies looked at the levels of KIM-1 and NGAL, urinary biomarkers for acute tubular necrosis, and found no difference in levels whether the subjects were hydrating with fructose-containing sports drinks or water.[16] This latter study gives some support to proposing that high fructose containing drinks, though theoretically dangerous to renal function in animal models, may be safe for short term use in workers with cultural/personal aversion to unsweetened oral hydration.

Another important potential effect of sports drinks is that high glucose, hypertonic beverages cause a secretion of water into the intestinal lumen. Evans[17] compared a hypotonic 2% glucose solution (111 mosms/kg) to a hypertonic 10% solution (565 mosms/kg). Despite predictable decreases in urine osmolality and increases in urine volume post ingestion, the magnitude of these changes was not correlated with the concentration of the ingested fluids. This suggests that concentrated glucose can reduce plasma volume transiently, but overall hydration status appears to normalize by 60 minutes after ingestion. Therefore, in a high risk environment, although subjects ingesting sugary drinks ultimately maintain euvolemia via ADH and aldosterone secretion, high glucose solutions are not preferred for rehydration due to the transient acute declines in plasma volume.

Finally, sports drinks with high glucose content can cause metabolic syndrome and predispose to diabetes with chronic use. The Union of European Football Associations (UEFA) recommends that its players ingest 6 mL/kg of fluid and 2 g/kg of carbohydrates 3 hours before a match.[18] It does not clarify which type of fluid. Wolyniec[19] investigated whether hydrating with sports drinks that contain the popular sweetener xylitol, instead of sugar, would help amateur soccer players maintain hydration. She found that drinks sweetened with xylitol can cause diarrhea and lead to elevations in creatinine. This indicates that zero sugar sports drinks should not be recommended for maintaining hydration.

Public health messaging should be simple and broadly applicable. In consideration of concerns about the safety of high fructose drinks, xylitol-containing drinks, and the increased prevalence of metabolic syndrome in the US, rehydration with sugary beverages should not be encouraged, even though their short-term use could be beneficial.

Caffeinated Beverages

Recommendations to avoid caffeine during strenuous activity are often justified by the diuretic effect reportedly associated with this substance. Caffeine is a methylxanthine, which inhibits adenosine, likely through blockade of the adenosine 1 receptor.[20] This is believed to result in decreased proximal sodium reabsorption in the renal tubules. The ensuing diuresis on its face would seem to militate against the use of caffeinated beverages as an appropriate hydration fluid. Studies have demonstrated, however, that the diuretic effect is only seen at extremely high doses and is most marked on initiation of ingestion with notable waning of effect with continued use.[21]

A recent trial[22] evaluating effects on athletic agility of low dose caffeine, used a double-blind, cross-over design with nine moderately trained male soccer players who consumed caffeine (6 mg/kg) or a placebo 60 minutes before completing balance, reaction time, vertical jump, agility, 30 m sprint, and ball-kicking speed tests. The caffeine had positive effects on many features of athletic performance including jump height (P=0.01) and power (P=0.08), and faster completion time according to the Illinois Agility Test (P=0.08) as compared to placebo. Of note, hydration status as measured by saliva assay demonstrated no significant negative effect following the ingestion of caffeine as compared to placebo. Caffeine intake significantly improved jump height, agility, and reaction time (P<0.05) but did not affect 30 m sprint, ball-kicking speed, balance, and Rate of Perceived Exertion (RPE) values in soccer players (P>0.05). Although nonsignificant, caffeine intake also improved sprint (0.67%) and ball kicking (2.7%) performance percentages. Most significantly, caffeine consumption did not induce dehydration, and the athletes' body hydration levels were normal.

Another investigation[23] studied seven endurance-trained, heat-acclimated cyclists who pedaled for 120 minutes at 63%. VO_2max in a hot-dry environment (36°C; 29% humidity) on six occasions: 1) without rehydration; 2) rehydrating 97% of sweat losses with water; 3) rehydrating the same volume with a 6% carbohydrate-electrolytes solution; or combining these treatments with the ingestion of 6 mg caffeine/kg body weight 45 minutes before exercise. The study found no significant effect from caffeine on thermoregulation and heat dissipation but found increased sweat and urinary losses, though not sufficient to induce volume depletion or other negative effects. Prior studies, however, did not demonstrate the same degree of urinary and sweat losses.[24,25]

A large meta-analysis[26] showed that caffeine had no harmful metabolic effects. In fact, the literature in neonates suggests caffeine had protective effects in preventing AKI under stress.

Taken together, these studies suggest that caffeinated beverages may enhance performance significantly and may result in diuresis, but the effect does not seem to result in harmful outcomes. Any negative effects may be limited to higher doses of caffeine and may also be attenuated by chronic use. These studies are limited by small sample sizes, and nonstandardized methods for assessing hydration and outcomes. Public health recommendations against caffeine are not warranted at this time.

HEAT ACCLIMATIZATION

Heat acclimatization is the process by which an organism adjusts to a change in its environment, allowing it to maintain fitness across a range of environmental conditions. For a worker in a warming climate, it would represent the ability of the worker to maintain functional capacity, without injury, during periods of strenuous workloads and excessive heat. The mechanism of acclimatization has been a matter of controversy, but there is evidence that total body volume increases over the first several days of exposure. There is also evidence of cardiovascular changes affecting distribution of blood flow to skin and muscle, as well as modulation of cardiac functions, which helps in heat dissipation.[27]

It has been proposed that heat acclimatization occurs over time and may mitigate against heat-related injury. According to a review by Shapiro et al, acclimatization is 75% complete at 5 days and fully complete at 14 days.[28] Monitoring of various physiologic parameters could aid in assessing risk of heat-related injury. It remains to be studied directly, but a modification of work schedule that allows for adequate acclimatization, such as increased time off periods, while simultaneously ensuring and enforcing adequate salt and water repletion during this period, might prove beneficial. The CHIPs study suggests that body weight and core body temperature changes could be useful surrogates for heat-related risk assessment.[29] Further research would be needed to validate the utility of using these data to monitor progress of acclimatization and/or the effects of other mitigation strategies and to determine the risk associations of these measurements.

RECOMMENDATIONS

Based on our review of the physiology and available data, it is apparent that there may be a discrepancy between the broad health recommendations for management of heat stress and the actual benefit. Ideally, public health messaging should be simple, evidence based, reasonable, and holistic. It should take into account the available science, as well as realistic cultural limitations to compliance.

This review examined the current recommendations regarding the avoidance of ethanol, glucose/fructose-containing, caffeinated, and sugar-free sweetened beverages in high heat environments in light of available evidence.

We conclude that ethanol, via yet unclear mechanisms, likely has diuretic effect. Furthermore, with the absence of significant solute in such beverages, they would not be preferred for the acute repletion of salt or water. Caffeinated beverages, however, are probably safe for maintaining hydration, and may even positively affect performance metrics with no predictable worsening of volume depletion. High fructose/glucose drinks, such as commonly available carbonated sodas, carry the theoretical risk of fructose induced acute kidney injury; however, these data are largely from animal studies and have yet to be confirmed in humans. Concentrated sugary beverages likely cause transient hypovolemia due to intestinal sequestration, which would be detrimental in settings of acute volume and water depletion, though they are probably safe in the postheat stress environment. These drinks are widely available and often culturally preferred, however, their capacity to aggravate metabolic syndrome and obesity in vulnerable populations should not be overlooked. Finally, drinks sweetened with zero-calorie xylitol can cause diarrhea and lead to elevations in creatinine and should be avoided.

Conclusions and Relevance

Occupational and public health messaging should be modified to recommend against the use of ethanol and xylitol-containing drinks for rehydration. Caffeinated drinks (coffee) are acceptable for rehydration, contrary to commonly held beliefs against their use. Sugary drink consumption need not be strictly curtailed but would best be ingested in the post heat-stress period (e.g., after work). Though human data are scarce, there is reason for OSHA and CDC to consider these data in designating the appropriate beverages for workers exposed to high heat environments. Finally, this is an area that is ripe for randomized controlled human trials, which could serve to more accurately guide best practices; such studies could reduce barriers to adequate workplace hydration by dispelling misinformation found on the web and in the popular media.

REFERENCES

1. National Academies of Sciences, Engineering, and Medicine. *Attribution of Extreme Weather Events in the Context of Climate Change*. Washington, DC: The National Academies Press; 2016.
2. Centers for Disease Control and Prevention (CDC). Heat-related deaths among crop workers —United States, 1992–2006. *MMWR Morb Mortal Wkly Rep* 2008;57:649–653.
3. De Sario M, de'Donato FK, Bonafede M, et al. Occupational heat stress, heat-related effects and the related social and economic loss: a scoping literature review. *Front Public Health* 2023;11:1173553.
4. Occupational Safety and Health Administration. 2024 OSHA Heat Standard. Available at: https://www.osha.gov/sites/default/files/Heat-NPRM-Final-Reg-Text.pdf. Accessed October 8, 2024
5. Murray MM. The diuretic action of alcohol and its relation to pituitrin. *J Physiol* 1932;76:379–386.
6. Eggleton MG. The diuretic action of alcohol in man. *J Physiol* 1942;101:172–191.
7. Roberts KE. Mechanism of Dehydration Following Alcohol Ingestion. *Arch Intern Med* 1963;112:154–157.
8. Taivainen H, Laitinen K, Tähtelä R, Kilanmaa K, Välimäki MJ. Role of plasma vasopressin in changes of water balance accompanying acute alcohol intoxication. *Alcohol Clin Exp Res* 1995;19:759–762.
9. Hobson RM, Maughan RJ. Hydration status and the diuretic action of a small dose of alcohol. *Alcohol Alcohol* 2010;45:366–373.
10. Saini J, Boisvert P, Spiegel K, Candas V, Brandenberger G. Influence of alcohol on the hydromineral hormone responses to exercise in a warm environment. *Eur J Appl Physiol Occup Physiol* 1995;72(1–2):32–36.
11. Shirreffs SM, Maughan RJ. Restoration of fluid balance after exercise-induced dehydration: effects of alcohol consumption. *J Appl Physiol (1985)* 1997;83:1152–1158.
12. Moyce S, Mitchell D, Vega A, Schenker M. Hydration choices, sugary beverages, and kidney injury in agricultural workers in California. *J Nurs Scholarsh* 2020;52:369–378.
13. Roncal Jimenez CA, Ishimoto T, Lanaspa MA, et al. Fructokinase activity mediates dehydration-induced renal injury. *Kidney Int* 2014;86:294–302.
14. García-Arroyo FE, Cristóbal M, Arellano-Buendía AS, et al. Rehydration with soft drink-like beverages exacerbates dehydration and worsens dehydration-associated renal injury. *Am J Physiol Regul Integr Comp Physiol* 2016;311:R57–R65.
15. Wesseling C, Aragón A, González M, et al. Kidney function in sugarcane cutters in Nicaragua—a longitudinal study of workers at risk of Mesoamerican nephropathy. *Environ Res* 2016;147:125–132.
16. Atkins W, McKenna Z, McDermott B. Sports drinks do not increase acute kidney injury risk in males during industrial work in the heat when euhydration is maintained, a randomized crossover trial. *Appl Physiol Nutr Metab* 2024;49:844–854.
17. Evans GH, Shirreffs SM, Maughan RJ. Acute effects of ingesting glucose solutions on blood and plasma volume. *Br J Nutr* 2009;101:1503–1508.
18. Collins J, Maughan RJ, Gleeson M, et al. UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. *Br J Sports Med* 2021;55:416.
19. Wołyniec W, Szwarc A, Kasprowicz K, et al. Impact of hydration with beverages containing free sugars or xylitol on metabolic and acute kidney injury markers after physical exercise. *Front Physiol* 2022;13:841056.
20. Rieg T, Steigele H, Schnermann J, Richter K, Osswald H, Vallon V. Requirement of intact adenosine A1 receptors for the diuretic and natriuretic action of the methylxanthines theophylline and caffeine. *J Pharmacol Exp Ther* 2005;313:403–409.
21. Maughan RJ, Griffin J. Caffeine ingestion and fluid balance: a review. *J Hum Nutr Diet* 2003;16:411–420.
22. Del Coso J, Estevez E, Mora-Rodriguez R. Caffeine during exercise in the heat: thermoregulation and fluid-electrolyte balance. *Med Sci Sports Exerc* 2009;41:164–173.
23. Mor A, Acar K, Alexe DI, et al. Moderate-dose caffeine enhances anaerobic performance without altering hydration status. *Front Nutr* 2024;11:1359999.
24. Wemple RD, Lamb DR, McKeever KH. Caffeine vs caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. *Int J Sports Med* 1997;18:40–46.
25. Millard-Stafford ML, Cureton KJ, Wingo JE, Trilk J, Warren GL, Buyckx M. Hydration during exercise in warm, humid conditions: effect of a caffeinated sports drink. *Int J Sport Nutr Exerc Metab* 2007;17:163–177.
26. Poole R, Kennedy OJ, Roderick P, Fallowfield JA, Hayes PC, Parkes J. Coffee consumption and health: umbrella review of meta-analyses of multiple health outcomes. *BMJ* 2017;359:j5024.
27. Périard JD, Travers GJS, Racinais S, Sawka MN. Cardiovascular adaptations supporting human exercise-heat acclimation. *Auton Neurosci* 2016;196:52–62.
28. Shapiro Y, Moran D, Epstein Y. Acclimatization strategies—preparing for exercise in the heat. *Int J Sports Med* 1998;19(Suppl 2):S161–S163.
29. Mitchell DC, Castro J, Armitage TL, et al. Recruitment, methods, and descriptive results of a physiologic assessment of Latino farmworkers: the California Heat Illness Prevention Study. *J Occup Environ Med* 2017;59:649–658.

