Section: Original Investigation

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

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Title: Ingesting a bitter solution: The sweet touch to increasing short-term cycling performance.

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ABSTRACT

Purpose: We investigated the potential benefit of ingesting 2 mM of quinine (bitter tastant) on 3000 m cycling time-trial (TT) performance. ***Methods:*** Nine well-trained male cyclists (maximal aerobic power 386 ± 38 W; mean ± SD) performed a maximal incremental cycling ergometer test, three 3000 m familiarization TT and four 3000 m intervention TT (~4 min) on consecutive days. The four 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 seconds prior to 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 four conditions: Placebo, 348 ± 45 W (mean ± SD); 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 km 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 Bitter2 during the 2nd km. Bitter2 also induced a 11 ± 13 W increase during the 1st km compared with the Sweet condition. ***Conclusions:*** Ingesting 2 mM of quinine can improve cycling performance during the first 1/3 of a 3000 m TT and could be used for sporting events lasting ~80 s in order to potentially improve overall performance.

Key words: Tastants, sport, exercise, sprint, power output.

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INTRODUCTION

A recent addition to the range of acute nutrition strategies that can be undertaken on competition day to enhance sports 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 sports nutrition, typically known as "mouth rinsing', emerged from observations of the performance benefits of carbohydrate (CHO) intake during shorter (~1 hour) 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 spring-boarded. 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 hour 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 2.5-4%.[4] The activation of bitter taste receptors in the oral cavity and upper gastrointestinal tract appears to increase corticomotor excitability,[5] 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] since the specific receptors are concentrated in the back of the mouth and throat. Furthermore, current evidence of efficacy is limited to a 30 s 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 since we anticipated a duration of approximately four 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 (BM: 78 ± 11 kg; height: 181 ± 7 cm; age: 36 ± 8 y and maximal aerobic power: 386 ± 38 W; mean ± SD). Participants had a cycling training history of at least three 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 counter-balanced single-group design to evaluate the effects of quinine (Bitter 1 and Bitter 2), 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

Pre-trial standardization

A standardized pre-trial meal was provided to participants before all trials (familiarization and intervention) to minimize variation in macronutrient availability prior to exercise. The meal was consumed two hours prior to the trial, provided two grams CHO.kg^{-1} BM and consisted of raisin toast, margarine, honey, jam, banana, 250 ml liquid breakfast and confectionary, with 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 experimental 3000 m TT involving four different interventions over the course of seven separate visits to the laboratory. During the first visit, participants completed a 10-minute warm up at 100 W followed by a three-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 seconds 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 five-minute cool down and 30 minutes rest, the cyclists remounted the cycle ergometer and commenced their first familiarization 3000 m TT.

The three familiarization trials mimicked exactly the subsequent four 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 (CV) from 1.2% between the first two familiarization trials to 0.2% with subsequent familiarization trials.[7] 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: four minutes at 50% of their MAP, three minutes at 60% MAP, two minutes at 70% MAP and one minute at 80% MAP.[8] At the end of the warm up, participants were instructed to stop pedaling but remain seated on the cycle ergometer for 2.5minutes, 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^{R} Dynafit Pro (RacerMate Inc, USA) cycle ergometer (validity ± 1.5%; reliability <0.2%), which was paired with associated Velotron 3D software. Participants were able to view their progress along the course on a large television screen which 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[9] before testing and the Velotron CS AccuWatt verification function (RacerMate Inc, USA) 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 time trials 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 or Perceived Exertion (RPE) was recorded at the end of each trial scale (6-20 units).

Pacing Index (PI) 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.[10]

*Pacing Index = (power output for each 150 m split *100 / overall power output for 3000 m TT)-100.*[11]

Intervention solutions

The four 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 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, Australia), named Bitter1 and Bitter2. Since 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 carbohydrate rinsing. We used a concentrated sweetened diet cordial with the same color as the two bitter solutions and free of carbohydrates in view that the mouth rinsing benefit is achieved by carbohydrate rather than sweetness per se.[1]

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.[12] A crossover group analysis was employed to estimate the mean difference between interventions. Data modeling involved estimation of the true unknown difference between the four 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 per cent coefficient of variation (% CV). The magnitude of change between the standardized means (ES) was interpreted against the following criteria: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 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 four conditions was similar: Placebo, 348 ± 45 W; Sweet, 355 ± 47 W; Bitter1, 354 ± 47 W; and Bitter2, 355 ± 48 W (mean ± SD). However, quinine administration increased power output during the first km by ~ 18 ± 4 W (mean difference ± 90% CL) over the Placebo intervention, and by ~8 ± 4 W compared with the Sweet intervention, followed by a steep decay in power output of 25-43 W during the second km (Table 1). The Sweet and Placebo conditions had a smaller decay in power output in the second km (20 W and 17 W respectively). The power output during the third km was similar between conditions: Placebo, 358 ± 61 W; Sweet, 361 ± 64 W; Bitter1 358 ± 69 W; and Bitter2, 355 ± 63 W (mean ± SD).

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 familiarization trial 1 to 2 and only a 1% increase in power output from familiarization trial two to three (334 W to 349 W and 349 W to 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 – 900 m with both Bitter conditions showing an increase of 18-30 ± 10-19 W (mean difference ± 90% CL) compared with Placebo (Figure 1) and an increase of 12-20 ± 12-17 W during Bitter2 compared to 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, HR and perceived exertion

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

The mean HR (bpm) for all four interventions was similar: Placebo, 164 ± 9 bpm; Sweet, 168 ± 11 bpm; Bitter1, 166 ± 12 bpm; and Bitter2, 168 ± 9 bpm (mean ± SD). 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 (mean ± SD).

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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 40-80 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 (2nd km) 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 seconds) 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 2nd km after quinine ingestion subsided by the 3rd km. Therefore, it is possible that athletes can use quinine ingestion as a training strategy to produce higher power output or speeds and subsequent greater metabolic adaptations that evoke enhanced overall performances.

The overall performance of the _ENREF_23000 m TT from well trained cyclists observed in this study was completed in □4 min, which is similar to the duration of 4 km team pursuit event at the elite level (WR, 3:50.265). We wanted to match the duration of the maximal effort in this study to the effort elite level athletes sustain in this event to transfer the outcomes to a competitive elite situation. After observing for the first time, that the effects of quinine might last longer than the 30 s previously recorded in the literature [10], there is likely a wider range of sporting events for which quinine ingestion might improve exercise performance. In

our study, we observed the greatest effect of quinine during the second 500 m (□40-80 s) of the TT, although the first whole km (80 s) of the TT generated substantially higher power output in both quinine interventions compared with the water intervention. This difference was not as clear when comparing the quinine interventions to the sweet drink. There is evidence that carbohydrates may activate taste transduction pathways that respond to carbohydrate independently of those for sweetness[17,18], and therefore non-nutritive sweeteners may not trigger a positive response to exercise. However, sweet taste receptors do activate the dorsolateral prefrontal cortex that [19]believed to reflect an engagement in cognitive and attentional processing induced by taste input.

In our study, we saw the greatest effect of quinine during the 450-900 m section (~40-80 seconds), 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 km (~80 seconds) 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% carbohydrate were not as robust. There is evidence that exercise performance is improved after ingesting non-sweet carbohydrates such as maltodextrin, suggesting that it is not the sweetness of the solution that triggers a response, but carbohydrate specific. It is known that carbohydrates induce a taste transduction pathway that respond to carbohydrate independently of those for sweetness.[13,14] However, 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 four interventions suggests that the cyclists were highly skilled at finding the cadence at which they are most comfortable. Despite the difference in power output during the lead position (550-600W) and following the lead in second, third or

fourth position (350-400W), riders keep a narrow range in cadence.[15] In this study, participants were free to change gears to accommodate for 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 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 30-35% higher than the teammates following.[16] 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 three cyclists.[17,18] 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 towards the back of the group, power output demands decrease.[19] The rider in first position could ingest the bitter solution for the first km, 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 km after quinine ingestion, it might be more appropriate to ingest quinine

towards the end of an event rather than at the beginning (i.e. 800 m track & field, 2000 m rowing, track cycling team pursuit, etc.). It is also worth considering the potential for sporting events lasting ~80 s in order to improve overall performance, which is the time-frame that we showed quinine having an effect in this study. There is an opportunity, practicality of quinine delivery permitting, to benefit from quinine during the middle stages of an effort lasting 3-4 minutes (i.e. 1500 m in track & field, or a 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 (i.e. lozenge or gum) may need further consideration.

CONCLUSION

Despite a similar overall performance for the 3000 m TT for all four 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.

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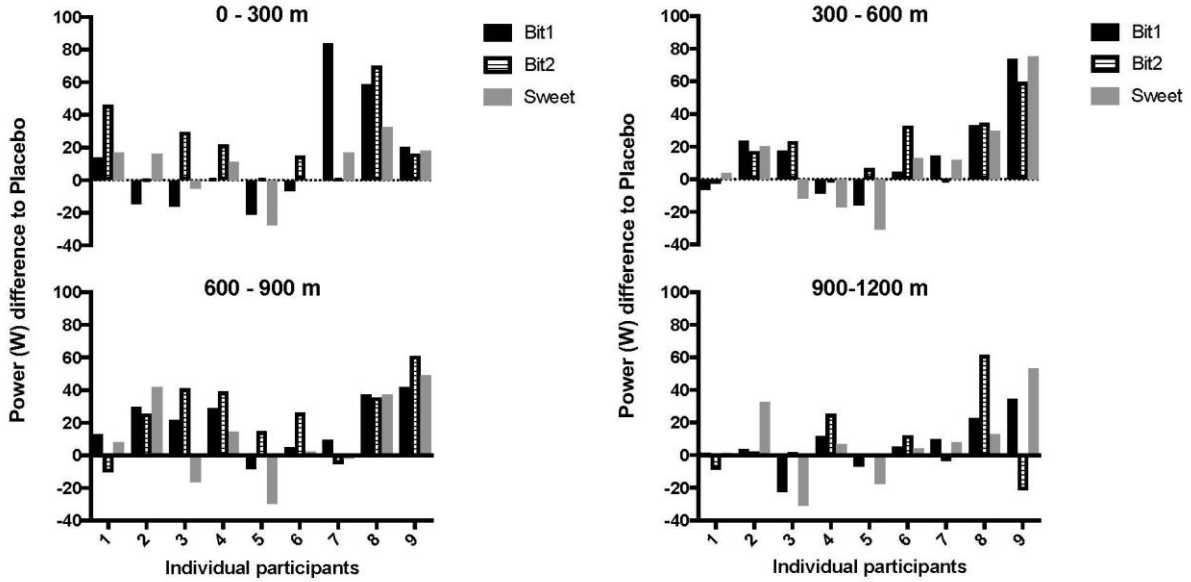

Figure 1. Individual responses to the different treatments during the first 1200 m for each 300 m split during the 3000 m TT.

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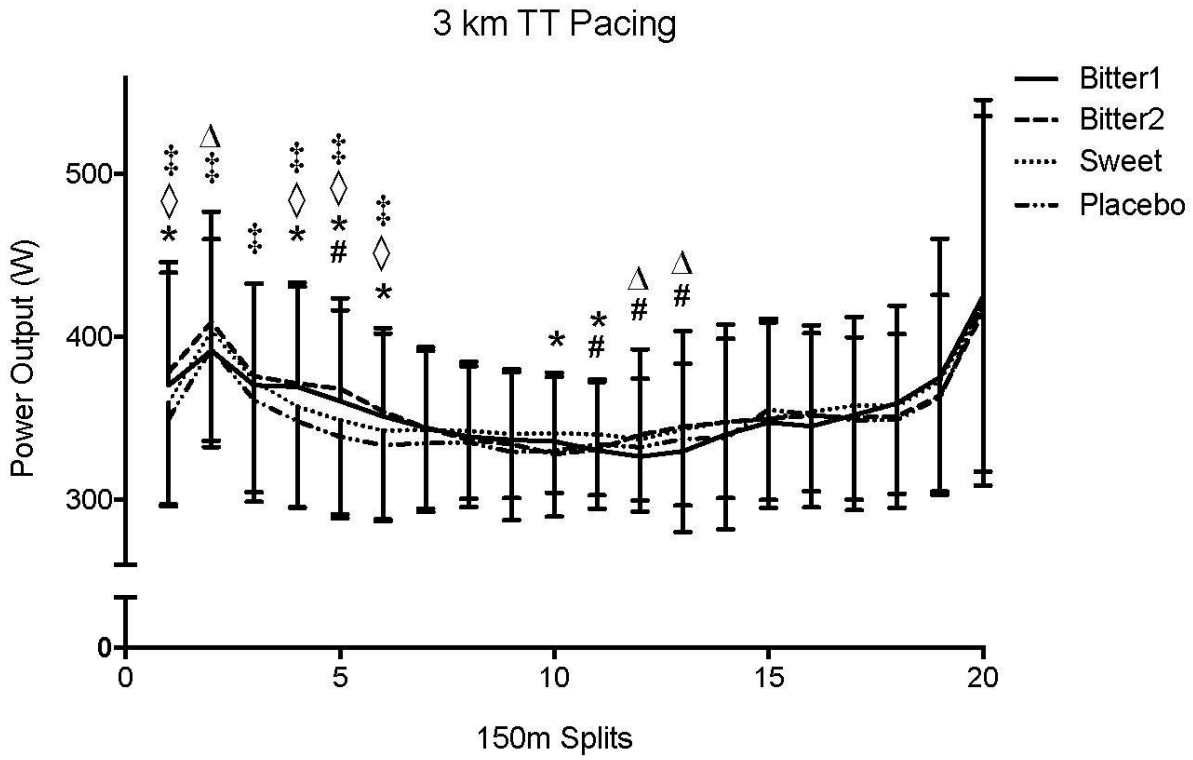

Figure 2. Power output for all 4 experimental conditions for the 150m splits, standardized differences ± 90% confidence limits (CL). Cohen's small effect size differences (0.2 – 0.6) are identified as follows: # ; Bitter1 – Sweet, * ; Bitter2 – Sweet, ◊ ; Bitter1 – Placebo, ‡ ; Bitter2 – Placebo, and Δ ; Bitter1 – Bitter2.

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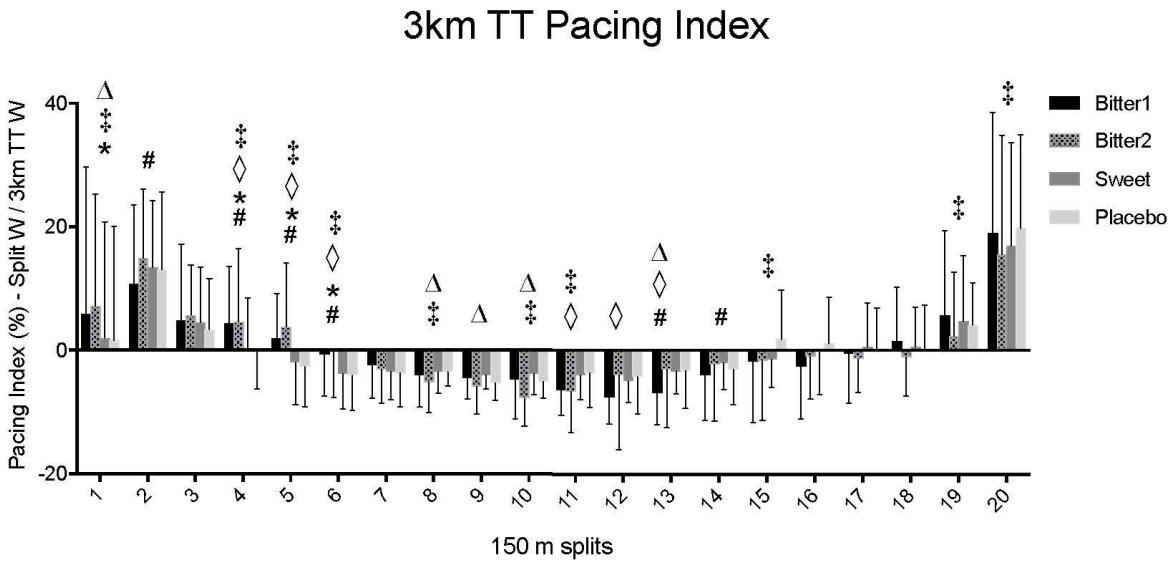

Figure 3. Pacing Index represented as what per cent of the power output they sustain for each 150m split in relation to the entire 3000 m TT *(power output for each 150m split *100 / overall power output for 3000 m TT)-100* across the 3000 m TT for all 4 interventions. Cohen's small-moderate effect size differences (0.2 – 0.6) are identified as follows: # ; Bitter1 – Sweet, ***** ; Bitter2 – Sweet, ◊ ; Bitter1 – Placebo, ‡ ; Bitter2 – Placebo, and Δ ; Bitter1 – Bitter2.

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Table 1. Differences between interventions in power output (watts) for the 3000 m time trial (TT), and the first, second and third km of the 3000 m TT. Standardized differences ± 90% confidence limits (CL), mean power output (W) ± 90% CL, and Effect Size (ES) ± 90% CL as specified.

	Standardized differences ± 90% CL, and ES, ± 90% CL			
	3000 m time trial	1st km	2nd km	3rd km
Bitter1 - Placebo	-0.10 ± 0.16 6 ± 8 Trivial	**-0.25 ± 0.19** **15 ± 11** **Small**	**0.27 ± 0.41** **11 ± 17** **Small**	0.01 ± 0.21 1 ± 14 Trivial
Bitter2 - Placebo	0.15 ± 0.16 -7 ± 8 Trivial	**-0.39 ± 0.17** **21 ± 10** **Small**	**-0.25 ± 0.54** **13 ± 27** **Small**	-0.04 ± 0.19 -2 ± 11 Trivial
Bitter1 - Sweet	0.04 ± 0.21 2 ± 11 Trivial	-0.09 ± 0.16 5 ± 8 Trivial	**0.45 ± 0.40** **19 ± 16** **Small**	0.05 ± 0.23 -2 ± 15 Trivial
Bitter2 - Sweet	0.00 ± 0.22 0 ± 11 Trivial	**-0.22 ± 0.25** **11 ± 13** **Small**	-0.10 ± 0.61 6 ± 30 Trivial	-0.09 ± 0.18 -5 ± 11 Trivial
Bitter1 - Bitter2	0.04 ± 0.10 7 ± 5 Trivial	0.12 ± 0.23 7 ± 11 Trivial	**0.57 ± 0.77** **25 ± 32** **Small**	-0.03 ± 0.13 3 ± 9 Trivial
Sweet - Placebo	-0.14 ± 0.15 7 ± 7 Trivial	0.18 ± 0.28 10 ± 14 Trivial	0.17 ± 0.27 8 ± 12 Trivial	-0.04 ± 0.14 3 ± 8 Trivial