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Effects of acute alkalosis and acidosis on performance: a meta-analysis.

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Ingestion of agents that modify blood buffering action may affect high-intensity performance. Here we present a meta-analysis of the effects of acute ingestion of three such agents - sodium bicarbonate, sodium citrate and ammonium chloride - on performance and related physiological variables (blood bicarbonate, pH and lactate). A literature search yielded 59 useable studies with 188 observations of performance effects. To perform the mixed-model meta-analysis, all performance effects were converted into a percentage change in mean power and were weighted using standard errors derived from exact p-values, confidence limits (CLs) or estimated errors of measurement. The fixed effects in the meta-analytic model included the number of performance-test bouts (linear), test duration (log linear), blinding (yes/no), competitive status (athlete/nonathlete) and sex (male/female). Dose expressed as buffering mmoL/kg/body mass (BM) was included as a strictly proportional linear effect interacted with all effects except blinding. Probabilistic inferences were derived with reference to thresholds for small and moderate effects on performance of 0.5% and 1.5%, respectively. Publication bias was reduced by excluding study estimates with a standard error >2.7%. The remaining 38 studies and 137 estimates for sodium bicarbonate produced a possibly moderate performance enhancement of 1.7% (90% CL ± 2.0%) with a typical dose of 3.5 mmoL/kg/BM (~0.3 g/kg/BM) in a single 1-minute sprint, following blinded consumption by male athletes. In the 16 studies and 45 estimates for sodium citrate, a typical dose of 1.5 mmoL/kg/BM (~0.5 g/kg/BM) had an unclear effect on performance of 0.0% (±1.3%), while the five studies and six estimates for ammonium chloride produced a possibly moderate impairment of 1.6% (±1.9%) with a typical dose of 5.5 mmoL/kg/BM (~0.3 g/kg/BM). Study and subject characteristics had the following modifying small effects on the enhancement of performance with sodium bicarbonate: an increase of 0.5% (±0.6%) with a 1 mmoL/kg/BM increase in dose; an increase of 0.6% (±0.4%) with five extra sprint bouts; a reduction of 0.6% (±0.9%) for each 10-fold increase in test duration (e.g. 1-10 minutes); reductions of 1.1% (±1.1%) with nonathletes and 0.7% (±1.4%) with females. Unexplained variation in effects between research settings was typically ±1.2%. The only noteworthy effects involving physiological variables were a small correlation between performance and pre-exercise increase in blood bicarbonate with sodium bicarbonate ingestion, and a very large correlation between the increase in blood bicarbonate and time between sodium citrate ingestion and exercise. The approximate equal and opposite effects of sodium bicarbonate and ammonium chloride are consistent with direct performance effects of pH, but sodium citrate appears to have some additional metabolic inhibitory effect. Important future research includes studies of sodium citrate ingestion several hours before exercise and quantification of gastrointestinal symptoms with sodium bicarbonate and citrate. Although individual responses may vary, we recommend ingestion of 0.3-0.5 g/kg/BM sodium bicarbonate to improve mean power by 1.7% (±2.0%) in high-intensity races of short duration.