Trehalose Improved 20-min Cycling Time-Trial Performance After 100-min Cycling in Amateur Cyclists

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Carbohydrate (CHO) supplementation during endurance exercise can improve performance. However, it is unclear whether low glycemic index (GI) CHO leads to differential ergogenic and metabolic effects compared with a standard high GI CHO. This study investigated the ergogenic and metabolic effects of CHO supplementation with distinct GIs, namely, (a) trehalose (30 g/hr), (b) isomaltulose (30 g/hr), (c) maltodextrin (60 g/hr), and (d) placebo (water). In this double-blind, crossover, counterbalanced, placebo-controlled study, 13 male cyclists cycled a total of 100 min at varied exercise intensity (i.e., 10-min stages at 1.5, 2.0, and 2.5 W/kg; repeated three times plus two 5-min stages at 1.0 W/kg before and after the protocol), followed by a 20-min time trial on four separated occasions. Blood glucose and lactate (every 20 min), heart rate, and ratings of perceived exertion were collected throughout, and muscle biopsies were taken before and immediately after exercise. The results showed that trehalose improved time-trial performance compared with placebo (total work done 302 ± 39 vs. 287 ± 48 kJ; p = .01), with no other differences between sessions (all p ≥ .07). Throughout the 100-min protocol, blood glucose was higher with maltodextrin compared with the other supplements at all time points (all p < .05). Heart rate, ratings of perceived exertion, muscle glycogen content, blood glucose, and lactate were not different between conditions when considering the 20-min time trial (all p > .05). Trehalose supplementation throughout endurance exercise improved cycling performance and appears to be an appropriate CHO source for exercise tasks up to 2 hr. No ergogenic superiority between the different types of CHO was established.

Keywords: carbohydrate, Palatinose, muscle glycogen, supplementation, endurance exercise

Carbohydrate (CHO) is considered an essential substrate for endurance cycling performance (Podlogar & Wallis, 2022). Nonetheless, there is debate regarding the optimal source of CHO for enhanced endurance performance, since high glycemic index (GI) supplements, such as maltodextrin (i.e., α,1,4-glicosidic) ingested before exercise may decrease lipolysis and free fatty acids availability (Febbraio & Stewart, 1996) and increase net muscle glycogen utilization (Costill et al., 1977). Conversely, low GI CHO ingestion before an exercise bout induces a slower/diminished increase in glycemia and greater fatty acid oxidation (Oosthuyse et al., 2015) while maintaining endurance performance benefits (Hamada et al., 2021, 2022). Isomaltulose (Palatinose) and trehalose are two low GI CHOs that have shown a lower rise in blood glucose during prolonged cycling after their intake before exercise compared with maltodextrin (Hamada et al., 2021, 2022; König et al., 2016; Notbohm et al., 2021; Venables et al., 2008). However, there is conflicting evidence regarding their ergogenic effects (Hamada et al., 2021, 2022; Jentjens & Jeukendrup, 2003) when compared with high GI CHO (i.e., maltodextrin). Importantly, most studies that compared different GI CHOs on endurance performance, and its underpinning mechanisms, provided CHO intake before the exercise bout (Hamada et al., 2021, 2022; Jentjens & Jeukendrup, 2003; Notbohm et al., 2021). To date, there is no comparison between high and low GI CHOs during prolonged exercise on performance, key physiological parameters, and perceived responses. This study investigated the glycemic response and performance effects of trehalose, isomaltulose, and maltodextrin supplementation compared with placebo during prolonged exercise. We hypothesized that trehalose and isomaltulose supplementation would slow the increase in glycemia compared with maltodextrin while showing similar effects on cycling performance and net glycogen utilization, and that performance in all three CHO conditions would be superior to placebo.
Materials and Methods

Participants

The sample size was calculated using G*Power (version 3.1, University of Düsseldorf), with \( \alpha = .05 \) and \( \beta = 0.80 \), a correlation of .5 and effect size \( d = 0.62 \) (Stellingwerff & Cox, 2014), and indicated that 16 participants were required. The inclusion criteria were male cyclists 18–45 years, maximal oxygen uptake \( \geq 45 \text{ ml·kg}^{-1}·\text{min}^{-1} \), and cycling volume \( \geq 260 \text{ km/week} \). The exclusion criteria were the presence of any kind of disease, smoking, current or past use of performance-enhancing drugs, and creatine-or beta-alanine-containing dietary supplements in the past 6 months. A total of 24 cyclists entered the study, though several dropped out for multiple reasons (inability to complete the exercise trial, personal reasons, and COVID-19 pandemic), with 13 recreationally trained cyclists (Pauw et al., 2013) (Table 1) completing the study (age 38 ± 7 years, height 1.79 ± 0.04 m, body mass 78.8 ± 9.1 kg). All participants completed an informed consent form. The experimental procedures followed the recommendations established by the Declaration of Helsinki and the study was approved by the local ethics committee (CAAE: 92384218.4.0000.5391).

Experimental Design

In the first visit, participants underwent anthropometric measurements followed by a step incremental cycling test to task failure to determine \( \dot{V}O_2\text{max} \) and peak power output. In the next two visits, they were familiarized with the cycling protocol (see details in the “100-min Cycling Protocol and 20-min TT” sections). The remaining four visits were performed in a double-blind, crossover, counterbalanced, and placebo-controlled manner, in which participants undertook the cycling protocol and supplemented throughout the session: placebo, maltodextrin, trehalose, and isomaltulose. Condition orders were randomized and balanced using an online Latin Square model tool (https://hamsterandwheel.com/grids/index2d.php) with a square size of 4, along with a random number generator (https://www.randomizer.org/) in a 1:1:1:1 ratio and based upon the order of entry into the study. The randomization procedure was performed by a researcher not involved in data collection.

Blood samples were taken from the antecubital vein at baseline and 20-min intervals throughout the exercise, and immediately post the 20-min time trial (TT). All blood samples were collected in a heparin-coated syringe and immediately analyzed (Stat Profile Prime Plus, Nova Biomedical). In all experimental sessions, muscle biopsies were taken from the vastus lateralis upon arrival at the laboratory and as quickly as possible after the 20-min TT.

Food consumption was assessed in the 24 hr before the first test session and participants were requested to repeat this food pattern (i.e., composition and timing) as closely as possible before the remaining visits. All sessions were performed at the same time of day for each individual (15.4% between 08:00 and 12:00; 38.5% between 12:00 and 18:00; and 46.1% between 18:00 and 22:00). Participants were requested to arrive a minimum of 2 hr after their last food consumption and avoid strenuous exercise, alcoholic and/or caffeine beverages in the 24 hr before the tests.

Maximal Step Incremental Cycling Test

The incremental cycling test was performed on a cycle ergometer (Lode Excalibur, Lode), starting at 100 W and increasing by 25 W every 3 min until task failure. The pedal cadence was self-selected between 80 and 90 rpm, and task failure was defined as the incapacity to maintain a cadence \( \geq 60 \text{ rpm} \) for 5 s despite strong verbal encouragement. Gas exchange and ventilation measurements were recorded breath-by-breath (K5; COSMED). Maximal power output (PO) was calculated as the last completed stage plus the fraction of time spent in the final noncompleted stage multiplied by 25 W (Kuipers et al., 1985). The highest oxygen uptake value averaged over 15 s was defined as maximal oxygen uptake. The gas exchange threshold (GET; Beaver et al., 1986) and the respiratory compensation point (RCP) (Whipp et al., 1989) were identified throughout the test. The PO at GET (PO\text{GET}) and RCP (PO\text{RCP}) were used to characterize the exercise intensity domains in which the 100- and 20-min TT cycling protocols were performed (i.e., the upper boundary of the moderate domain was determined as PO \( \leq \) PO\text{GET}; the upper boundary of the heavy domain was determined as PO \( \leq \) PO\text{RCP}; Azevedo et al., 2019).

100-min Cycling Protocol and 20-min Time Trial

The 100-min cycling protocol used varying exercise intensities related to body weight (in watts per kilogram), such as in a cycling event (Sandars & Heijboer, 2019) in an attempt to improve the study’s ecological validity. The protocol started with 5 min at 1 W/kg of body mass, followed by a sequence of three 10-min stages at standardized PO (i.e., 1.5, 2.0, and 2.5 W/kg) repeated three times, and finished with another 5-min stage at 1 W/kg (Figure 1). Pedal cadence was self-selected (range: 70–90 rpm). Following the 100-min cycling protocol, the software automatically switched into linear mode for the 20-min TT in which participants were instructed to complete as much mechanical work as possible. Total work done (in kilojoules) was computed as 20-min TT performance. Participants received verbal encouragement every 5 min of the TT, while cadence and total time were freely available to the participants throughout. Ratings of perceived exertion (RPE; 15-point Borg scale) were collected every 20 min throughout the 100-min cycling protocol and at Minutes 10 and 20 of the 20-min TT. For blood glucose and lactate, the incremental area under the curve (iAUC) throughout the 100-min cycling protocol was determined (Narang et al., 2020). RPE and heart rate (HR) throughout the 100-min cycling protocol were averaged for analysis. For the 20-min TT, RPE was analyzed considering three measurements: at the end of the 100-min cycling protocol and at Minutes 10 and 20 of the TT. HR and PO throughout the 20-min TT were averaged in 2-min intervals. Additionally, the RPE:PO ratio was calculated,

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Submaximal and Maximal Physiological Responses From the Step Incremental Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>RCP</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) (ml·kg(^{-1}·\text{min}^{-1} ))</td>
<td>35.8 ± 6.5</td>
</tr>
<tr>
<td>%( \dot{V}O_2 \text{max} )</td>
<td>63 ± 4</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>135 ± 9</td>
</tr>
<tr>
<td>%HR\text{max}</td>
<td>74 ± 4</td>
</tr>
<tr>
<td>PO\text{absolute} (W)</td>
<td>156 ± 18</td>
</tr>
<tr>
<td>%PO\text{peak}</td>
<td>48 ± 6</td>
</tr>
<tr>
<td>PO\text{relative} (W/kg)</td>
<td>2.0 ± 0.3</td>
</tr>
</tbody>
</table>

Note. HR = heart rate; GET = gas exchange threshold; RCP = respiratory compensation point; \( \dot{V}O_2 \) = oxygen uptake; \( \dot{V}O_2 \text{max} \) = maximal oxygen uptake; PO = power output.
based on averaged values from the 20-min TT, to investigate the relationship between perceived exertion and self-selected exercise intensity throughout the task (Sanders et al., 2018).

**CHO Supplementation**

Participants ingested either maltodextrin (Prozyn), isomaltulose (Palatinose; Vitafor), or trehalose (NAGASE Group) during exercise. The placebo solution contained no added CHO. All drink solutions were at approximately 4 °C, mixed with an orange flavoring (Clight) and zero-calorie sweetener (sucralose, Zerocal) to mask any differences in flavor and appearance. The concentration of maltodextrin, isomaltulose, and trehalose solutions were 10%, 5%, and 5%, which were ingested at 200 ml of liquid every 20 min, providing 60 g/hr of maltodextrin and 30 g/hr of trehalose and isomaltulose. The disaccharides had a lower CHO concentration due to their low dissolvability and tendency to generate gastrointestinal discomfort at higher concentrations and doses (Oosthuyse et al., 2015). Maltodextrin was used as a positive control to compare with these alternative CHO supplements (Jeukendrup, 2014). To assess the palatability of the CHO supplements and placebo, a small side study was performed, consisting of nine volunteers not involved in the main study, who were asked to rate the supplements on a 3-point scale (good, neutral, and bad) across six categories: appearance, smell, texture, acceptance, taste, and sweetness (more details in Supplementary Table S1 in the Supplementary Material [available online]). At the end of each randomized session, participants were asked if they believed they had ingested a supplement (i.e., a CHO) or not.

**Muscle Biopsies and Glycogen Content**

Muscle biopsies were taken using a 5-mm biopsy Allandale needle (Northern Hospital Supplies) (Neves et al., 2012). The incision through the skin and fascia reached the *vastus lateralis* muscle, 25 cm proximal from the tuberositas tibiae and 5 cm lateral from the midline of the femoral course, under local anesthesia (3 ml of lidocaine 1%, Linisol). The muscle samples (~100 mg) were immediately frozen in liquid nitrogen and stored at −80 °C for posterior homogenized muscle glycogen analysis using the colorimetry protocol of a Glycogen Assay Kit (number MAK016, Sigma-Aldrich).

**Statistical Analysis**

Data were analyzed using SAS OnDemand for Academics and presented as mean ± 1 SD. Statistical significance was accepted at *p* ≤ .05. Data normality was determined using the Shapiro–Wilk test. The 100-min cycling protocol variables (blood glucose, blood lactate, HR, and RPE) and 20-min TT variables (total work done, PO, HR, RPE, total time within intensity domains, muscle glycogen, blood glucose and lactate, and RPE:PO ratio) were compared between conditions and across time using mixed model analysis. Fixed factors were defined as condition and time, and random factors were defined as participants. Post hoc Tukey–Kramer adjustments were performed when the *F* value was significant. Effect sizes for 20-min TT performance were calculated using Hedge’s *g* for small sample size correction and 95% confidence intervals (CIs), with threshold values of 0.01 (very small), 0.2 (small), 0.5 (moderate), and 0.8 (large) (Sawilowsky, 2009).

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For the palatability test, the frequency of the responses was compared using Fisher’s exact test. Blinding success was determined within each condition using Bang’s Blinding Index, with successful blinding considered −0.30 to 0.30 (Bang et al., 2010).

Results

100-min Cycling Protocol

Absolute blood glucose values were different between conditions ($p < .001$), as maltodextrin, trehalose, and isomaltulose were higher than placebo (all $p < .001$; Figure 2), and maltodextrin was higher compared with trehalose ($p = .005$) and isomaltulose ($p = .039$). There was no effect of time ($p = .084$) nor Condition × Time interaction ($p = .369$) for blood glucose. Additionally, iAUC blood glucose was not different between conditions ($p = .189$). There was an effect of time for blood lactate ($p < .001$), but no effect of condition ($p = .657$) nor Condition × Time interaction ($p = .999$); blood lactate was higher at 40, 60, and 100 min compared with 0 min (all $p < .001$). There was no difference in iAUC blood lactate between conditions ($p = .684$).

There was no difference between conditions for HR ($p = .122$) or RPE ($p = .191$) during the 100-min cycling protocol (Table 2). Exercise intensities were mostly within the moderate domain.

![Figure 2](image)

**Figure 2** — Blood glucose and lactate responses during the cycling protocol in each condition. (A) Blood glucose throughout the 100-min cycling protocol in each condition; (B) blood lactate throughout the 100-min cycling protocol in each condition; (C) iAUC for blood glucose in each condition; and (D) iAUC for blood lactate in each condition. *Statistically different from other time points. #Statistically different between conditions. iAUC = incremental area under the curve.

**Table 2** HR and RPE During the 100-min Cycling Protocol in Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Placebo</th>
<th>Maltodextrin</th>
<th>Trehalose</th>
<th>Isomaltulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats/min)</td>
<td>128 ± 13</td>
<td>131 ± 12</td>
<td>130 ± 11</td>
<td>130 ± 14</td>
</tr>
<tr>
<td>%HR$_{\text{max}}$</td>
<td>70 ± 7</td>
<td>72 ± 6</td>
<td>72 ± 6</td>
<td>71 ± 7</td>
</tr>
<tr>
<td>RPE (6–20)</td>
<td>11 ± 2</td>
<td>10 ± 2</td>
<td>11 ± 2</td>
<td>11 ± 2</td>
</tr>
</tbody>
</table>

Note. HR = heart rate; %HR$_{\text{max}}$ = percent of maximal HR derived from the step incremental test; RPE = ratings of perceived exertion.
(58 ± 23% of the total time), compared with the heavy (37 ± 18%) and severe domain (5 ± 11%). One participant performed the entire 100-min cycling protocol within the moderate domain, while two participants performed the 2.5 W/kg stages within the severe domain (i.e., a total of 30 min).

20-min TT

The 20-min TT performance was different between conditions ($p = .015$; Figure 3A), with greater total work done in trehalose than placebo ($p = .012$; $g = 0.34$; 95% CI $[-0.44, 1.10]$). There were no...
differences for maltodextrin versus placebo ($p = 0.07$, $g = 0.26$; 95% CI $[-0.52, 1.02]$), isomaltoolose versus placebo ($p = 0.13$; $g = 0.19$; 95% CI $[-0.59, 0.96]$), trehalose versus maltodextrin ($p = 0.88$; $g = 0.08$; 95% CI $[-0.69, 0.85]$), trehalose versus isomaltoolose ($p = 0.79$; $g = 0.14$; 95% CI $[-0.62, 0.91]$), or maltodextrin versus isomaltoolose ($p = 0.97$; $g = 0.06$; 95% CI $[-0.71, 0.83]$). Additionally, the coefficient of variation between the first ($291 \pm 44$ kJ) and second ($291 \pm 45$ kJ) familiarizations of the 20-min TT (both proceeded by the 100-min cycling protocol) was 4 ± 3%.

The pacing strategy throughout the 20-min TT did not show a Condition \times Time interaction ($p = 0.93$), but there were differences in average PO between conditions ($p = 0.004$) and across time ($p < 0.001$) (Figure 3B). Overall, PO was greater in trehalose ($p = 0.022$) and maltodextrin ($p = 0.045$) than placebo, but not between isomaltoolose and placebo ($p = 0.999$). PO was higher at 18–20 min compared with all other time points in all conditions ($all p < 0.05$).

There were no differences between conditions for HR ($p = 0.271$; Figure 3C) or RPE ($p = 0.691$; Figure 3D), but both variables increased throughout the 20-min TT (both $p < 0.001$). HR was lower at Minutes 0–2 and 4–6 compared with the remaining time points (all $p < 0.05$), while RPE continuously increased until the end of the trial (all $p < 0.001$). Furthermore, RPE:PO was different among conditions ($p = 0.012$), with a lower ratio for trehalose (0.0610 ± 0.009 a.u., $p = 0.01$) and maltodextrin (0.0615 ± 0.009 a.u., $p = 0.04$), but not isomaltoolose (0.0623 ± 0.008 a.u., $p = 0.11$) compared with placebo (0.0649 ± 0.011 a.u.). Time spent within the heavy and severe exercise intensity domains was different between conditions ($p = 0.02$ and $p = 0.01$; Figure 3E), with less time spent within the heavy domain and greater time within the severe domain in trehalose and maltodextrin compared with placebo and isomaltoolose conditions (all $p < 0.05$); these were not different between the maltodextrin and trehalose conditions (all $p > 0.05$). There was no effect of condition ($p = 0.714$) or Condition \times Time interaction ($p = 0.353$) for net muscle glycogen utilization, but there was an effect of time ($p < 0.0001$), with lower values postexercise versus preexercise (Figure 3F). Blood glucose and lactate increased throughout the exercise ($p = 0.001$ and $p < 0.001$) with no difference between conditions ($p = 0.26$ and $p = 0.21$) nor a Condition \times Time interaction ($p = 0.32$ and $p = 0.30$) (Table 3).

### Palatability, Food Intake, and Blinding Success

Overall, there was no difference between supplements (i.e., the three CHOs and placebo) in terms of appearance, smell, texture, sweetness, and intensity. However, maltodextrin taste and acceptability were rated worst in comparison to trehalose, isomaltoolose, and placebo (results in Supplementary Figure S1 in the Supplementary Material [available online]). Additionally, there was no difference in food intake (total energy, CHO, protein, and fats) in the 24 hr before exercise, or the last meal before exercise, in each condition (results in Supplementary Tables S2 and S3 in the Supplementary Material [available online]). Finally, participants were able to correctly guess the placebo 61.5% of the time (Bang’s Blinding Index = 0.23), and across all CHO sessions, participants believed that they ingested CHO 64.1% of the time (Bang’s Blinding Index = 0.28), indicating successful blinding.

### Discussion

Our results showed that (a) trehalose supplementation improved 20-min TT performance compared with placebo, (b) there was a lower glycemic response with trehalose and isomaltoolose than maltodextrin during the 100-min cycling protocol, and (c) net muscle glycogen depletion was similar between CHO types and placebo. To our knowledge, this is the first study to compare CHOs of different GIs during endurance exercise.

### 20-min TT Performance

Trehalose supplementation improved TT performance compared with placebo, whereas there was no difference between isomaltoolose, maltodextrin, and placebo conditions. Maltodextrin supplementation did elicit greater PO compared with placebo, but did not improve overall TT performance, despite similar effect sizes for performance improvements with trehalose and maltodextrin compared with placebo. The lack of difference between maltodextrin and placebo might be due to artifacts in the data (e.g., intrindividual variability) and/or potential differences in statistical analysis, where the performance was compared between conditions, but PO included condition and time main effects. Trehalose resulted in a greater PO (Figure 3B) and time spent within the severe domain (Figure 3E) compared with placebo despite similar perceived exertion (Figure 3D) and physiological responses (Figure 3 and Table 3), thus resulting in a lower RPE:PO ratio. Perceived responses during self-paced exercise ultimately underpin overall performance (Azevedo et al., 2021), and exercise intensity varies to achieve maximal RPE values at the finish line and avoid premature exercise cessation. Isomaltoolose supplementation did not improve exercise performance, which contrasts with some findings (König et al., 2016; Oosthuyse et al., 2015) but is in accordance with others (Notbohm et al., 2021). This may be due to the dose of disaccharides which was on the lower end of recommendations (30 g/hr) (Sawka et al., 2007), although this amount was chosen to avoid gastrointestinal discomfort (Oosthuyse et al., 2015). This is the first study to compare low and high GI CHO supplementation during 120-min cycling, showing that 30 g/hr of trehalose improved final 20-min TT performance compared with placebo.

### 100-min Cycling Protocol

Glycemic values were higher for maltodextrin compared with trehalose and isomaltoolose (Figure 2A), without physiological

#### Table 3 Blood Glucose and Lactate Responses Throughout the 20-min TT in Each Condition

<table>
<thead>
<tr>
<th></th>
<th>Placebo</th>
<th>Maltodextrin</th>
<th>Trehalose</th>
<th>Isomaltoolose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-20-min TT</td>
<td>Post-20-min TT</td>
<td>Pre-20-min TT</td>
<td>Post-20-min TT</td>
</tr>
<tr>
<td>Glucose (mg/dl)</td>
<td>97 ± 7</td>
<td>113 ± 22</td>
<td>110 ± 13</td>
<td>112 ± 31</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>2.9 ± 2.5</td>
<td>8.4 ± 2.6*</td>
<td>2.7 ± 2.7</td>
<td>10.5 ± 3.6*</td>
</tr>
</tbody>
</table>

Note: TT = time trial.

*Statistically different from pre-20-min TT values.

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differences (i.e., blood lactate, HR, or RPE). The rise in blood glucose following ingestion of low GI CHO was slower and of lower magnitude compared with high GI CHO (i.e., maltodextrin). Specifically, whereas the iAUC analysis did not show differences between conditions for the total glycemic load (e.g., see individual responses in Figure 2C), the absolute blood glucose values during the 100-min cycling protocol were higher with maltodextrin than the other conditions (Figure 2A). Some of this difference is undoubtedly due to the differences in CHO quantity (Bourdas et al., 2021). It is worth mentioning that the point-by-point analysis of blood glucose illustrates the time-course glycemic responses throughout the 100-min cycling protocol, while the iAUC analysis compares the total glucose load between conditions, normalized by baseline values. Thus, although these two analyses shed some light on the effect of CHO intake on metabolism when supplemented throughout endurance exercise, it remains unclear whether low GI is superior to high GI CHO for endurance performance and why only trehalose improved exercise performance here.

Muscle Glycogen Content

Muscle glycogen content was not different between conditions, which would suggest similar net muscle glycogen utilization regardless of the type of CHO ingested. Muscle glycogen was not fully depleted post-TT, which may have minimized the potential positive impact of CHO supplementation on cycling performance. Evidence suggests that very little muscle glycogen is used during exercise lasting up to 4 hr when CHO feeding occurs (Coyle, 1992), suggesting that blood glucose may be more important for exercise performance. Another biopsy sample before the 20-min TT could have provided more information as to muscle glycogen utilization during the 100-min cycling protocol, and further explain the mechanisms underpinning the performance improvements seen with trehalose. Despite no differences in net muscle glycogen utilization, there was greater PO and time spent within the severe domain with trehalose and maltodextrin supplementation compared with placebo. It is intriguing that greater CHO provision, as was provided with maltodextrin compared with the other CHOs, did not lead to greater performance benefits. It is also possible that other mechanisms influenced performance here, including blood glucose fluctuations and liver glycogen use, but these remain speculative, warranting further investigations.

Methodological Considerations

The concentration of maltodextrin (10%) was higher than that of isomaltulose and trehalose (5%) due to their low dissolvability and tendency to generate gastrointestinal discomfort at higher concentrations and doses, while maltodextrin was maintained at the recommended dosing strategy. Some of the differences shown here are undoubtedly due to differences in CHO quantity (Bourdas et al., 2021). Additionally, the sample size might have elicited a Type II error in the 20-min TT performance, since only 13 out of 16 desired participants completed the study, thus the lack of difference between maltodextrin and placebo was not detected due to low statistical power rather than a true absence of an effect. Finally, only male participants were included in the study, mostly because the menstrual cycle may affect metabolic responses during the exercise (Devries et al., 2019), and our budget did not allow for the quantification of sex hormones (Elliott-Sale et al., 2021).

Conclusion

Trehalose supplementation throughout 120-min endurance exercise improved cycling performance compared with placebo. Importantly, our findings do not imply an ergonomic superiority of any form of the tested CHOs, considering that isomaltulose, maltodextrin, and trehalose elicited comparable metabolic, perceptual, and performance responses.

Acknowledgments

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