Ingesting a Bitter Solution: The Sweet Touch to Increasing Short-Term Cycling Performance

Naroa Etxebarria, Megan L. Ross, Brad Clark, and Louise M. Burke

Purpose: The authors investigated the potential benefit of ingesting 2 mM of quinine (bitter tastant) on a 3000-m cycling time-trial (TT) performance. Methods: Nine well-trained male cyclists (maximal aerobic power: 386 [38] W) performed a maximal incremental cycling ergometer test, three 3000-m familiarization TTs, and four 3000-m intervention TTs (~4 min) on consecutive days. The 4 interventions were (1) 25 mL of placebo, (2) a 25-mL sweet solution, and (3) and (4) repeat 25 mL of 2-mM quinine solutions (Bitter1 and Bitter2), 30 s before each trial. Participants self-selected their gears and were only aware of distance covered. Results: Overall mean power output for the full 3000 m was similar for all 4 conditions: placebo, 348 [45] W; sweet, 355 [47] W; Bitter1, 354 [47] W; and Bitter2, 355 [48] W. However, quinine administration in Bitter1 and Bitter2 increased power output during the first kilometer by 15 ± 11 W and 21 ± 10 W (mean ± 90% confidence limits), respectively, over placebo, followed by a decay of 34 ± 32 W during Bitter1 and the second kilometer. Bitter2 also induced a 11 ± 13-W increase during the first kilometer compared with the sweet condition. Conclusions: Ingesting 2 mM of quinine can improve cycling performance during the first one-third of a 3000-m TT and could be used for sporting events lasting ~80 s to potentially improve overall performance.

Keywords: tastants, sport, exercise, sprint, power output

A recent addition to the range of acute nutrition strategies that can be undertaken on competition day to enhance sport performance is the intake of certain dietary components and tastants to exploit the sensory outcomes that are achieved by exposing receptors in the mouth and gastrointestinal tract to these ingredients.1 This new area of sport nutrition, typically known as “mouth rinsing,” emerged from observations of the performance benefits of carbohydrate (CHO) intake during shorter (~1 h) protocols of sustained higher-intensity exercise. During these shorter protocols, CHO was unlikely to play its typical metabolic role of addressing fuel limitations in the muscle.2 Once it was established that these benefits only occurred when CHO was placed in the oral space,2 rather than being infused directly into the bloodstream,3 a new branch of research on interactions between oral receptors to CHO and the central nervous system was springboarded. There is now robust evidence that the exposure (5–10 s) of these receptors to CHO activates areas in the brain that control perceptions of effort and pacing decisions. This activation creates a cascade of events that signal energy provision and enhance exercise capacity and performance.1 These benefits are specific to CHO rather than sweetness and can be repeatedly exploited during sporting protocols involving ~1 h maximal sustained or intermittent exercise.1 This has led to the further investigation of other nutrients, food chemicals, and tastants that might have sensory-driven effects of value to sports performance. Positive outcomes have already been identified for the gut sensing of caffeine, fluid, acetic acid, menthol, and quinine.1

Quinine, a bitter tasting solution originating from the bark of the cinchona tree, has been shown to enhance capacity for short-term maximal cycling performance by 2.5% to 4%.4 The activation of bitter taste receptors in the oral cavity and upper gastrointestinal tract appears to increase corticomotor excitability5 and, in turn, improve cycling efforts requiring maximal effort. However, unlike the case for CHO mouth rinsing, the quinine solution needs to be ingested for it to prove effective,6 as the specific receptors are concentrated in the back of the mouth and throat. Furthermore, current evidence of efficacy is limited to a 30-second maximal cycling effort. Although these data are of interest to track cyclists, it is unknown if the findings are transferrable to events of longer duration. Therefore, the aim of this study was to quantify the effects of 2-mM quinine ingestion prior to a 3000-m maximal cycling TT. This protocol was chosen, as we anticipated a duration of approximately 4 minutes in highly trained cyclists to mirror the competition times of elite track endurance cyclists in the 4000-m individual pursuit (world record of 4:07.251 for male cyclists).

Methods

Subjects
Nine well-trained male participants were recruited for the study (body mass: 78 [11] kg; height: 181 [7] cm; age: 36 [8] y; and maximal aerobic power, MAP: 386 [38] W). Participants had a cycling training history of at least 3 years and completed a pre-participation screening questionnaire to ensure they were injury-free and healthy before participating in the study.

Study Design
We implemented a randomized counterbalanced single-group design to evaluate the effects of quinine (Bitter1 and Bitter2), water (Placebo), and a sweet drink (Sweet). We duplicated the quinine intervention to test the reliability of its effects. The study
was approved by the Committee for Ethics in Human Research at the University of Canberra and according to the Helsinki Declaration. All participants provided their written informed consent before participating.

Methodology

**Pretrial Standardization.** A standardized pretrial meal was provided to participants before all trials (familiarization and intervention) to minimize variation in macronutrient availability prior to exercise. The meal was consumed 2 hours prior to the trial, provided 2 g-CHO·kg·BM⁻¹ and consisted of raisin toast, margarine, honey, jam, banana, a 250-mL liquid breakfast, and confectionary, with the combination and amount of the foods being individually adjusted to the body mass of the participants.

**Exercise Protocol.** Participants performed a maximal incremental test, three 3000-m familiarization time trials (TT), and four 3000-m experimental TT involving 4 different interventions over the course of 7 separate visits to the laboratory. During the first visit, participants completed a 10-minute warm-up at 100 W followed by a 3-minute break prior to the start of a maximal, progressive incremental test on a cycle ergometer (starting at 100 W with 5 W increments every 15 s until volitional fatigue). The power output of the last minute of the test was then averaged to estimate the participants’ maximal aerobic power (MAP). After a brief 5-minute cool down and 30-minute rest, the cyclists remounted the cycle ergometer and commenced their first familiarization 3000-m TT.

The 3 familiarization trials mimicked exactly the subsequent 4 intervention trials and they were undertaken to help the cyclists understand the protocol the cycle ergometer and the instructions provided before each TT. These familiarization trials also enabled us to reduce the effect of any potential learning effect on subsequent experimental trials. Similar trials have been shown to reduce the coefficient of variation from 1.2% between the first 2 familiarization trials to 0.2% with subsequent familiarization trials. The exercise protocol for all seven 3000-m TT completed during the study commenced with a 10-minute incremental (submaximal) warm-up consisting of the following: 4 minutes at 50% of their MAP, 3 minutes at 60% MAP, 2 minutes at 70% MAP, and 1 minute at 80% MAP. At the end of the warm-up, participants were instructed to stop pedaling but remain seated on the cycle ergometer for 2.5 minutes, after which they were given a solution (Placebo for all familiarization trials and the randomized treatment during the intervention trials) to swirl in their oral cavity for 10 seconds before ingesting it. During the 20 seconds after ingesting the solution and prior to the commencement of the 3000-m TT, the principal researcher read out TT instructions followed by the final countdown for the start of the TT. The instruction was “This is a maximal performance trial, you should give your best effort you have on the day, each and every day. You are free to change gears during the TT as you see fit and can adopt your own pacing strategy.”

All TTs were performed on a Velotron Dynafit Pro (RacerMate Inc, Seattle, WA) cycle ergometer (validity ±1.5%; reliability <0.2%), which was paired with the associated Velotron 3D software. Participants were able to view their progress along the course on a large television screen that also showed distance covered; however, they were blinded to power output, cadence, and any other feedback. The cycle ergometer was checked against the Australian Institute of Sport’s dynamic calibration rig before testing, and the Velotron CS AccuWatt verification function (RacerMate Inc) was used between tests to ensure power output measurement was within factory calibration. Participants could self-select their gear at the start of each trial and were free to change them during the TT as they saw fit. Power output (W), cadence in revolutions per minute (rpm), and heart rate (HR) in beats per minute (bpm) were monitored continuously during all trials. The position on the cycle ergometer for all cyclists was standardized between tests. Rating of perceived exertion (RPE) was recorded at the end of each trial scale (6–20 units).

Pacing Index was calculated to represent the percentage of power output sustained for each 150-m split in relation to the entire 3000-m TT. This index, or similar ones related to cycling velocity, have been previously used to reflect the relative effort for each split in relation to the entire effort in various studies.

Pacing Index = (power output for each 150-m split × 100/overall power output for 3000-m TT) − 100

**Intervention Solutions.** The 4 treatments, administered in a randomized and counterbalanced manner, 30 seconds prior to the TT commencement, were (1) 25 mL of Placebo (water), (2) a 25-mL diet cordial (Cottee’s; Schweppes, Melbourne, Australia) solution (Sweet), and (3) and (4) repeat administration of 25 mL of 2-mM quinine solution (Quinine Hydrochloride Dehydrate, S1125; Sigma-Aldrich Pty Ltd, Castle Hills, Australia), named Bitter1 and Bitter2. As it was impossible to disguise the taste of the quinine to provide a true blinded Placebo, we used the sweet solution as a distraction to the real purpose of the investigation. At the time of conducting the study, the subjects were unaware of the hypotheses regarding mouth rinsing with bitter tastants but were knowledgeable about the benefits of CHO rinsing. We used a concentrated sweetened diet cordial with the same color as the 2 bitter solutions and free of CHO in view that the mouth-rinsing benefit is achieved by CHO rather than sweetness per se.

Statistical Analysis

Descriptive data are presented as mean (SD). All raw and derived data were collated, checked for outliers, and corrected for any errors. All data was log-transformed, then back-transformed to obtain changes in means and variation as a percent. A crossover group analysis was employed to estimate the mean difference between interventions. Data modeling involved estimation of the true unknown difference between the 4 interventions and interval estimates of the uncertainty about the value of these parameters. Within- and between-participant variability in power output for each intervention are reported as the percent coefficient of variation. The magnitude of change between the standardized means (effect size) was interpreted against the following criteria: ≤0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; and >2.0, very large. Precision of estimation was determined using 90% confidence limits (CL). When the magnitude of the standardized effect crossed the threshold of a small positive and small negative (±0.2), the change or difference was deemed unclear.

Results

**Power Output**

There was no substantial ergogenic effect of quinine on overall 3000-m TT cycling performance as the mean power output for all 4 conditions was similar: Placebo, 348 (45) W; Sweet, 355 (47) W; Bitter1, 354 (47) W; and Bitter2, 355 (48) W. However, quinine administration increased power output during the first kilometer by
respectively). The familiarization trials served their purpose to decrease performance variability and remove any learning effect on 3000-m TT performance, with a 4.5% increase in power output from performance variability and remove any learning effect on 3000-m TT performance, with a 4.5% increase in power output from familiarization trial 1 to 2 and only a 1% increase in power output from familiarization trial 2 to 3 (334–349 W and 349–353 W, respectively).

**Pacing**

Power output for every 150-m split of the TT shows that the effects of quinine were most noticeable between 450 and 900 m, with both Bitter conditions showing an increase of 18 to 30 W ± 10 to 19 W (mean difference ± 90% CL) compared with Placebo (Figure 1) and an increase of 12 to 20 W ± 12 to 17 W during Bitter2 compared with Sweet (Figure 2). The Bitter1 condition also induced a 12 ± 10 W increase in power output compared with the Sweet condition. There were no significant differences between any of the conditions during the last 1000 m. The Pacing Index calculated for each of the 150-m splits for all interventions shows a similar trend to the pacing described as power output (Figure 3).

**Cadence, Heart Rate, and Perceived Exertion**

The mean cadence sustained for the entirety of the 3000 m during all 4 interventions was similar: Placebo, 107 (6) rpm; Sweet, 108 (6) rpm; Bitter1, 108 (6) rpm; and Bitter2, 108 (8) rpm. The cadence was also comparable during the first, second, and third kilometer of the TT.

The mean heart rate for all 4 interventions was similar: Placebo, 164 (9) bpm; Sweet, 168 (11) bpm; Bitter1, 166 (12) bpm; and Bitter2, 168 (9) bpm. The answer to the question ‘how much of yourself did you give?’ for each one of the conditions were also similar: Placebo, 95%; Sweet, 94%; Bitter1, 96%; and Bitter2, 95%. There were mainly unclear differences between the interventions in regard to the RPE given large uncertainty, with a small difference in RPE after Bitter2 (19 ± 1) condition compared with Placebo (18 ± 2; mean difference ±90% CL). The RPE of Bitter1 intervention was rated 19 (2) and the Sweet intervention was rated 17 (4).

**Discussion**

The primary aim of this investigation was to examine the effect of ingesting a bitter solution on 3000-m cycling performance. Although the bitter solution (quinine) did not improve overall 3000-m TT performance, power output was higher in the initial third of the TT and particularly during the 40 to 80 seconds after quinine ingestion. However, the increased physiological cost of higher power output during the initial third may have led to an observed reduction in power output through the middle section (second kilometer) of the TT compared with Sweet and Placebo trials such that any potential performance benefits conferred by the initial increase in power output were diminished.

This study supports the concept that quinine ingestion increases short-term (30 s) power output, although the ergogenic benefits from it lasted even longer for up to 80 seconds. However, it is also plausible that while the body generates superior power output as a consequence of quinine ingestion, it consequently struggles with the physiological consequences of this higher intensity causing downregulation of the pacing strategy straight after. As the last third of all TT are similar, the steeper decline in power output during the second kilometer after quinine ingestion subsided by the third kilometer. Therefore, it is possible that athletes can use

| Table 1 Standardized Differences ± 90% CL for Power Output (W) Between Interventions for the 3000-m Time Trial and the First, Second, and Third Kilometers of the 3000-m Time Trial |
|-----------------|-----------------|-----------------|-----------------|
| 3000-m time trial | First kilometer | Second kilometer | Third kilometer |
| Bitter1 – Placebo | -0.10 ± 0.16    | -0.25 ± 0.19    | 0.27 ± 0.41     | 0.01 ± 0.21     |
| 6 ± 8            | 15 ± 11         | 11 ± 17         | Small           | 1 ± 14          |
| Trivial           |                |                |                | Trivial         |
| Bitter2 – Placebo | 0.15 ± 0.16     | -0.39 ± 0.17    | -0.25 ± 0.54    | -0.04 ± 0.19    |
| -7 ± 8           | 21 ± 10         | 13 ± 27         | -2 ± 11         | Trivial         |
| Trivial           |                |                |                | Trivial         |
| Bitter1 – Sweet  | 0.04 ± 0.21     | -0.09 ± 0.16    | 0.45 ± 0.40     | 0.05 ± 0.23     |
| 2 ± 11           | 5 ± 8           | 19 ± 16         | -2 ± 15         | Trivial         |
| Trivial           |                |                |                | Trivial         |
| Bitter2 – Sweet  | 0.00 ± 0.22     | -0.22 ± 0.25    | -0.10 ± 0.61    | -0.09 ± 0.18    |
| 0 ± 11           | 11 ± 13         | 6 ± 30          | -5 ± 11         | Trivial         |
| Trivial           |                |                |                | Trivial         |
| Bitter1 – Bitter2| 0.04 ± 0.10     | 0.12 ± 0.23     | 0.57 ± 0.77     | -0.03 ± 0.13    |
| 7 ± 5            | 7 ± 11          | 25 ± 32         | 3 ± 9           | Trivial         |
| Trivial           |                |                |                | Trivial         |
| Sweet – Placebo  | -0.14 ± 0.15    | 0.18 ± 0.28     | 0.17 ± 0.27     | -0.04 ± 0.14    |
| 7 ± 7            | 10 ± 14         | 8 ± 12          | 3 ± 8           | Trivial         |
| Trivial           |                |                |                | Trivial         |

Abbreviations: CL, confidence limits; ES, effect size. Note: Standardized differences ± 90% CL, mean power output ± 90% CL, and ES as specified. The values in bold show a substantial or meaningful difference.

---

Quinine’s Improvement of the Start of a 3-km Cycling TT 729

Brought to you by AUSTRALIAN CATHOLIC UNIVERSITY | Downloaded 07/18/19 12:01 AM UTC
quinine ingestion as a training strategy to produce higher power output or speeds and subsequent greater metabolic adaptations that evoke enhanced overall performances.

In our study, we saw the greatest effect of quinine during the 450 to 900 m section (∼40 to 80 s), which is approximately 1 minute after ingesting the solution. This observation might be related to the timing of the ingestion of the bitter solution, and future work might look into this. Regardless, the first kilometer (∼80 s) of the TT generated substantially higher power output in both quinine interventions compared with the Placebo intervention. Nevertheless, the differences between the quinine interventions and the Sweet condition with 0% CHO were not as robust. There is evidence that exercise performance is improved after ingesting nonsweet CHO such as maltodextrin, suggesting that it is not the sweetness of the solution that triggers a response, but it is CHO specific. It is known that CHO induces a taste transduction pathway that responds to CHO independently of those for sweetness.13–17 Perhaps the Sweet condition managed to have a Placebo effect to a certain extent; however, the quinine conditions proved to have a higher positive impact during the early stages of the TT.

The consistency in cadence during the 4 interventions suggests that the cyclists were highly skilled at finding the cadence at which they are most comfortable. Despite the 150- to 200-W difference in power output during the lead position (550–600 W), and following the lead in second, third, or fourth positions (350–400 W), riders kept a narrow range in cadence.18 In this study, participants were
free to change gears to accommodate a higher or lower capacity to produce power output throughout the TT during any given intervention, which is not the case in track cycling where they perform at a fixed gear.

**Practical Applications**

The ability to sustain high power outputs for relatively short periods of time is a crucial asset in many sports, including a 4-km TT. Using the example of the pursuit TT in track cycling, the pacing strategy of a rider who is completing the effort solo (less variability in power output throughout the event) is quite different to that performed as part of a team. In this study, it is apparent that quinine administration would potentially benefit the lead-off rider of a team pursuit at the start of the event rather than the riders competing in the individual pursuit. The lead-off rider in the team pursuit is required to lead the team from a static start to high speeds and produce a power output that is 30% to 35% higher than the teammates following. This extra effort required is as a consequence of the given drag he/she faces being positioned at the front and the benefit of a drafting effect obtained by the other 3 cyclists. It is important to remember that this study focuses on individual performance for the entire TT; however, the team pursuit has other characteristics that were not necessarily reproduced in this study. For example, once the lead rider has set up the pace and moves toward the back of the group, power output demands decrease. The rider in first position could ingest the bitter solution for the first kilometer, without being affected by the consequent decrease in power output as the demands also decrease in that situation.

It is worth considering the possible applications of quinine ingestion in the different sporting events and contexts. For example, given the greater decay in power output observed during the second kilometer after quinine ingestion, it might be more appropriate to ingest quinine toward the end of an event rather than at the beginning (ie, 800-m track and field, 2000-m rowing race). The use of any ergogenic aid is always context specific, and different individuals may not respond the same way either. Thus, it is always important to keep in mind that quinine ingestion should be trialed with the individual athlete in training first before testing it in competition. Furthermore, the mode of ingestion of quinine in its fluid form used in this study might not suit many sporting environments, and other routes of ingestion (ie, lozenge or gum) may need further consideration.

**Conclusions**

Despite a similar overall performance for the 3000-m TT for all 4 interventions, the difference in the pacing strategy freely implemented by the participants indicates that quinine ingestion has the potential to improve team pursuit in track cycling, especially during the early stages of the lead-off rider.

**Acknowledgments**

The authors would like to thank Jason Bartram, Cycling Australia; Hamilton Lee, Australian Institute of Sport; and Olivia Warnes, Cycling Australia, for their contribution to the development of the study design and the pretrial nutritional standardization process.

**References**


