IMPROVING PERFORMANCE

A QUESTION OF TASTE?

– Written by Russell Best, New Zealand

OVERVIEW

Taste is one of our most powerful and useful senses, it has the potential to inform us of foods' nutrient availability and readiness to eat, as well as evoke halcyon childhood memories and elicit seemingly unrelated physiological responses. Taste and experiences related to taste are made up of several sub-senses including smell, sight and receptor stimulation e.g. the trigeminal nerve with wasabi. So, taste, is not one sense, but a manifestation of multiple pathways working in synergy with one another.

Through processes of evolutionary economy, the chemosensory highways that are responsible for our experience of taste, often share lanes with more deep rooted physiological effects such hedonic experiences, muscle recruitment or thermoregulation[1]. This is particularly apparent in individuals who have lost their sense of taste, but can still experience psychobiological responses to tastants, or when foods and beverages are served at different temperatures and their flavour profile appears to be intensified or supressed e.g. coffee, chocolate or wine.

Over the last decade, sports scientists and nutrition practitioners have begun to explore the effects of taste in the lab and in the field, with further mechanistic insights from neuroscientists and practical application facilitated by food scientists. Two approaches to applying tastes have emerged in sports performance: swilling and ingestion. Swilling consists of taking in a small amount (typically 25-50ml of fluid) and coating the oral cavity with the substance before expectorating it, much like a sommelier would recommend one samples wine. Ingestion, one the other hand, is the 'traditional' approach to tasting – where one briefly tastes the substance and then swallows it, to undergo further digestion and metabolism. Both approaches have merit in the field and in the lab, so where appropriate are discussed in this article.

In the following sections, we'll explore the range of tastes that have been shown to be of benefit in sport and exercise to date, emerging tastes and the potential for placebo effects (and maximising them), concluding with a short checklist of which taste to administer and when to do so. It is important to emphasise that these supporting strategies can be easily personalised, and sports nutrition practitioners are encouraged to work closely with athletes and other support staff to achieve performance outcomes (Figure 1).

A Bitter taste in the mouth: Caffeine and Quinine

Bitter tastes have been shown to stimulate areas of the brain associated with motor and emotion processing[1], namely the anterior cingulate cortex, amygdala and striatum[2], providing a neural underpinning for improved sports performance. The most notable bitter tastant, and arguably most well researched sports nutrition aid, is caffeine. Pickering[3] recently questioned whether caffeine's bitter taste may be attributable to some of its ergogenic effects. Indeed, enhancements in repeated power and self-paced endurance performance are noted following caffeine swilling, similarly cognitive function and resistance to mental fatigue are also shown to improve, but exhaustive endurance tasks across a range of modalities derive no benefit[1]. This suggests that caffeine's bitterness may drive psychophysiological improvements when applied locally to the mouth, but ingestion may be required to extend the duration of these benefits to match typical endurance performance durations[1,3].

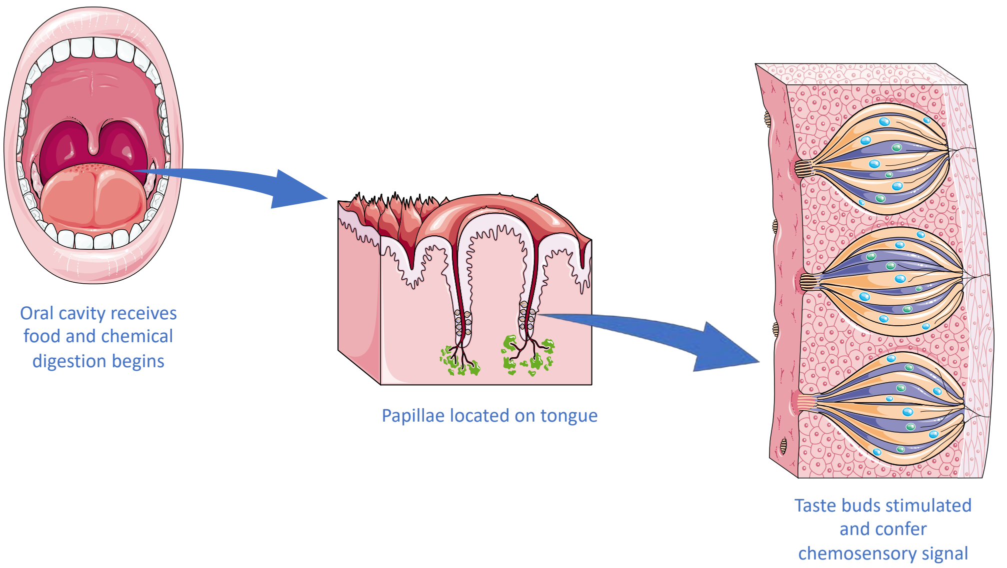


Figure 1: A recap of taste – foodstuffs, beverages or targeted tastants are applied to the oral cavity, and chemical and mechanical digestion being. Papillae increase surface area of the tongue, intensifying tastants and increasing potential likelihood of tastant: taste bud interaction. Taste buds are housed in papillae and are stimulated by tastants; upon stimulation they confer a chemosensory signal e.g. flavour, intensity, temperature, etc. Adults typically possess 2000 – 4000 taste buds, and these are renewed approximately weekly. It is important to consider that taste is not just confined to the tongue, and that people who have lost their sense of taste, may also be able to experience some of these tastes and their downstream effects, albeit differently from normal tasters.

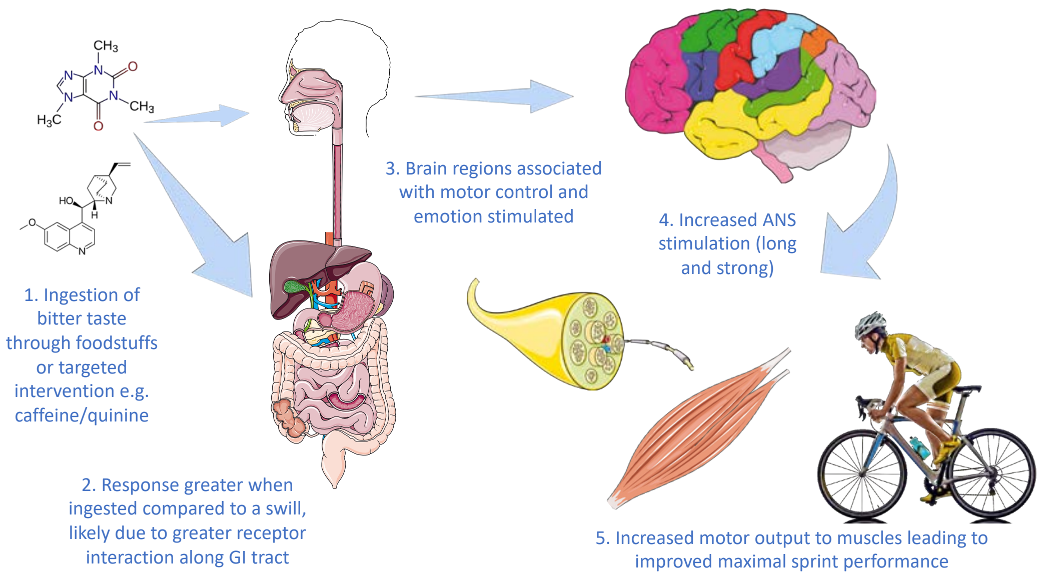


Figure 2: An overview of bitter tastants and their effects. Please note point 2, that ingestion is required for bitter tastants to be most effective and in point 4 autonomic nervous system (ANS) stimulation has been noted to be longest and strongest following bitter tastants, in comparison to sweet, sour or salty tastes[3].

Quinine, the tastant responsible for tonic water's distinctive flavour, has been shown to improve performance in a collection of studies by Gam and colleagues[4–6]. Enhancements in average power output of 2.4% during a 30-sec maximal cycle were seen when quinine was swilled and ingested at a low concentration (2 mM), but not when quinine was only swilled at a higher concentration (10 mM). It should be noted that these concentrations may elicit nausea in some participants.

This suggests that stimulating solely oral bitter receptors may not surpass a currently undetermined receptor threshold required to confer a meaningful effect upon performance, independent of bitterness intensity/ solution concentration. Hence, due to the location and density of bitter taste receptors along the gastrointestinal tract, ingestion of quinine solutions is likely required to improve performance. Outside of these works, there is relative paucity of studies employing bitter tastants, so further investigation is encouraged, especially in the areas of strength and power activities (Figure 2).

Sweet taste of success: Carbohydrate

Carbohydrate mouth rinsing emerged as a strategy to improve performance in the early 2000's following seminal work by James Carter and Asker Jeukendrup[7]. This work, which demonstrated improvements in 1-hr cycling performance, led to the notion that some of carbohydrate's ergogenic effects are mediated by central pathways, stimulating areas of the brain associated with reward and energy availability. Stimulation of these areas is thought to enhance motivation and central drive, and thus improve power on the pedals. This has not only been shown to improve endurance performance, but may also contribute to preservation of exercise intensity in repeated sprint protocols too[8].

Given the likely interaction between feelings of energy availability and carbohydrate swilling, it is interesting and important to note that these effects may be more pronounced when undertaking fasted exercise. This has implications for the athlete and practitioner, and points to a periodised and targeted approach to carbohydrate swilling across the training cycle.

Of further interest are the differential effects seen when non-sweet carbohydrates

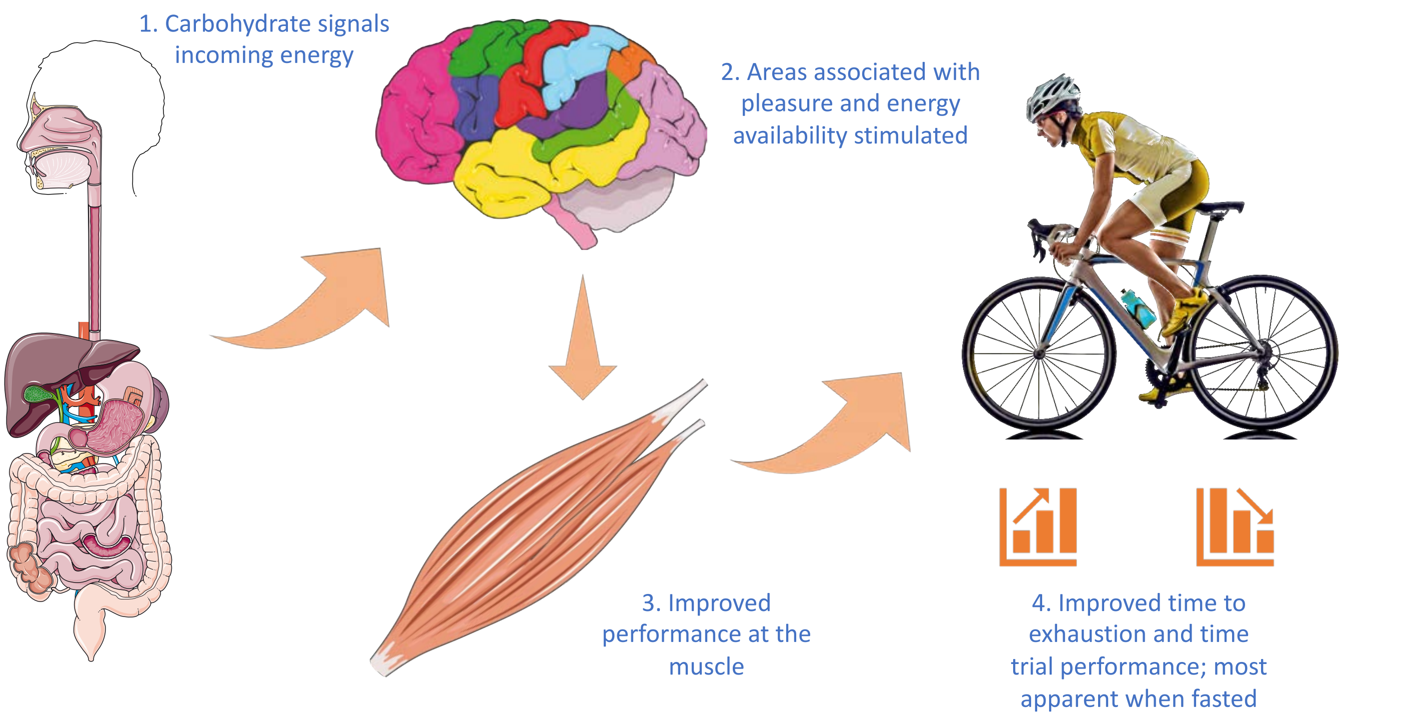


Figure 3: An overview of carbohydrate tastes and their stimulatory and performance enhancing effects.

and artificial sweeteners are compared. Non-sweet carbohydrates appear to improve performance and stimulate similar brain regions to the same extent as sweet tasting carbohydrates, when swilled. However, artificial sweeteners provide comparatively lower levels of brain stimulation, than their carbohydrate containing counterparts. This points to the potential for unidentified carbohydrate receptors within the oral cavity[9], and further supports the evolutionary perspective that a function of taste, is to simply confer energy availability and prime one's system for its imminent ingestion (Figure 3).

Feeling hot: Capsaicin

The hot sensation we experience when eating chilli comes from capsaicin stimulating transient receptor potential vanilloid-1 proteins (TRPV1). TRPV1 are also stimulated during hot temperatures (>35°C), hence capsaicin containing foods feel and taste hot[10]. This perceptual heat extends to topical application; most sports medics will be familiar with warming topical ointments, patches and sprays as targeted analgesic treatments.

Four studies have investigated capsaicin's ergogenic properties via ingestion or mouth swilling. Three of these studies employed a consistent dose and timing (12mg administered 45-minutes pre-performance), and assessed 1500m running performance, four sets of 70% 1RM repeated squats to failure, and time to exhaustion during a repeated sprint protocol 15 second at velocity equating to 120% $VO2_{Peak}$ with 15-second recoveries. Capsaicin supplementation improved performance by 1.1 %, 23.2 % and 14.0 % compared to placebo, respectively. Concomitant significant reductions in RPE were also seen, alluding to capsaicin's analgesic effect. Increased endurance may also be a product of increased lipolysis and or increased calcium release at the sarcoplasmic reticulum by TRP-V1 stimulation.

These promising results suggests that ingesting capsaicin may be ergogenic across a range of sporting scenarios. However, when capsaicin is consumed in foods, the potential side effects may outweigh its ergogenic potential. TRPV1 receptors are found along the entire digestive tract, thus the possibility of gastrointestinal discomfort is increased following capsaicin induced stimulation of these receptors, in doses from as low as 1mg. Opheim & Rankin's[11] participants reported gastrointestinal symptoms increased 6.3 times compared to placebo and resulted in the withdrawal of three participants, thus capsaicin induced GI discomfort may even impair performance.

Two possible solutions exist at present, firstly as proposed by Gibson et al.,[12], a capsaicin mouth swill may directly target TRPV1 receptors but bypass the gut, hopefully alleviating symptoms. Whilst this strategy did not improve repeated sprint performance, it did not worsen it either, and interestingly did not worsen sensations of thermal sensation or comfort. Secondly, capsiate, a non-pungent analogue of capsaicin, has also been shown to stimulate TRPV1 receptors and elicit similar biological effects to capsaicin in humans and rodent models, but notably does not confer a warming sensation. Further work on capsiate is required to confirm its ergogenic potential in sports, but like carbohydrate swilling, it may be the stimulation of targeted receptors that is of importance, as opposed to taste, when it comes to running faster, lifting more, or lasting longer.

Fresh perspective: Menthol

Menthol is familiar for its minty flavour, feeling and tasting cool, and almost ubiquitous in everyday oral hygiene products, confectionary etc. Menthol achieves the cooling part of its flavour profile via stimulating transient receptor melastatin 8 (TRP-M8) receptors, this mimics a cold temperature range of 8-28°C, and so reduces thermal sensation (how hot am I?) and improves thermal comfort (how comfortable am I in the heat?). These effects are particularly powerful when menthol is swilled or ingested because menthol's effects are greater when skin is thinner, hence lower concentrations can be used than when applying menthol to the skin[13]. Of further relevance to sport, is that TRP-M8 activity can be increased with airflow. Whilst this can be engineered in the laboratory through manipulating wind-speed and air density, it is likely that this is of greater importance when applying menthol in the field, as athletes typically experience faster wind and performance velocities.

To date menthol's effects upon intermittent and time to exhaustion cycling, as well as running time trial performance have been assessed in hot conditions (all >30°C). Intermittent performance did not improve, however time to exhaustion and time trial performance showed trivial-moderate improvements (Hedge's g: 0.40; 0.04 – 0.76[14]) following menthol mouth swilling. As mentioned above, improvements in thermal comfort and thermal sensation were reported across these studies, with an increase in ventilation also commonly seen.

Despite menthol's ability to impart subjective improvements, no changes in body temperature have been reported to date when menthol is applied exclusively. Physiological cooling strategies such as ice slurries may make an effective partner to menthol's subjective cooling effects, but anecdotally there is an increased risk for "brain freeze" in some individuals, which obviously detracts from performance. An emerging secondary effect of menthol use is its ability to reduce thirst, however the potential importance of this to improve or impair performance is unknown; highlighting that menthol should be applied to sport cautiously[15], especially if water intake is limited due to event demands e.g. ultramarathon, or in athletes with high sweat rates (Figure 4).

The future of food engineering?

Whilst we have focused upon those tastes with a somewhat established body of research, there are emerging tastes that also may prove ergogenic in the future.

Salt (NaCl) solutions are commonly used to desensitise the mouth prior to dental procedures, suggesting that their administration prior to exercise may confer an analgesic effect too. Preliminary work has shown that repeatedly swilling a 6% salt solution during a 30min cycle, preserved maximal voluntary contractile ability in comparison to a water only control[16] – these effects were comparable to glucose swilling. Extrapolating these findings hints at a potential alternative swill either for athletes who don't have a sweet tooth, or later in events when flavour fatigue may occur.

Pickle juice has also been shown to affect the central nervous system when taken during exercise, reportedly having anti-cramping effects[17]. This evidence is preliminary, but has strong anecdotal backing from endurance athletes and supporting practitioners that warrants further exploration. Pickle juice also represents the first strategy that could be described as a 'composite taste', incorporating elements of acid, bitter, sweet and warmth. Teasing out the ergogenic effects attributable to each taste would

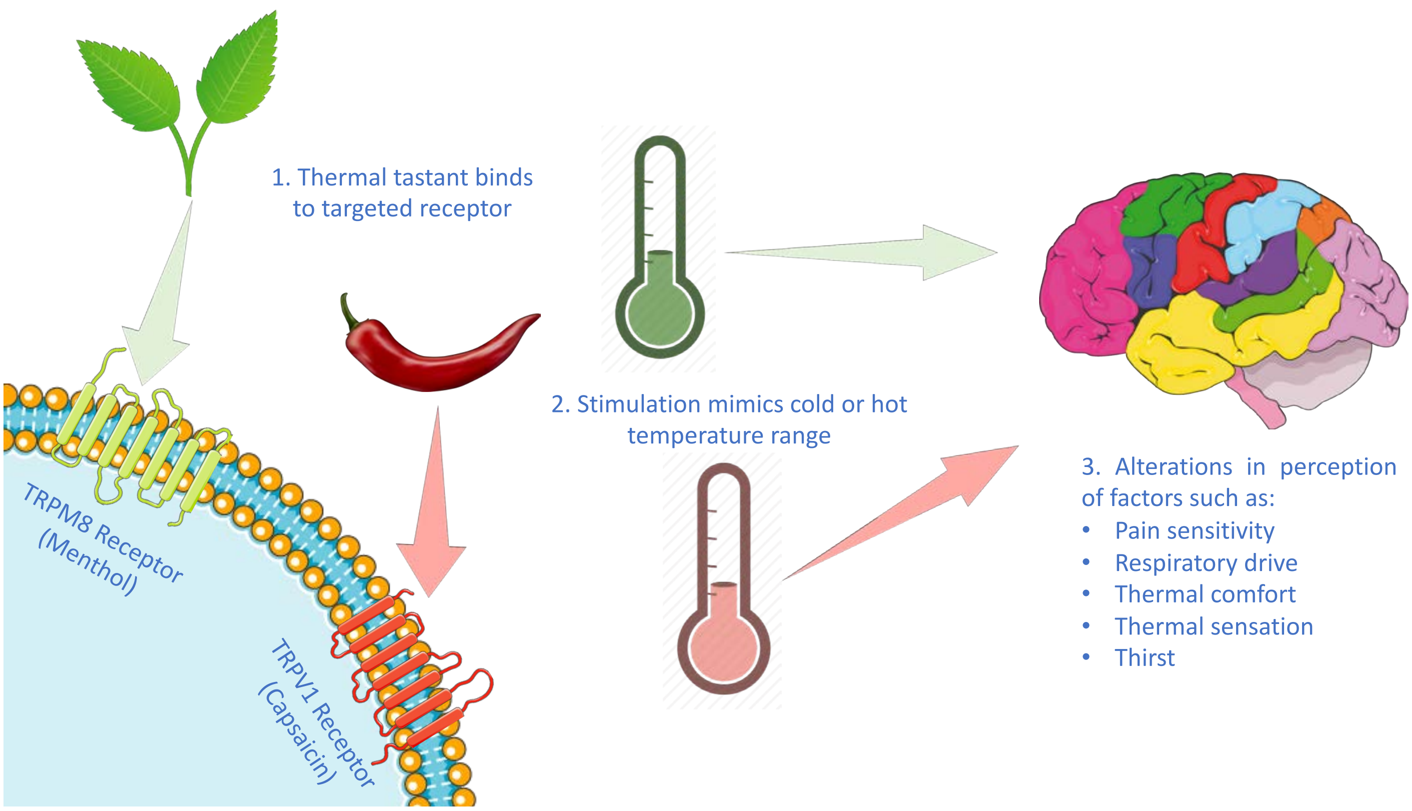
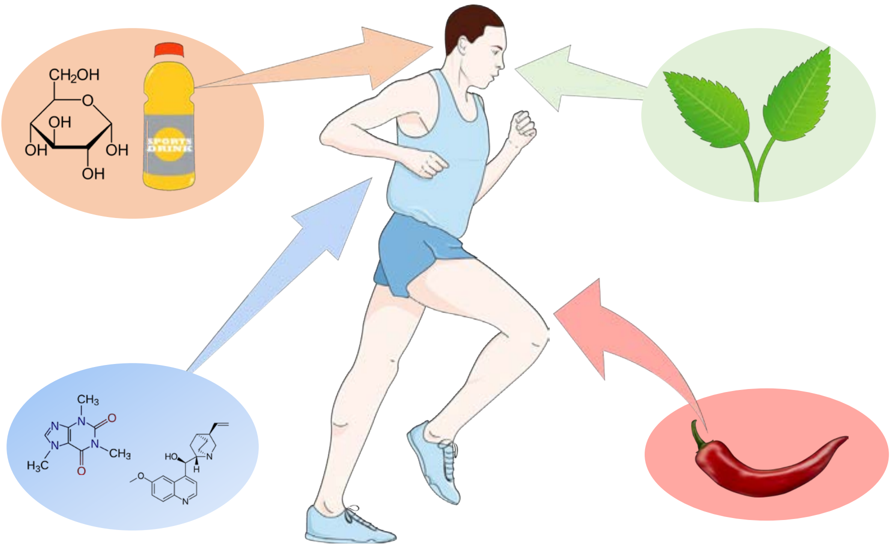
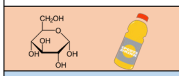
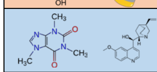


Figure 4: Thermal tastants and their potential perceptual effects. Note that these tastes are probably the best demonstration we have within taste of evolutionary economy, whereby a thermal taste can infer similar responses to that of real changes in temperature/thermal strain and the accompanying perceptual responses too. The reader is also reminded that when these chemical compounds (menthol and capsaicin) are applied topically, we see similar perceptual responses to those listed here, but differing physiological responses. Readers are directed to references (x) and (y), for menthol and capsaicin, respectively.



Tastant	Strength	Power	Repeated Sprint	Endurance
	✗	✓	✓	✓
 *	✓	✓	✓	✓
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 *	✓	✓	✗	✗

* Ingestion may be required to see beneficial effects from these tastants

Carbohydrate – range of activities where glycogen availability may limit performance; consideration of an athlete's nutritional status and purpose(s) of training session(s) is required.

Bitter tastes – power type activities of a short duration; anhydrous caffeine or quinine may not always be available to athletes, so products containing these ingredients whilst retaining bitterness should be considered.

Menthol – short to moderate endurance events, ~15 - 60 minutes long, especially in the heat. Hydration needs of the athlete also need to be considered, as does pairing with other cooling strategies.

Capsaicin – short duration, anaerobic and aerobic power events ≤ 5 minutes long. It is recommended that this be ingested in a capsule as opposed to real food form to avoid GI distress and performance impairment

Figure 5: Overview of main tastants detailed in the present article.

be a substantial undertaking, but it is encouraging that real foodstuffs, that are readily available and affordable to many may prove mechanistically beneficial to performance.

Even established sports nutrition strategies may improve performance by mechanisms indirectly related to taste. Beetroot juice, a source of dietary nitrate, which has been shown to improve endurance performance via the nitrate ? nitrite ? nitric oxide pathway, is activated via enzymes in the oral cavity[18]. Furthermore, interindividual differences in response to beetroot juice supplementation may partially be explained by the oral microbiome of those consuming it[18]. Not only is the oral microbiome altered by dietary nitrate consumption, but the physiological response to it also correlates to microbial abundance. This presents an exciting avenue for the future intersection of 'omics', taste research and sports science.

Placebo: a potential problem or performance enhancer?

Placebo effects are a common topic of discussion in sports science literature and practice, but whilst experimentally they should be controlled for, in practice they may enhance performance by similar magnitudes to nutritional or mechanical strategies ($d = 0.35 – 0.47$;[19]) and so present another strategy in the applied sports scientist's toolbox.

Placebo effects have been attributed to a range of psychological and physiological mechanisms but in the context of sports performance, it may be the psychosocial relationship between athletes, practitioners and the environment in which a strategy is implemented that manifest in improved performance[1]. These effects may be further enhanced through manipulation of strategy-specific factors such as colour[20], dose, form and language used to describe the strategy[19].

Extending upon these interactions, taste may confer a placebo effect either by manipulating perceptions of resource allocation, or affecting the endogenous opioid system. As evidenced above, carbohydrate solutions may impart sensations of fuel availability and thus direct resources in favour of a greater energy output, whereas capsaicin or salt may confer analgesic effects. This is not to say that these responses are entirely the result of a placebo effect, but that the placebo effect may be partly responsible, and likely responds to similar neurobiological pathways, that are being stimulated by these tastants[1].

Which taste, when?

Much like matching wine and food, the evidence points to pairing specific tastes with certain sporting scenarios, but individual preference will trump evidence if these tastants are not administered in a manner that is practical and/ or tolerable and is meaningful to the athlete and their performance. The potential for deleterious gastrointestinal side effects when most tastants are improperly administered is likely due to an overstimulation of pertinent receptors, so thorough trials in key training sessions are warranted. In the field, where winning matters more than the smallest worthwhile change, placebo effects may also be maximised with a view to further enhancing these strategies. In summary, the following taste and activity pairings provide a starting point:

- Bitter tastes – power type activities of a short duration; anhydrous caffeine or quinine may not always be available to athletes, so products containing these ingredients whilst retaining bitterness should be considered.
- Carbohydrate – range of activities where glycogen availability may limit performance; consideration of an athlete's nutritional status and purpose(s) of training session(s) is required.
- Capsaicin – short duration, anaerobic and aerobic power events ≤ 5 minutes long. It is recommended that this be ingested in a capsule as opposed to real food form to avoid GI distress and performance impairment.
- Menthol – short to moderate endurance events, ~15 - 60 minutes long, especially in the heat. Hydration needs of the athlete also need to be considered, as does pairing with other cooling strategies (Figure 5).

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