Ammonia Inhalants: Use, Misuse, and Role in Sports Performance

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Context: Ammonia inhalants, also known as smelling salts, are preparations of ammonia designed to treat fainting but more commonly used by athletes to boost awareness and arousal during competition. Despite their widespread use, the physiological and performance-enhancing effects of ammonia inhalants remain poorly understood. The aim of the present study was to review the current literature surrounding the benefits, risks, and physiological effects of ammonia inhalants.

Evidence Acquisition: An extensive literature review of articles pertaining to ammonia inhalants was performed through MEDLINE and Google Scholar. The search terms "smelling salts," "ammonia inhalants," "strength," "performance," "head injury," and "concussion" were used.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: The physiological response to acute ammonia inhalation includes cerebral vasodilation and heart rate elevation without change in blood pressure. The existing evidence demonstrates an ergogenic benefit to ammonia inhalant use only during repeated bouts of high-intensity exercise; in these subjects, ammonia inhalation was associated with increased power as measured by the Wingate anaerobic test. In contrast, there is no performance benefit to ammonia inhalants in a short burst of maximal effort despite elevated arousal and an associated perception of performance enhancement. Importantly, ammonia inhalants have no role in medical management of head injuries, as they have the potential to exacerbate an underlying brain injury due to the involuntary withdrawal reflex associated with ammonia inhalation. Furthermore, the signs and symptoms of a concussion or more threatening head injury may be masked by ammonia inhalation and lead to continued participation in competition, causing additional harm.

Conclusion: Ammonia inhalants have no role in medical management of head injuries and have limited benefit with regards to sports performance.

Strength of Recommendation: B

Keywords: concussion; ergogenic; head injury; smelling salts; performance

In today's highly competitive world of professional and amateur sports, athletes use every method available to gain a competitive advantage. Many ergogenic aids, such as anabolic steroids, growth hormone, and recombinant human erythropoietin, have been banned by governing organizations such as the United States Olympic and Paralympic Committee and the National Collegiate Athletic Association; others, including creatine and ammonia inhalants, are largely unregulated.[1,29] Ammonia inhalants, also known as smelling salts (Figure 1), are used widely among professional and amateur athletes to provide an "awareness wakeup" and "a little jolt," according to coaches and players in the National Hockey League.[23] Even Wayne Gretzky, known as "The Great One," and widely considered the most prolific ice hockey player of all time,[8] used ammonia inhalants for a boost as both a player and a coach.[23] Ammonia inhalants are also commonly used by powerlifters, soccer players, and an estimated 80% of players in the National Football League.[11,24] Despite their widespread use, there is a paucity of literature describing the physiological and ergogenic effects of ammonia inhalants.[18] The purpose of this

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Figure 1. Example of an ammonia inhalant commonly used by athletes before competition.

article is to review the available evidence for the medical uses and misuses of ammonia inhalants, as well as their impact on sports performance.

WHAT ARE SMELLING SALTS?

Traditionally, smelling salts consisted of ammonium carbonate ($[NH_4]_2CO_3$), a colorless-to-white crystalline solid, mixed with perfume and sniffed as a stimulant to relieve faintness or swooning.[18] However, most modern preparations of ammonia inhalants consist of 15% ammonia dissolved in water, ethanol, lavender oil, lemon oil, and/or nutmeg oil,[2] which are more correctly described as "aromatic spirits of ammonia."[18]

In the seventeenth century, crystallized ammonia carbonate was isolated from the shavings of hart's (common red male deer) horns and hooves and was used by bakers as a leavening agent before the discovery of modern baking powder and baking soda.[18,34] Today, ammonia is produced using the Haber process, which converts atmospheric nitrogen to ammonia via a reaction with hydrogen (Figure 2).[3] This purified ammonia is packaged with water and other solvents, which release ammonia gas and carbon dioxide when the capsules are crushed and the 2 solutions mix.

Although the physiological response to ammonia gas remains incompletely understood, it is theorized that inhalation of ammonia causes an acute irritation of the mucus membranes of the nasal cavity, which triggers chemoreceptors that send signals along the trigeminal and olfactory nerves to the respiratory and vasomotor centers within the medulla oblongata, leading to a reflexive increase in respiratory and heart rate (HR) via the sympathetic nervous system.[9,12,16,18,32,35] Perry et al[21] demonstrated an acute increase in HR and middle cerebral artery blood flow velocity (MCAv) in response to ammonia inhalation, without an increase in mean arterial pressure (MAP). The authors postulated that this response was mediated by a transient hyperammonemia (although blood ammonia levels

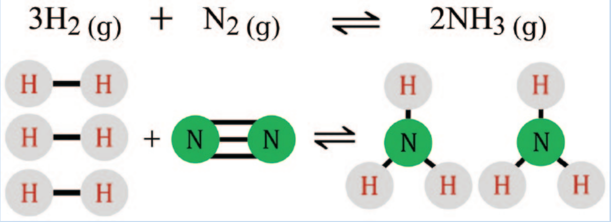

Figure 2. The Haber process: atmospheric nitrogen reacts with hydrogen gas to produce ammonia.

were not measured) leading to cerebral vasodilation and increased cerebral conductance index, as hyperammonemia is associated with elevated cerebral blood flow in acute liver failure.[21,31] This hypothesis has yet to be corroborated with empiric evidence; therefore, further investigation is warranted to clarify the underlying physiological response to ammonia inhalation.

DO SMELLING SALTS HAVE A ROLE IN MEDICINE?

The product description and directions for use of modern ammonia inhalants specify that their product is "only used to prevent or treat fainting."[2] Fainting, also known as syncope, is a sudden and brief loss of consciousness resulting from an acute reduction in cerebral blood flow.[14] Due to the brief cerebrovascular vasodilatory effect of ammonia,[21] ammonia inhalants are an intuitive remedy for fainting. However, given the typical rapid recovery from syncope and the relative scarcity of ammonia inhalants in today's culture, ammonia inhalants are rarely used effectively as a treatment for fainting.[25]

There have been reports of ammonia inhalant use in the management of sporting concussions[23,28]; however, the use of ammonia inhalants in head injury is not recommended.[18,25,33] Signs and symptoms of a concussion or more threatening head injury may be masked by ammonia inhalation due to an increase in arousal, which could potentially lead to continued participation in competition and a delay in diagnosis and treatment. Furthermore, the acute irritation of nasal mucous membranes after ammonia inhalation can lead to an involuntary withdrawal reflex, which may cause a rapid contraction of the head and neck and exacerbate an underlying injury.[17,18,30,32]

DO SMELLING SALTS HAVE A ROLE IN SPORTS PERFORMANCE?

Given the proposed physiologic response to ammonia inhalants (increased HR, respiratory rate, cerebral blood flow), it might be hypothesized that ammonia inhalation could result in performance-enhancing effects. However, the evidence to support this theory is sparse and inconsistent, with most of the literature examining primarily the effect of ammonia inhalation on athletes performing resistance and ballistic exercise

Table 1. Studies investigating the ergogenic effects of ammonia inhalants

Author, Year	Study Participants	Outcomes Measured	Findings
Richmond,[25] 2014	25 resistance-trained college-aged male athletes	Number of repetitions of bench press or back squat at 85% 1RM	No significant difference between AI and placebo
Perry,[20] 2016	15 resistance-trained male athletes	MCAv, HR, MAP, maximal MTP force, RFD, EMG activity	Mean MCAv and HR increased after AI use; MAP, MTP force, RFD, and EMG activity were all unchanged
Bartolomei,[4] 2018	20 resistance-trained male athletes	CMJ power; MTP maximal force and peak RFD	MTP peak RFD was increased after AI use; no significant effects of trial were noted for CMJ power or MTP maximal force
Vigil,[32] 2018	20 resistance-trained college students (10 men, 10 women)	Deadlift 1RM	No significant difference between AI and control trials
Campbell,[8] 2021	14 nonresistance-trained male athletes	Perceived performance, HR, alertness; reaction time, electromechanical delay, RFD, and peak force during handgrip and knee extension maximal voluntary contractions; CMJ peak power	HR, alertness, and perceived performance were elevated by AI use; all other markers of functional performance were unaltered by ammonia inhalants when compared with control and sham
Rogers,[26] 2022	12 physically active female athletes	HR, fatigue index, peak power and mean power (Wingate anaerobic test), perceived alertness, “psyched-up energy” (subjective)	Mean and peak power were significantly increased with AI use compared with control, despite no change in HR or fatigue index; AI use significantly elevated perceived alertness and “psyched-up energy”

1RM, 1-repetition maximum; AI, ammonia inhalant; CMJ, countermovement jump; EMG, electromyography; HR, heart rate; MAP, mean arterial pressure; MCAv, middle cerebral artery blood flow velocity; MTP, mid-thigh pull; RFD, rate of force development.

(Table 1). The earliest peer-reviewed study of the ergogenic effects of ammonia inhalants involved the measurement of anaerobic strength performance in 25 resistance-trained college-aged male altheтes.[26] In this study, the participants performed as many repetitions as possible of the back squat and bench press at 85% of 1-repetition maximum (1RM) after inhaling either ammonia inhalants or placebo (Vicks VapoRub) in a double-blinded design. They found no significant differences in performance after ammonia inhalation when compared with placebo or the initial baseline testing session.

In a subsequent study, Perry et al[21] set out to determine the cardiovascular response to acute ammonia inhalation and understand its impact on maximal muscular performance. In 2 separate trials, MCAv, HR, MAP, and maximal single mid-thigh pull (MTP) strength were measured at various timepoints (baseline, 15 seconds post ammonia inhalation, 30 seconds post ammonia inhalation; 45 seconds post ammonia inhalation, 60 seconds post ammonia inhalation) in 15 healthy resistance-trained male athletes. Compared with control trials (no ammonia inhalation), MCAv and HR increased soon after ammonia inhalation, although MAP remained unchanged. Despite the cerebrovascular and cardiovascular response to ammonia inhalation, no effect was observed during the MTP, as maximal force, rate of force development (RFD), and electromyography activity remained unchanged after ammonia inhalation.

In a similar study, Bartolomei et al[4] studied the influence of ammonia inhalants on lower body power, maximal force production, and RFD during an isometric MTP in 20 healthy male participants. Ammonia inhalation led to a significantly increased RFD but did not affect countermovement jump power or maximal force production during isometric MTP. These results suggest that the potential ergogenic effect of ammonia inhalation is related to explosive force output rather than maximal force production; however, these results oppose the findings of Perry et al,[21] who reported no significant effect of ammonia inhalants with respect to RFD. In another study of maximum strength, Vigil et al[33] examined the effect of ammonia inhalants on deadlift 1RM in healthy college-aged male and female recreational weightlifters. Similar to previous analyses, this study found no significant difference in absolute deadlift 1RM after ammonia inhalation, compared with either a water control or baseline measurement.

The most recent study to evaluate the effect of ammonia inhalants on anaerobic strength performance examined the psychological and neuromuscular impact of acute ammonia inhalation in 14 nonresistance-trained male participants completing handgrip and knee extension maximal voluntary isometric contractions and countermovement jump. They found that HR, alertness, and perceived performance were all elevated significantly by ammonia inhalants, but markers of functional performance, including reaction time, electromechanical delay, RFD, peak force, and peak power, were unaltered by ammonia inhalation.[9]

In the only peer-reviewed journal article to investigate the effect of ammonia inhalants on repeated high-intensity exercise performance, Rogers et al[27] examined performance and psychophysiological responses in 12 physically active female participants completing 3 sequential Wingate anaerobic tests after water (control) or ammonia inhalation. They showed a significant increase in mean power and peak power after ammonia inhalation, despite no change in HR or fatigue index (rate at which power output declines). The ergogenic effect of ammonia inhalation was correlated with a subjective increase in perceived alertness and "psyched-up energy," suggesting that the performance enhancement observed with ammonia inhalant use may be governed by adaptive increases in psychological arousal and alertness, rather than any neuromuscular or cardiovascular effect.

In summary, there is very limited and mixed evidence regarding any ergogenic effect of ammonia inhalants. Bartolomei et al[4] showed an increased RFD during isometric MTP after ammonia inhalation, although this is in opposition to similar studies by Perry et al[21] and Campbell et al,[9] which showed no increase in RFD after ammonia inhalation. There are many possible explanations for this discrepancy, as these studies all used small sample sizes without significant diversity in participants. One additional potential ergogenic benefit of ammonia inhalants is an increase in power during repeated bouts of high-intensity exercise, as demonstrated in the study by Rogers et al[27] of 12 trained female participants completing successive Wingate anaerobic tests. This observed effect may be related to an increase in arousal that mitigates exercise-induced fatigue, which is defined as a decline in force-generating capacity after repeated high-force contractions of skeletal muscles.[5] One previous study showed a greater impairment of rapid muscle contractions during repeated, rather than single, attempts of maximal force production in athletes tested after running a half marathon,[7] suggesting that stimulant-mediated performance benefits may be observable in only persons experiencing greater levels of fatigue.

WHAT ARE THE DANGERS OF SMELLING SALTS?

Ammonia inhalants are approved by the Food and Drug Administration for the treatment of fainting and are also available for purchase over the counter in the United States. They are generally considered safe for their indicated use in treating syncope; however, improper use can be harmful and lead to serious adverse effects.[6] Exposure to large doses of ammonia can cause severe damage to the respiratory tract, manifested by bronchitis, bronchiolitis, emphysema, bronchiectasis, pulmonary edema, and possibly leading to permanent injury or death.[15,19,20] However, commercially available ammonia inhalants only release 50 to 100 ppm of ammonia vapors, which is significantly lower than the amounts reported to cause serious respiratory tract injury.[17]

One notable concern with ammonia inhalant use is the potential for an allergic reaction requiring medical management, which has been reported in a young female powerlifter who inhaled a portion of an ampule of aromatic ammonia before a powerlifting contest.[13] Shortly after inhalation, she developed rhinitis, rhinorrhea, conjunctivitis, dizziness, and a severe headache, which progressively worsened. Within 1 hour, she developed wheezing, shortness of breath, severe periorbital edema, and a nonpruritic urticaria over the extremities. Treatment with subcutaneous epinephrine and intravenous diphenhydramine hydrochloride led to immediate resolution of all symptoms without recurrence. While this is an uncommon reaction, physicians should be aware of the potential adverse reactions of ammonia inhalants, and appropriate treatment should be instituted immediately to avoid progression of anaphylaxis.

In addition, while ammonia inhalants are intended to be used in the treatment of fainting, it is theorized that ammonia inhalant use in weightlifting may increase the likelihood of syncope in some instances.[21] Perry et al[21,22] demonstrated that ammonia inhalation leads to an increase in cerebral perfusion, which is presumed to be the mechanism by which ammonia inhalants alleviate light-headedness. However, it was also shown that inhalation may induce hypotension, which can be exacerbated by heavy upright resistance exercise and the Valsalva maneuvers required to perform such lifts.[10,21,22] This may reduce blood pressure below the level of the cerebral circulation and culminate in cerebral hypoperfusion and syncope.

Lastly, ammonia inhalants present a danger when used in the management of head injuries, as previously discussed. Ammonia inhalant use may mask the symptoms of a neurologic injury, leading to continued participation in activity and a delay in diagnosis and treatment. Moreover, the involuntary inhalation reflex may exacerbate a head or neck injury if the patient rapidly jerks their head away from the noxious substance. There is no role for the use of ammonia inhalants as treatment for a suspected concussion or head injury during competition.

CONCLUSION

In summary, ammonia inhalants have no role in the medical management of head injuries and have limited benefit with regards to sports performance. The physiological response to acute ammonia inhalation is poorly understood but is thought to be related to cerebral vasodilation and HR elevation without change in blood pressure. Limited evidence demonstrates an ergogenic benefit to ammonia inhalants only in athletes completing repeated bouts of high-intensity exercise; in these subjects, ammonia inhalation was associated with increased power as measured by the Wingate anaerobic test. In contrast, there is no performance benefit to ammonia inhalant use during a short burst maximal effort despite elevated arousal and an associated perception of performance enhancement. The more significant concern is the improper use of the ammonia inhalant as a substitute for a medical assessment, which can delay diagnosis and optimal treatment of a suspected head injury. Importantly, there is a notable lack of high-quality studies examining the physiological and performance-related effects of these frequently employed substances. This highlights the need for additional research in this area, particularly with larger groups and focusing on understudied groups such as women.

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