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Mouth Rinsing and Ingestion of Unpleasant Salty or Bitter Solutions Does Not Improve Cycling Sprint Performance in Trained Cyclists

Edward A. Gray,[1,2] Rocco Cavaleri,[1,2] and Jason C. Siegler[1,3]

[1]School of Health Sciences, Western Sydney University, Campbelltown, Australia; [2]Brain Stimulation and Rehabilitation (BrainStAR) Lab, School of Health Sciences, Western Sydney University, Campbelltown, Australia; [3]College of Health Solutions, Arizona State University, Phoenix, AZ, USA

The purpose of this study was to investigate the influence of mouth rinsing and ingesting unpleasant salty or bitter solutions on cycling sprint performance and knee extensor force characteristics. Eleven male and one female trained cyclists (age: 34 ± 9 years, maximal oxygen uptake 56.9 ± 3.9 ml·kg^{-1}·min^{-1}) completed a ramp test and familiarization followed by four experimental trials. In each trial, participants completed an all-out 30-s cycling sprint with knee extensor maximal voluntary contractions before and immediately after the sprint. In a randomized, counterbalanced, cross-over order, the four main trials were: a no solution control condition, water, salty (5.8%), or bitter (2 mM quinine) solutions that were mouth rinsed (10 s) and ingested immediately before the cycling sprint. There were no significant differences between conditions in mean power (mean ± *SD*, no solution: 822 ± 115 W, water: 818 ± 108 W, salt: 832 ± 111 W, bitter: 818 ± 105 W); peak power (no solution: 1,184 ± 205 W, water: 1,177 ± 207 W, salt: 1,195 ± 210 W, bitter: 1,184 ± 209 W); or fatigue index (no solution: 51.5% ± 5.7%, water: 50.8% ± 7.0%, salt: 51.1% ± 5.9%, bitter: 51.2% ± 7.1%) during the sprint. Maximal force and impulse declined postexercise; however, there were no significant differences between conditions in knee extensor force characteristics. The present data do not support the use of unpleasant salty or bitter solutions as an ergogenic aid to improve sprint exercise performance.

Keywords: quinine, tastant, maximal voluntary contraction, power output

The importance of an athlete's nutrition to support exercise performance is well recognized (Thomas et al., 2016). In general, nutrients must be ingested, digested, and metabolized to have a benefit for an athlete. However, tasting certain nutrients, even without ingestion, can also have a positive effect on exercise performance (Best et al., 2021). Tasting menthol, caffeine, carbohydrate, salt, and quinine have all been identified as having the potential to influence performance (Best et al., 2021).

Quinine, an unpleasant bitter compound, was first investigated in an exercise performance context when it was shown that mouth rinsing and ingesting a 2-mM quinine solution improved 30-s cycling sprint mean power output by ~4% compared with control conditions (Gam et al., 2014). The solution was ingested as many of the bitter taste-sensing Type 2 receptors, part of a family of G protein-coupled receptors (Hoon et al., 1999), may only be activated upon swallowing, as they are located on the posterior tongue and upper gastrointestinal tract (Behrens et al., 2007). Indeed, these same authors have shown that mouth rinsing quinine without ingestion does not influence 30-s cycling sprint performance (Gam, Tan, et al., 2015). The mechanisms via which tasting quinine may influence exercise performance are ambiguous. Tasting quinine evokes an autonomic nervous system response (Gam et al., 2014; Rousmans, 2000) that may influence exercise by increasing heart and breathing rate, and by altering muscle fiber contractility (Roatta & Farina, 2010). Interestingly, the autonomic nervous system response to tasting quinine may be attributable to its unpleasantness (Rousmans, 2000), highlighting that other unpleasant tastes may also influence exercise performance. In addition to the autonomic nervous system disturbance, it was initially found that tasting quinine increased corticomotor excitability and; therefore, enhanced motor output (Gam, Guelfi, et al., 2015). However, the motor-evoked potential changes were observed in the upper limb, which may not be relevant to whole-body exercise. Indeed, we recently found that tasting quinine, or a similarly unpleasant salt solution, did not influence knee extensor corticomotor excitability or neuromuscular function (Gray et al., 2023a).

Despite initial research showing ingesting quinine to improve 30-s cycling sprint performance (Gam et al., 2014), the ergogenic effect of tasting a bitter solution has not been observed since. Etxebarria et al. found that ingesting quinine at the start (Etxebarria et al., 2019) or during the latter stages (Etxebarria et al., 2021) of a 3-km cycling time trial did not influence overall performance. Furthermore, we recently found tasting unpleasant salty or bitter solutions did not influence 1-min cycling sprint performance after 45 min of heavy-intensity cycling, suggesting the unpleasant tastes have no effect on cycling performance when fatigued (Gray et al., 2023b). Therefore, in addition to the equivocal mechanisms, the performance effects of tasting quinine, or other unpleasant tastes, are unclear. Thus, the purpose of the present study was to investigate the influence of tasting unpleasant bitter or salty solutions on 30-s cycling sprint performance and knee extensor force characteristics. The experiment was designed to be similar to the original research demonstrating ingesting quinine improves 30-s cycling sprint performance (Gam et al., 2014). Due to our previous work, we hypothesized that the unpleasant salty or bitter solutions would not improve cycling sprint performance or knee extensor force production.

Methods

All data collection occurred at Western Sydney University in November and December 2022. One female and 11 male trained

Cavaleri https://orcid.org/0000-0001-9499-1703
Siegler https://orcid.org/0000-0003-1346-4982
Gray (edwardandrew@live.co.uk) is corresponding author, https://orcid.org/0000-0003-2274-2147

cyclists (Tier 2; McKay et al., 2022) completed the present study (mean ± *SD*, age: 34 ± 9 years, height: 1.79 ± 0.04 m, weight: 77.7 ± 8.6 kg, maximal oxygen uptake [VO_2max]: 56.9 ± 3.9 ml·kg^{-1}·min^{-1}). Two further male cyclists began the study; however, they contracted COVID-19 during data collection and; therefore, did not finish the study. Participants were recruited from local cycling clubs using social media with the inclusion criteria: self-identifies as trained cyclist for >1 year, injury-free >3 months, VO_2max > 50 ml·kg^{-1}·min^{-1}, and age >18 and <50 years old, not reporting any gustatory disorders. Participants visited the laboratory on five occasions. During the first visit to the laboratory, participants performed a VO_2max ramp test followed by familiarization to the experimental procedures. Subsequently, participants completed four main trials consisting of a 30-s all-out cycling sprint with assessment of knee extensor force characteristics immediately before and after the sprint using maximal voluntary contractions (MVCs). The independent variable for the main trials was a no solution control or water, salt, or bitter solutions that were mouth rinsed (10 s) and ingested immediately before the cycling sprint. All trials were conducted within a randomized (performed using www.calculator.net/random-number-generator), counterbalanced, cross-over design. All experimental procedures were conducted in accordance with the Declaration of Helsinki after approval by Western Sydney University Human Research Ethics Committee (H14902).

Preliminary Testing

Participants' first visit to the laboratory began with a ramp test on a stationary cycling ergometer (Wahoo KICKR Bike, Wahoo). The ramp test began at 100 W (60 W for females) and increased by 1 W every 3 s until volitional exhaustion. Expired gas was measured using a breath-by-breath analyzer (Quark, COSMED). VO_2max was calculated as the highest 30-s average VO_2 throughout the test. Once the participants had recovered from the ramp test (~10 min), they were familiarized with the knee extensor MVCs. This entailed coaching of best practice throughout at least four MVCs. Following this, participants were familiarized with the all-out 30-s cycling sprint. The sprint was performed on a Wattbike Pro (Wattbike) using a fixed fan resistance determined in consultation with the researcher and after a 10-s practice sprint. Immediately following the 30-s sprint, participants performed two further knee extensor MVCs to replicate the procedure during the main trials.

Experimental Trials

In the 24 hr before each main trial, participants abstained from moderate/high-intensity exercise and were asked to record a food and training diary. The 24-hr food and training diary was then replicated before each subsequent trial. To standardize nutritional status between participants, no food or drink (other than water) was permitted in the 3 hr before the visit. Experimental trials were separated by at least 2 days and were conducted at the same time of day for each participant.

All experimental trials began with a 10-min warm-up at 40% of the ramp test end power output using the Wattbike Pro. During the warm-up at Minutes 6 and 8, participants stopped pedaling and performed a 3- to 5-s maximal standing-start sprint. Following the cycling warm-up, participants completed two knee extensor MVCs (see knee extensor force section) with 1-min rest between contractions. Five minutes after the cycling warm-up, participants began the 30-s all-out sprint. Immediately before the sprint, participants mouth rinsed (10 s) and ingested the relevant test solution, or in the case of the no solution condition, were informed of the countdown time. The sprint began from a standing start at a fixed fan resistance. Participants were instructed to perform the sprint in an all-out manner, without pacing, so that every pedal stroke was as powerful as possible. To help achieve this, participants were blinded to all data during the sprint and strong verbal encouragement was provided throughout. To ensure parity between conditions, the verbal encouragement was predetermined and standardized to specific timepoints during the sprint. To further encourage maximal effort, participants could win $700 AUD in vouchers for having the highest 30-s mean power averaged across the four main trials. Power output was measured continuously enabling calculation of mean power, 0- to 15-s mean power, 15- to 30-s mean power, and peak power. Peak/lowest power was determined as the highest/lowest 5-s averaged power output. Fatigue index was then calculated as Fatigue index = (peak power − low power)/peak power (Coppin et al., 2012).

As soon as possible after the sprint (~30 s), participants completed two MVCs with 1-min rest between contractions. After the postexercise MVCs, participants rated their perceived exertion during the sprint using the Borg 6–20 rating of perceived exertion scale (Borg, 1982). Participants also rated the hedonic value of the solution and their holistic nausea (i.e., a combination of the solution and the sprint) using 10-cm visual analog scales anchored by the labels "*Highly Pleasant* (0 cm), *Highly Unpleasant* (10 cm)" and "*No Nausea* (0 cm), *Extreme Nausea* (10 cm)," respectively.

Intervention Conditions

All 25-ml solutions were served at room temperature in identical containers. The salt condition was a 1 M (5.8%) salt solution (Table Salt; Coles), a concentration determined from a pilot study from our previous research (Gray et al., 2023a). The bitter condition was a 2 mM quinine hydrochloride dihydrate solution (Sigma Aldrich) to replicate the concentration used in prior research (Etxebarria et al., 2019, 2021; Gam et al., 2014; Gam, Guelfi, et al., 2015). The no solution and water (25 ml) conditions were controls for the unpleasant salty and bitter solutions.

The independent variable in the present experiment was taste. Consequently, participants could not be blinded to condition. To reduce the influence of any placebo/nocebo effects, participants were not informed which condition they were receiving until ~15 s before the beginning of the sprint when they first tasted the solution. Furthermore, to try to determine the existence of any placebo/nocebo effects, we provided participants a questionnaire prior to beginning the experiment to determine their perceptions about how the different conditions might influence exercise performance. This approach does not remove any placebo/nocebo effects; however, it does allow the extent of these effects within our sample to be estimated.

Knee Extensor Force Production

Knee extensor force characteristics were assessed using MVCs. Participants were seated on a purpose-built chair with hip and knee angles of 90°. The ankle was restrained using a thinly padded cuff tightly secured above the malleoli. The cuff was connected to a force transducer sampling at 4000 Hz (Powerlab; AD Instruments). Participants were instructed to contract their knee extensors as hard and as fast as possible for a duration of ~2 s. To increase reliability, two MVCs were conducted, both before the sprint, and postexercise and the mean of the two was calculated. The cuff remained

attached to the participant during the cycling sprint to enable the postexercise MVC to occur as soon as possible upon completion of the sprint.

For each MVC, measures of maximum force and impulse were assessed. Impulses for 0–100 ms and 100–200 ms from contraction onset were calculated using the trapezium rule. The onset of contraction was determined as the baseline force being exceeded by 5 N. Conducting two MVCs preexercise enabled the reliability of the technique within our lab to be assessed within and between trials. Maximum force had good reliability demonstrated by within-trial coefficient of variation (CV) of 2.7% and a between-trial CV of 4.4%, similar to previous reliability work (Place et al., 2007; Todd et al., 2004). Impulse of 0–100 ms and 100–200 ms had within-trial CVs of 11.6% and 5.8% and between-trial CVs of 14.8% and 8.6%, respectively, which is similar to previous reliability work (Courel-Ibáñez et al., 2020).

Data Analysis

A sensitivity analysis was conducted post hoc showing that for our sample ($n = 12$), we could detect effect sizes (ES) >0.88 with 80% statistical power and $\alpha = .05$. This magnitude of ES is comparable to previous work finding ES of 0.81–0.85 for 30-s mean power output between quinine ingestion and control conditions (Gam et al., 2014).

All data were analyzed using SPSS Statistics. Due to rating of perceived exertion being ordinal data, differences between conditions were assessed using a Friedman test. 30-s sprint performance variables, hedonic value, and nausea data were analyzed using a one-way repeated-measures analysis of variance. Impulse variables and maximal force were analyzed using a repeated-measures analysis of variance with factors "time" (preexercise and postexercise) and "condition" (no solution, water, salt, and bitter). Mauchly's test of sphericity was used to assess sphericity, and following this, Greenhouse–Geisser adjustment was conducted when appropriate. Following a significant main effect for the analysis of variance, post hoc analyses were conducted using Bonferroni-adjusted multiple comparison tests. Data are presented as mean change (Δ) ±95% confidence interval (CI) alongside Cohen's *d* ES.

Results

Sprint Performance

There was no significant difference between conditions in mean power (Figure 1) [$F(3, 33) = 1.89$, $p = .15$, $\eta^2 = .15$], peak power [$F(3, 33) = 0.88$, $p = .46$, $\eta^2 = .07$], 0- to 15-s power [$F(3, 33) = 1.81$, $p = .17$, $\eta^2 = .14$], 15- to 30-s power [$F(3, 33) = 1.06$, $p = .38$, $\eta^2 = .09$], or fatigue index [$F(3, 33) = 0.18$, $p = .91$, $\eta^2 = .02$]. All data are shown in Table 1.

There were no trial-order effects in peak power [$F(3, 33) = 2.24$, $p = .10$, $\eta^2 = .17$], or fatigue index [$F(3, 33) = 1.24$, $p = .31$, $\eta^2 = .10$]. However, there was a significant effect of order on mean power output [$F(3, 33) = 3.59$, $p = .02$, $\eta^2 = .25$]. Post hoc tests showed no differences between Trials 1, 2, and 3 ($p > .05$). However, mean power output in Trial 4 was significantly higher (2.6%) than in Trial 1 ($p = .04$, mean Δ ± 95% CI: 20 ± 19 W, ES = 0.18).

Knee Extensor Force

There was a significant effect of time for maximum force production [$F(1, 11) = 13.90$, $p = .003$, $\eta^2 = .56$], with maximum force being 14% lower postexercise ($p = .003$, mean Δ ± 95% CI: −102 ± 60 N, ES = 0.70). However, there were no significant effects of condition (Table 2) [$F(3, 33) = 1.80$, $p = .17$, $\eta^2 = .14$], or Time × Condition interaction [$F(3, 33) = 0.22$, $p = .88$, $\eta^2 = .02$], for maximum force.

There was a significant effect of time for 0- to 100-ms [$F(1, 11) = 8.12$, $p = .02$, $\eta^2 = .43$], impulse and 100- to 200-ms impulse [$F(1, 11) = 11.64$, $p = .006$, $\eta^2 = .51$]. Specifically, 0–100 ms declined 17% postexercise ($p = .02$, mean Δ ± 95% CI: −4.5 ± 3.5 Ns, ES = 0.55) and 100- to 200-ms impulse declined 18% ($p = .006$, mean Δ ± 95% CI: −9.2 ± 5.9 Ns, ES = 0.89). However, there

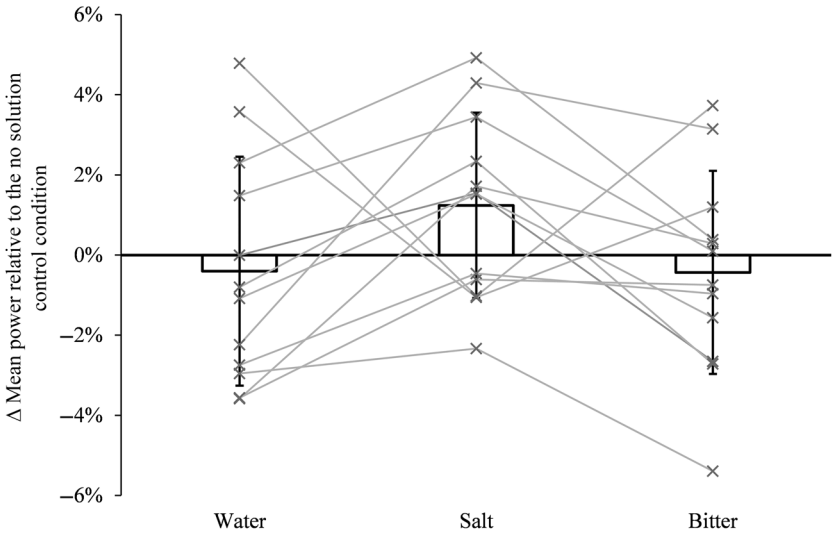

Figure 1 — Percentage change in mean power output during the 30-s maximal cycling sprint relative to the no solution control condition after mouth rinsing (10 s) and ingesting water, salt, or bitter solutions. Bars show mean ± *SD* with lines and crosses displaying individual responses for 12 trained cyclists.

Table 1 Performance Variables for the Maximal 30-s Cycling Sprint After a No Solution Control Condition or Mouth Rinsing (10 s), and Ingesting Water, Salt, or Bitter Solutions

	Control	Water	Salt	Bitter
Mean power (W)	822 ± 115	818 ± 108	832 ± 111	818 ± 105
Mean change vs. control (%)		–0.4 ± 2.9	1.2 ± 2.3	–0.4 ± 2.5
Peak power (W)	1,184 ± 205	1,177 ± 207	1,195 ± 210	1,184 ± 209
Mean change vs. control (%)		–0.7 ± 3.8	0.8 ± 2.8	–0.2 ± 2.8
0- to 15-s power (W)	998 ± 152	991 ± 147	1,008 ± 153	990 ± 145
Mean change vs. control (%)		–0.7 ± 2.7	1.0 ± 2.3	–0.8 ± 2.9
15- to 30-s power (W)	647 ± 83	646 ± 78	655 ± 75	646 ± 75
Mean change vs. control (%)		–0.1 ± 4.2	1.5 ± 3.2	–0.1 ± 3.6
Fatigue index (%)	51.5 ± 5.7	50.8 ± 7.0	51.1 ± 5.9	51.2 ± 7.1
Mean change vs. control (%)		–2.0 ± 6.9	–1.1 ± 5.4	–1.1 ± 6.2

Note. Data presented as mean ± *SD* for 12 trained cyclists.

Table 2 Knee Extensor Force Characteristics Pre and Immediately Post the Maximal 30-s Cycling Sprint After a No Solution Control Condition or Mouth Rinsing (10 s) and Ingesting Water, Salt, or Bitter Solutions

	Control	Water	Salt	Bitter
Maximal force preexercise (N)	727 ± 196	739 ± 189	713 ± 170	739 ± 139
Maximum force postexercise (N)	624 ± 114	636 ± 103	617 ± 100	634 ± 108
0- to 100-ms impulse preexercise (Ns)	25.7 ± 11.1	26.2 ± 6.8	26.0 ± 9.2	27.8 ± 9.1
0- to 100-ms impulse postexercise (Ns)	20.9 ± 8.9	23.7 ± 4.9	20.8 ± 7.7	22.2 ± 7.8
100- to 200-ms impulse preexercise (Ns)	50.0 ± 14.9	53.4 ± 12.6	50.9 ± 11.7	53.6 ± 13.7
100- to 200-ms impulse postexercise (Ns)	41.6 ± 6.4	45.0 ± 5.0	41.5 ± 8.0	43.0 ± 8.1

Note. Data presented as mean ± *SD* for 12 trained cyclists.

was no significant effect of condition for 0- to 100-ms impulse (Table 2) [$F(3, 33) = 20.77$, $p = .41$, $\eta^2 = .08$], or 100- to 200-ms impulse (Table 2) [$F(3, 33) = 63.03$, $p = .06$, $\eta^2 = .20$]. In addition, there were no significant Time × Condition interactions for 0- to 100-ms impulse [$F(3, 33) = 11.73$, $p = .44$, $\eta^2 = .08$], or 100- to 200-ms impulse [$F(3, 33) = 7.16$, $p = .65$, $\eta^2 = .05$].

Perceptual Variables

In the preexperiment perceptual questionnaire when participants were asked "Do you think any of the tastes will influence (either positively or negatively) muscle strength or cycling sprint performance?", 4/12 participants selected "I don't know" and 4/12 selected "No." Of the 4/12 participants who selected "Yes," all four thought the salt solution would improve performance while three of the four thought the bitter would impair performance.

There was a significant effect of condition on hedonic value (Table 3) [$F(2, 22) = 47.4$, $p < .001$, $\eta^2 = .81$]. Hedonic value was significantly higher (i.e., more unpleasant) in the salt and bitter conditions compared with water (salt: $p < .001$, mean Δ ± 95% CI: 53% ± 22%, ES = 3.02; bitter: $p < .001$, mean Δ ± 95% CI: 63% ± 20%, ES = 3.27). However, there was no significant difference in hedonic value between the salt and bitter solutions ($p = .22$, mean Δ ± 95% CI: 11% ± 11%, ES = 0.72).

There was no significant difference in nausea between conditions (Table 3) [$F(1.67, 18.33) = 3.23$, $p = .07$, $\eta^2 = .23$]. There was also no significant difference in rating of perceived exertion between conditions (Table 3) [$\chi^2(3) = 1.67$, $p = .64$].

Table 3 Perceptual Variables Measured After the 30-s Maximal Cycling Sprint After a No Solution Control Condition or Mouth Rinsing (10 s) and Ingesting Water, Salt, or Bitter Solutions

	Control	Water	Salt	Bitter
Solution hedonic value (%)	—	20 ± 21**	72 ± 12*	83 ± 17*
Nausea (%)	16 ± 17	14 ± 21	17 ± 18	30 ± 30
RPE	20 (2)	20 (1)	20 (2)	20 (3)

Note. Solution hedonic value and nausea are presented as mean ± *SD*. RPE is presented as median (range). Data are shown for 12 trained cyclists. RPE = rating of perceived exertion.
*Significantly different to water. **Significantly different to salt and bitter conditions.

Discussion

Previous research has shown that mouth rinsing and ingesting the bitter compound quinine can enhance cycling sprint performance (Gam et al., 2014). The mechanisms that may explain the ergogenic effect of tasting quinine are suggested to be due to increases in autonomic nervous system activation (Gam et al., 2014, 2016),

driven by the compounds' unpleasantness, and/or increases in corticomotor excitability facilitating enhanced motor output (Gam, Guelfi, et al., 2015). However, the proposed neural mechanisms are ambiguous as we recently found that mouth rinsing and ingesting unpleasant bitter or salt solutions had no effect on knee extensor neuromuscular function or corticomotor excitability (Gray et al., 2023a). Furthermore, multiple studies have found tasting quinine to have no influence on short-duration exercise performance (Etxebarria et al., 2019, 2021). Supporting the latter research, the present study finds mouth rinsing and ingesting a quinine or salt solution to have no influence on 30-s cycling sprint performance compared with water or no solution control conditions. Furthermore, the unpleasant salty and bitter solutions had no influence on knee extensor maximal force production or impulse.

We designed the present experiment to closely replicate the initial research showing a positive effect of tasting quinine on cycling sprint performance (Gam et al., 2014). This work found ingesting a 2-mM quinine solution to increase mean power (3.9% vs. water and 3.9% vs. control) and peak power (3.7% vs. water and 3.5% vs. control) during a maximal 30-s cycling sprint (Gam et al., 2014). The present study had a similar cohort of trained cyclists compared with the previous research (present study vs. Gam et al., 2014; age: 34 vs. 30 years; weight: 78 vs. 77 kg; VO_2max: 56.9 vs. 61.9 ml·kg^{-1}·min^{-1}; 30-s mean power: 822 vs. 894 W; 30-s peak power: 1,185 vs. 1,263 W). In both studies, a 2-mM quinine solution was mouth rinsed (10 s) and ingested before participants undertook an all-out 30-s cycling sprint. However, different from the previous work, we found that the quinine solution had no influence on mean power (Figure 1; –0.1% vs. water and –0.4% vs. control) or peak power (0.4% vs. water and –0.2% vs. control) during the cycling sprint. Furthermore, the salt solution had no effect on mean or peak power, despite a similar unpleasantness and autonomic nervous system response to the bitter condition (Gray et al., 2023a).

A notable difference between the present study and that of Gam et al. is the fasted/fed state of participants prior to undertaking the cycling sprint. In the present study, participants had no food or drink other than water for 3 hr before exercise, whereas in Gam's research, participants began exercise after an overnight fast (Gam et al., 2014). We chose to conduct the sprint in a fed state to ensure ecological validity; however, it is possible that the response to tasting quinine was somewhat diminished due to participants not being fasted. For example, the ergogenic effect carbohydrate mouth rinsing has on endurance exercise performance is greater when participants are fasted versus fed (Ataide-Silva et al., 2016; Fares & Kayser, 2011; Lane et al., 2013). The reduced effect of carbohydrate mouth rinsing in the fed state is likely due to a reduction in the activation of brain regions involved with emotional processing when individuals are satiated (Rolls et al., 2010). However, this phenomenon, known as sensory-specific satiety, only occurs with repeated detection of the same taste, and therefore, when a new taste is introduced, a reduction in neuronal activity is not observed (Rolls et al., 1986). Consequently, because the present study used highly unpleasant salty and bitter solutions, it is unlikely that taste-induced changes in brain activation were diminished as a result of sensory-specific satiety. Indeed, for sensory-specific satiety to occur, the participants would have needed to have tasted and/or consumed similar unpleasant compounds in their habitual diet. Nevertheless, differences in prandial state should not be discounted as the explanation for the divergent outcomes in sprint performance between the present study and Gam et al. (2014) without further research directly comparing the influence of prandial state on the ergogenic effect of bitter tastes.

The mechanisms via which tasting quinine, or other unpleasant tastes may influence exercise performance are unclear. It was initially suggested that the ergogenic effect is attributable to activation of the autonomic nervous system (Gam et al., 2014, 2016) and/or increases in corticomotor excitability (measured in the upper limb at rest) facilitating enhanced motor output (Gam, Guelfi, et al., 2015). However, lower limb muscles have more motor units that are driven by larger alpha motor neurons with higher activation thresholds (Kesar et al., 2018). Therefore, it is possible that the effect of tasting quinine on corticomotor excitability that was previously observed in the upper limb (Gam, Guelfi, et al., 2015) would be reduced if measured in the lower limb muscles, the latter being more relevant to most exercise contexts. Indeed, we recently found that unpleasant salty or bitter tastes have no influence on knee extensor corticomotor excitability or neuromuscular function in a nonfatigued state (Gray et al., 2023a). Mouth rinsing a salty solution has been shown to ameliorate neuromuscular fatigue (Khong et al., 2020); however, we have found unpleasant salty and bitter tastes to have no influence on knee extensor force characteristics in a fatigued state (Gray et al., 2023b). Supporting the latter work, in the present study, the salty or bitter solutions had no influence on knee extensor maximal force or impulse measured with MVCs immediately post the 30-s cycling sprint.

Like other ergogenic aids, the effect taste may have on exercise performance is likely a combination of "true" effect and placebo effect (Best et al., 2021). Discriminating between "true" and placebo effects is challenging when participants cannot be blinded to condition due to the independent variable being taste. Therefore, in the present study to acknowledge the presence of any placebo/nocebo effects, before the experimental trials began, we asked participants how/whether they thought the different tastes may influence exercise performance. This questionnaire revealed that most participants (8/12) did not think that the unpleasant salty or bitter tastes would positively or negatively influence exercise performance. This suggests placebo/nocebo effects did not influence the majority of our sample. However, 4/12 participants thought the salt solution would improve performance and 3/12 participants thought the bitter would impair performance. Nevertheless, for the three participants who may have experienced nocebo effects in the bitter condition, changes in 30-s mean power output relative to the no solution control condition were the same between these three participants (–0.4%) and the other nine participants (–0.4%). Similarly, relative change in performance in the salt condition versus the no solution was of a similar magnitude between the four participants who may have experienced placebo effects (1.8%) and the other eight participants (0.9%). These differences between participants who were, and were not, potentially placebo/nocebo influenced are much lower than the CV for mean power output (1.7%). Consequently, the null effect of salty or bitter tastes on cycling sprint performance appears to have been minimally influenced by placebo/nocebo effects.

The present study was not without limitation. Despite a thorough familiarization to the full experimental procedure, a small trial-order effect was detected for mean power output between Trial 1 and Trial 4 (ES = 0.18). The influence this small order effect had on the experimental outcomes, however, is minimal due to appropriate counterbalancing of the condition order. For example, participants had high reliability between the water and no solution condition demonstrated by a low CV for mean power (1.7%) and peak power (1.9%). Another potential limitation is the loss of taste induced by COVID-19 (Boscolo-Rizzo et al., 2022; Tan et al.,

2022) dampening any influence of taste on exercise. To control for this, participants who were knowingly experiencing gustatory disorders, such as those caused by COVID-19, were excluded from the study. Indeed, suggesting normal gustatory function, participants rated the salty and bitter solutions as highly unpleasant (72% and 83% hedonic value, respectively), which is very similar to the hedonic value ratings of the same solutions (71% salt and 80% bitter) in our previous work conducted prior to the high prevalence of COVID-19 in Australia (Gray et al., 2023a). However, it cannot be ruled out that some participants may have experienced changes in taste perception after COVID-19 that could have diminished any performance-enhancing effect of the unpleasant tastes.

In conclusion, the present data show that mouth rinsing and ingesting unpleasant salty or bitter solutions have no influence on 30-s cycling sprint performance. Furthermore, the unpleasant tastes had no effect on knee extensor force characteristics measured postexercise. These results do not support that tasting quinine, or other unpleasant solutions, should be used as an ergogenic aid for sprint exercise performance.

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