Clinical Study

Comparison of the Effects of Glucose and Fructose on Exercise Metabolism, Perceived Exertion, and Recovery in Untrained Females

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Received 22 September 2013; Revised 28 November 2013; Accepted 16 December 2013; Published 19 February 2014

Academic Editor: Germán Vicente-Rodriguez

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This double-blinded, crossover randomized controlled trial study was designed to establish if combined ingestion of glucose and fructose (GLU + FRU) at the moderate rate $0.5 \text{ g} \cdot \text{min}^{-1}$ would result in higher rates of carbohydrate (CHO) oxidation compared with glucose (GLU) alone. Eight untrained females ($\text{VO}_{2\text{max}}: 25.8 \pm 3.2 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) cycled on two different occasions for 60 min at 50% of maximal power output ($60\% \pm 1\% \text{ VO}_{2\text{max}}$) and consumed 12% CHO solution of either providing $0.33 \text{ g} \cdot \text{min}^{-1}$ glucose + $0.17 \text{ g} \cdot \text{min}^{-1}$ fructose (GLU + FRUC) or $0.5 \text{ g} \cdot \text{min}^{-1}$ of glucose (GLU) alone. Heart rate (HR) and rate of perceived exertion (RPE) were assessed during exercise and subjective exercise experience assessed two days after each trial. CHO oxidation was not significantly different ($P > 0.05$) between GLU + FRU and GLU ($0.8 \pm 0.06 \text{ g} \cdot \text{min}^{-1}$ and $0.78 \pm 0.05 \text{ g} \cdot \text{min}^{-1}$, resp.). CHO oxidation rates during the final 30 min of the recovery period were not significantly different between GLU + FRU and GLU ($0.17 \pm 0.04 \text{ g} \cdot \text{min}^{-1}$ and $0.14 \pm 0.05 \text{ g} \cdot \text{min}^{-1}$, resp.). Experience of distress was significantly higher ($P < 0.05$) for GLU compared to GLU + FRU. The results reveal that consuming modest amounts of glucose plus fructose does not boost CHO oxidation above that of glucose alone during submaximal exercise.

1. Introduction

There is growing interest from industry, clinicians, patients, and athletes in identifying nutritional approaches to optimise performance [1]. Much research has shown that carbohydrate (CHO) ingestion during exercise and recovery is beneficial for endurance exercise; it maintains plasma glucose levels and high levels of CHO oxidation [2], prolongs time to exhaustion [3], and aids recovery from exercise [4].

It is recognised that absorption of CHO is an important rate-limiting step in CHO metabolism during exercise [5]. Use of more than one CHO in an exercise drink is said to

enhance CHO absorption via separate transport mechanisms across the intestinal wall [6]. A combination of glucose and fructose has also been found to enhance gastric emptying [7] and fluid delivery [8] and enhances short-term recovery after exhaustive exercise [9]. Thus, it is hypothesized that a mixed CHO drink will enable greater improvement in endurance exercise performance than a drink of glucose alone through increased oxidation of exogenous CHO and maintenance of endogenous glucose stores [5]. This conjecture is supported by experiments on male endurance trained athletes [10, 11] with the assumption that the conclusions also apply to women [12].

Research into the response to different forms of carbohydrate has focused on male subjects who are trained in endurance sports [7, 9–11, 13]. There is a dearth of research relating to untrained individuals especially untrained females which informed our decision to investigate this important but often overlooked group. It is recognised that females use fat oxidation more than their male counterparts during exercise [14, 15] and that training alters substrate metabolism in athletes [16]. This study investigated whether glucose alone and glucose plus fructose effects on carbohydrate metabolism during and after endurance exercise in untrained women are different to those observed previously in trained men. Another important aspect of exercise in the untrained female population is their perceived exertion as this may limit their ability to sustain participation in endurance exercise. Jeukendrup and Moseley [7] reported that perceived exercise exertion in male subjects was lower after ingestion of a glucose plus fructose mix compared with glucose alone or water. We were interested in examining if this phenomenon is the same in untrained females during cycle exercise.

The main aim of this study was to investigate whether there are differences in carbohydrate utilization when untrained female subjects consume either glucose alone or a combination of glucose and fructose following a protocol of submaximal exercise (60% $\text{VO}_{2\text{max}}$) aimed at depleting muscle glycogen stores. We hypothesise that female subjects will have similar results to those previously observed in male subjects [11], such that there will be no significant difference in the RER measured with consumption of different forms of carbohydrate. This study also investigated perceived exertion or exhaustion after exercise and perceived recovery two days after exercise. We hypothesise that a mixed drink of glucose and fructose will improve subject's recovery from exercise by reducing perceived fatigue and residual exercise-related pain and stiffness.

2. Materials and Methods

2.1. Study Design. This was a crossover randomised double-blinded trial to measure responses to a 1-hour cycling intervention following administration of two carbohydrate (CHO) drinks in 2 separate trials.

2.2. Participants. Ten sedentary females between the ages of 18 and 30 years were recruited from the University of Nottingham campus for this study. Two subjects dropped out due to a new job commitment and illness, leaving only eight subjects for the study. The subjects were informed of the nature, risks, and potential benefits of the study orally and in writing, and then subjects provided written, informed consent. The procedures were reviewed and approved by the Nottingham University Medical School Research Ethics Committee. Untrained was defined as participation in less than 2 hours of regular strenuous activity per week for at least the last 6 months and having maximum oxygen consumption ($\text{VO}_{2\text{max}}$) between 20 and 40 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The mean time spent walking and sitting per week by the subjects was 5.6 ± 3.6 hrs and 75.3 ± 17.8 hrs, respectively. They participated in vigorous and moderate physical activity

weekly for 0.1 ± 0.4 hrs and 0.7 ± 1.0 hrs, respectively. All subjects were at a low risk for cardiovascular disease according to ACSM's Guidelines [17]. All subjects were eumenorrheic, with a normal cycle length of 28–34 days and were in the follicular phase (5–11 days after onset of the menstrual cycle). Exclusion criteria included anyone without a regular (28- to 35-day) menstrual cycle, anyone smoking, anyone who was pregnant or lactating, anyone taking regular medication except contraceptives, and anyone with metabolic disease or musculoskeletal injury. Subjects completed a health questionnaire, Food Frequency Questionnaire, and International Physical Activity Questionnaire prior to participation in the study. The subjects were then thoroughly familiarised with all the procedures involved in the exercise protocol.

2.3. Interventions

2.3.1. Exercise Protocol. All subjects participated in 2 exercise trials and on each occasion they performed a standardised exercise test on a cycle ergometer while ingesting one of two drinks identical in appearance and taste and supplied in identical containers. Subjects were required to refrain from any strenuous exercise for at least 72 hours before the experiment, abstain from alcohol or caffeine 48 hours prior to the exercise, and fasted for at least 6 hours. A food record was provided to standardise food ingested before the experiment while an identical diet was prescribed for the day before the subsequent exercise. Figure 1 provides a schematic view of the protocol. For a given subject, all trials were conducted at the same time of the day to avoid any influence of circadian variation. The subjects got on a cycle ergometer (Tunturi, E630, Tunturi Fitness B.V, Almere, Finland) and a resting breath sample was collected directly from a mixing chamber. Resting heart rate and gas exchange were measured 5 min later. The subjects then cycled at 60% of the $\text{VO}_{2\text{max}}$ and between 60 and 65 rpm with the time starting when the subject attained this cadence on the braked cycle ergometer at the predetermined workload. Following 60 mins of exercise, the subject's gas exchange was further measured during the recovery period in the laboratory for at least 30 mins before leaving. Immediately before exercise, subjects ingested an initial bolus (600 mL) of either of two experimental drinks: GLU or GLU + FRU. Thereafter, a beverage volume of 150 mL was provided at 15-minute intervals (15, 30, 45 min) and after terminating the exercise (60 min). All exercise tests were performed under normal and standard environmental conditions (20–26°C dry bulb temp, 50–60% relative humidity). During the exercise trials, subjects were cooled with a table fan to minimise thermal stress. Subjects returned to the laboratory at least 7 days after the first trial to avoid fatigue and/or training effect for trial 2. The protocol was repeated exactly as in trial 1 but with a different nutritional solution.

2.3.2. Nutritional Solutions. A total of 1.2 L of lemon-flavoured carbohydrate (CHO) solutions were prepared for ingestion during each exercise bout by an independent member of the research staff blinded to both subjects and the research team. The GLU solution was 90 g glucose, 6 tsp of lemon juice in 1200 mL of water and lemon juice.

FIGURE 1: Schematic representation of the study protocol for trial 1 and trial 2.

600 mL of this mixture was consumed before the start of the exercise bout, and the remaining volume was taken in 150 mL aliquots at 15, 30, 45, and 60 min of the exercise period. The GLU + FRU solution was 60 g glucose and 30 g fructose in 1200 mL of water and 6 tsp of lemon juice, again 600 mL was consumed before exercise and 150 mL every 15 min during the exercise. The glucose powder used in the drink supplements was maize-derived labelled “Glucose for Oral Use”, (Courtin and Warner, Ltd., London) and 100% glucose. The fructose powder was from 100% fruit sugar found naturally in most fruits and honey (“Fruisana” Pure Fructose, Surrey, UK). The CHO energy content was 1692 kJ/375 kcal per 100 g.

2.4. Study Measures

2.4.1. Anthropometric and Physiological Measurements. Height, body mass, and skinfolds were measured and body mass index (BMI) and percent body fat were calculated. Subject’s body mass index (BMI) was between 20 and 27 $\text{kg}\cdot\text{m}^{-2}$. Skinfold thicknesses (SFT) were measured at four standard sites: biceps, triceps, subscapular, and suprailiac with a skinfold caliper with manual read-out (accuracy 0.2 mm (range 0–19 mm) John Bull, British Indicators, UK) by a female investigator and procedures were done according to ACSM guidelines [17]. The percentage of body fat using equation of Siri: $(\text{Percent fat} = (4.95/\text{density} - 4.50) \times 100)$ was estimated from the logarithm of the sum of the SFT measurements (log 4 SFTs) and the age-specific prediction equations [19] for body density. Body composition was also assessed using bioelectrical impedance analysis (BIA) (QuadScan 4000, Bodystat Limited, Isle of Man, UK). Subjects were fitted with a chest strap monitor (Sports tester, Polar-S610, Finland) and a three-lead electrocardiogram to monitor physiological response throughout the test. Weekly physical activity and associated MET values were calculated using the Compendium of Physical Activity [20].

2.4.2. Maximal Oxygen Consumption: $\text{VO}_{2\text{max}}$ Test. The test was undertaken at least one week prior to the initiation of

the experiment while subjects cycled on a stationary bicycle ergometer (Tunturi, E630, Tunturi Fitness B.V, Almere, Finland). The seat height was adjusted to allow a slight bend in the knee with the leg at full extension and the foot parallel to the floor. The subject continued to wear the HR monitor and was fitted with a mouthpiece and head gear for collection of expired gases. A metabolic cart (V_{max} 29; Sensor Medics Corporation, Yorba, Linda, CA) was used during testing sessions to measure pulmonary ventilation and gas exchange. The volume sensor was calibrated before each test against a 3.0 L syringe and CO_2 and O_2 sensors were calibrated against known gases. The subjects were allowed to settle with the mouth piece/breathing valve and nose clip in place while becoming accustomed to the ergometer. $\text{VO}_{2\text{max}}$ was determined during an incremental cycling protocol as described by Storer et al. [21] lasting between 10 and 15 minutes, with each workload applied for three-minute periods, during which the pedalling speed was maintained at 60 revolutions per minute. The average oxygen uptake (VO_2) value obtained during the final minute of each 3-minute period was taken as the VO_2 for that workload. Subjects were verbally encouraged during the latter stages of the protocol and the test ended when the subject could no longer maintain 60 rpm. $\text{VO}_{2\text{max}}$ was calculated as the average oxygen uptake (VO_2) over the last 60 s of the test. $\text{VO}_{2\text{max}}$ criteria were met with at least two of the three criteria:

- (1) a levelling off of VO_2 with increasing workload (increase of no more than $2 \text{ mL}\cdot\text{kg}^{-1}$ body weight per minute),
- (2) heart rate within 10 $\text{beats}\cdot\text{min}^{-1}$ of predicted maximum (HR of $220 \text{ beats}\cdot\text{min}^{-1}$ age), and
- (3) a respiratory exchange ratio (RER) greater than 1.05.

To calculate $\text{VO}_{2\text{max}}$ in this present study, a graph was plotted of the workload against VO_2 showing the linear relationship. The workload at which subjects were cycling at 60% $\text{VO}_{2\text{max}}$ was then read from the graph and used as the W_{max} during the experimental exercise protocol. The mean $\text{VO}_{2\text{max}}$ for the group was $25.8 \pm 3.2 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

2.4.3. Oxygen Consumption (VO_2), Respiratory Exchange Ratio (RER). During the exercise tests, subjects wore a nose-clip and breathed through a mouthpiece which allowed room air to be inhaled and directly exhaled to a $V_{\text{max}} 29$, SensorMedics, metabolic cart, which was calibrated before each trial. Oxygen consumption (VO_2) and carbon-dioxide production (VCO_2) were determined for every minute, from which the respiratory exchange ratio (RER) was calculated as VCO_2/VO_2 . Gas exchange was measured continuously for 5 min after ingestion of the drink, during exercise at 15 min intervals (10, 25, 40 and 55 min) and in the recovery period (10 and 25 min). RER values from 5 to 65 mins were averaged and compared between the nutritional solution interventions.

2.4.4. Carbohydrate and Fat Oxidation. Carbohydrate and fat oxidation (g/min) were calculated using stoichiometric equations from VO_2 and VCO_2 (L/min), with the assumption that protein oxidation during exercise was negligible according to Frayn [22]:

$$\begin{aligned}\text{CHO oxidation} &= 4.55 \text{ VCO}_2 - 3.21 \text{ VO}_2, \\ \text{Fat oxidation} &= 1.67 \text{ VO}_2 - 1.67 \text{ VCO}_2.\end{aligned}\quad (1)$$

2.4.5. Heart Rate. The heart rate of each subject was recorded every 5 min during the cycling exercise and the same heart rate monitor was used for all subjects to avoid potential confounders.

2.4.6. Rate of Perceived Exertion. Perceived exertion was measured using Borg's Rating of Perceived Exertion (RPE) scale [23] which required participants to rate their perceptions of exertion on a 15-point (6–20) Likert scale. For the present study, RPE was assessed every 3 min during the $\text{VO}_{2\text{max}}$ test and at 15, 30, 45, and 60 min points of a 60 min bout of cycling exercise after ingesting GLU or GLU + FRUC. An overall RPE was calculated by taking the average of the four data points.

2.4.7. 2-Day Postexercise Response. All subjects completed a telephone interview using the Subjective Exercise Experience Scale (SEES) [24] with further questioning to ascertain the effects of level of fatigue in terms of activity and pain 2 days after each of the two exercise trials. The SEES is a 12-item questionnaire composed of 3 subscales: (a) psychological wellbeing (terrific, strong, positive, and great), (b) psychological distress (miserable, discouraged, crummy, and awful), and (c) fatigue (tired, fatigued, exhausted, and drained). The SEES items were scored on a 7-point scale and good discriminant and construct validity has been demonstrated for this measure [24]. The reported internal reliability of the three subscales of the SEES was 0.86, 0.85, and 0.88, respectively.

2.5. Statistical Analysis. A within-subject analysis of variance (ANOVA) for repeated measures on two factors (experimental trial $\times$ sampling time) was used to compare differences in substrate utilisation, heart rate, and rate of perceived exertion between the cycling trials with different nutritional solutions.

When statistical significance was observed, post hoc analysis was undertaken with Tukey's HSD to locate the difference. Wilcoxon signed rank test was used to analyse nonnormally distributed data. A paired-sample t -test was used to identify differences in SEES scores and area under the curve (AUC) for total CHO and fat oxidation between nutritional solutions during cycle trials. Statistical Package for the Social Sciences for Windows (version 18.0; SPSS^R Inc., Chicago, IL, USA) was used for data evaluation. All data are reported as means with their standard deviation except otherwise stated. Statistical significance was set at $P < 0.05$.

3. Results

3.1. Anthropometric and Physiological Measurements. All data are expressed as means $\pm$ SD. The mean age for the subjects was 24.0 ± 4.7 years. Descriptive statistics for age, weight, body mass index (BMI), body fat, maximal oxygen uptake ($\text{VO}_{2\text{max}}$), and workload are illustrated in Table 1.

3.2. Oxygen Consumption (VO_2) and Respiratory Exchange Ratio (RER). The mean VO_2 and RER values for GLU and GLU + FRUC are presented in Table 2. There was no significant difference in VO_2 ($P = 0.362$) during exercise (0–60 min) or exercise to recovery period (0–90 min) ($P = 0.451$). RER was not significantly different between GLU and GLU + FRUC trials during exercise ($P = 0.124$) or exercise to recovery period ($P = 0.797$). The average RER value during the last 15 min of exercise was identical. The rise in RER immediately after exercise was faster with GLU + FRUC ingestion and declined slower at the recovery period compared to GLU.

3.3. Carbohydrate and Fat Oxidation. The mean CHO and fat oxidation at different time points are shown in Table 2. No significant differences in total CHO oxidation were found between the GLU + FRUC and GLU during exercise ($P = 0.33$) or the subsequent recovery period ($P = 0.495$). Therefore, the total CHO area under the curve (AUC) during exercise was not significantly different between GLU and GLU + FRUC. Fat oxidation did not differ significantly between the two CHO trials during exercise ($P = 0.649$) or recovery period ($P = 0.311$) and the total fat AUC during exercise was not statistically significant between GLU and GLU + FRUC ($P = 0.25$). In both trials, CHO oxidation peaked at the beginning of exercise (15 min) and reached a plateau at 30 min followed by a steady decline at the start of the recovery period following exercise (Figure 3).

Simultaneously, fat oxidation declined in the initial 15 min following exercise, then rose to reach a peak at the end of the 60 min exercise, and declined during the recovery period (Figure 4). Comparing time points, there was no significant difference ($P > 0.05$) during exercise (0–60 min) and after exercise (61–90 min) in the oxidation of CHO and fat with GLU and GLU + FRUC trials.

3.4. Heart Rate. There was no significant difference in heart rate between GLU and GLU + FRUC trials during exercise

TABLE 1: Participant characteristics.

Characteristics	Mean	SD	Range
Age (years)	24.3	±2.7	18–30
Height (cm)	162.5	±0.1	1.53–1.67
Body mass (kg)	58.4	±9.0	47–71
¹ Waist circumference (cm)	72.2	±7.0	65.2–85.5
² Hip circumference (cm)	94.6	±9.7	75–104
BMI	22.5	±2.8	20–27
% body fat	24.6	±3.5	28.7–41.3
% LBM	75.4	±5.5	58.7–71.3
LBM (kg)	43.9	±4.2	31.2–41.9
60% VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	15.5	±1.86	14.46–18.24
Predicted 60% VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	19.67	±1.94	15.81–22.57
W _{max} (W)	129	±12	110–150
Moderate Activity·wk ⁻¹ (METS)	1320.5	±652.7	657–2376
HR _{max} (beats/min)	196.4	±4.39	191–202

BMI: body mass index; LBM: lean body mass, W_{max}: maximum power; METS: metabolic equivalent, HR_{max}: maximal heart rate. ¹Waist circumference was measured midway between the lower rib margin and the iliac crest at the end of expiration [18]. ²Hip circumference was measured at the widest point between the iliac crest and buttock [18].

Note: predicted 60% VO_{2max} is the mean value that was aimed for while the 60% VO_{2max} was the mean value that was achieved among the study subjects.

TABLE 2: Effect of GLU and GLU + FRUC on VO₂, RER, CHOtot, and FATtot in untrained women during submaximal exercise (0–60 min) and recovery period (61–90 min).

	Time (min)					
	0–15	16–30	31–45	46–60	61–75	76–90
GLU+FRUC						
VO ₂ (L/min)	1.02 ± 0.09	1.05 ± 0.09	1.08 ± 0.08	1.10 ± 0.08	0.29 ± 0.04	0.28 ± 0.04
RER (g/min)	1.00 ± 0.01	0.94 ± 0.00	0.93 ± 0.01	0.92 ± 0.01	0.93 ± 0.04	0.90 ± 0.04
CHOtot (g/min)	1.02 ± 0.09	0.83 ± 0.06	0.82 ± 0.06	0.80 ± 0.06	0.22 ± 0.04	0.17 ± 0.04
FATtot (g/min)	0.01 ± 0.02	0.08 ± 0.01	0.10 ± 0.01	0.11 ± 0.01	0.03 ± 0.02	0.04 ± 0.02
GLUC						
VO ₂ (L/min)	1.10 ± 0.07	1.14 ± 0.09	1.13 ± 0.08	1.14 ± 0.08	0.33 ± 0.06	0.27 ± 0.02
RER (g/min)	0.99 ± 0.02	0.93 ± 0.01	0.93 ± 0.01	0.91 ± 0.01	0.94 ± 0.02	0.85 ± 0.04
CHOtot (g/min)	1.06 ± 0.05	0.84 ± 0.04	0.84 ± 0.05	0.78 ± 0.05	0.26 ± 0.06	0.14 ± 0.05
FATtot (g/min)	0.02 ± 0.02	0.11 ± 0.03	0.11 ± 0.07	0.14 ± 0.02	0.03 ± 0.01	0.06 ± 0.02

GLU: glucose; GLU + FRUC: glucose + fructose, VO₂: mean oxygen uptake; RER: respiratory exchange ratio, CHOtot: total carbohydrate oxidation, and FATtot: total fat oxidation.

($P = 0.249$) and exercise to recovery period ($P = 0.309$). The mean values for HR during exercise were 132 ± 1.6 b·min⁻¹ and 130 ± 2.3 b·min⁻¹ for GLU + FRUC and GLU, respectively. The HR values peaked at 30 min in both trials (Figure 2).

3.5. Rate of Perceived Exertion. No significant difference in perceived exertion ($P > 0.05$) was observed between the two exercise sessions. The mean RPE values during exercise were 11.2 ± 0.3 and 11.2 ± 0.4 for GLU + FRUC and GLU, respectively. The RPE increased progressively throughout the time intervals and peaked at 60 min in both trials (Figure 5). However, subjects reported more exhaustion in the last 15 min of cycling following ingestion of GLU compared to GLU + FRUC.

3.6. 2-Day Exercise Response. Mean values for SEES: physical wellbeing (PWB), psychological distress (PD), fatigue (FT) with ingestion of GLU + FRUC, and GLU are presented in

Table 3. The highest score was reported for positive wellbeing and the lowest score was reported for psychological distress throughout the study. (Figure 6). Paired t -test analysis showed that there was no significant difference in PWB ($P = 0.74$) and FT ($P = 0.23$) between the two trials. However, PD scores were significantly higher after the GLU trial compared to GLU + FRUC ($P = 0.04$) (Figure 6). A further comparison of the subjects' PWB, PD, and FT mean values between visits 1 and 2 with the paired t -test revealed no significant difference ($P = 0.743$, $P = 0.623$, and $P = 0.85$, resp.) for the three constructs (Table 3).

4. Discussion

The main finding of this study was that with the amounts of CHO provided (0.5 g·min⁻¹ or 30 g·h⁻¹) the rate of CHO oxidation was similar between GLU and GLU + FRUC. According to Jeukendrup [25] studies on CHO supplementation in

FIGURE 2: Heart rate (HR) during 60 min exercise with ingestion of GLU or GLU + FRUC. Values are presented as means $\pm$ SE, $n = 8$. GLU: glucose; GLU + FRUC: glucose + fructose.

FIGURE 3: Total carbohydrate (CHO) oxidation during 60 min exercise and 30 min recovery with GLU or GLU + FRUC. Values are presented as means $\pm$ SE; $n = 8$. GLU: glucose; GLU + FRUC: glucose + fructose.

FIGURE 4: Total fat oxidation during 60 min exercise and 30 min recovery with GLU or GLU + FRUC. Values are presented as means $\pm$ SE; $n = 8$. GLU: glucose; GLU + FRUC: glucose + fructose.

TABLE 3: Paired t -test for constructs PWB, PD, and FT of the Subjective Exercise Experience Scale (SEES) comparing GLU + FRUC and GLU and trial 1 and trial 2.

	PWB	PD	FT
GLU + FRUC	21.31 $\pm$ 1.12	4.63 $\pm$ 1.8	8.88 $\pm$ 1.69
GLU	21.50 $\pm$ 1.24	6.00 $\pm$ 0.54	10.38 $\pm$ 1.66
<i>P</i> value	0.743	⁴ 0.036	0.233
Trial 1	21.31 $\pm$ 1.12	5.50 $\pm$ 0.46	9.50 $\pm$ 1.69
Trial 2	21.50 $\pm$ 1.24	5.12 $\pm$ 0.48	9.75 $\pm$ 1.71
<i>P</i> value	0.743	0.623	0.85

⁴Significant difference between GLU + FRUC and GLU ($P < 0.05$).

PWB: physical wellbeing; PD: psychological distress; FT: fatigue. Values are presented as means $\pm$ SE; $n = 8$. GLU: glucose; GLU + FRUC: glucose + fructose.

FIGURE 5: Rate of perceived exertion (RPE) during 60 min exercise with GLU or GLU + FRUC. Values are presented as means $\pm$ SE; $n = 8$. GLU: glucose; GLU + FRUC: glucose + fructose.

relation to timing and frequency of ingestion, concentration and type of CHO, show that hepatic and muscle glycogen is important to maintain performance during exercise.

In the study by Currell and Jeukendrup [26], it was demonstrated that GLU + FRUC improved performance compared to GLU alone. Cyclists improved their average power output by 9% after ingesting a GLU drink ($1.8 \text{ g} \cdot \text{min}^{-1}$) compared to placebo (254 versus 231 W) in a time trial lasting 60 min after an initial 2-hour exercise on a cycle ergometer at 54% $\text{VO}_{2\text{max}}$ following 2 hours on a cycle ergometer. Interestingly, when they ingested a composite GLU + FRUC (ratio 2:1) at $1.8 \text{ g} \cdot \text{min}^{-1}$ there was an additional 8% increase in power output besides the improvement from compared to GLU. These results have been confirmed in other related studies showing improved mountain bike race performance and improved high intensity laboratory cycling performance [27].

On the contrary, Hulston et al. [13] reported similar peak CHO oxidation rates with the ingestion of moderate amounts of isoenergetic GLU ($0.8 \text{ g} \cdot \text{min}^{-1}$) or GLU + FRUC ($0.8 \text{ g} \cdot \text{min}^{-1}$ ratio 2:1) during 150 min cycling at 65% $\text{VO}_{2\text{max}}$. Rowlands et al. [1] reported that low-medium (0.3 – $0.5 \text{ g} \cdot \text{min}^{-1}$) fructose coingestion rates produced the most

FIGURE 6: Subjective Exercise Experience Scale questionnaire comparing GLU and GLU + FRUC ingestion; (a) and visit 1 and visit 2; (b). Values are means $\pm$ SE. * Significant difference between reports of psychological distress between GLU and GLU + FRUC.

efficient use of exogenous carbohydrate. However, fatigue and the perception of exercise stress and nausea are reduced with moderate-high ($0.5\text{--}0.7\text{ g}\cdot\text{min}^{-1}$) fructose doses. Jeukendrup and Moseley [7] reported that ingesting $1.5\text{ g}\cdot\text{min}^{-1}$ GLU + FRUC (ratio 2:1) during 120 min cycling at 61% $\text{VO}_{2\text{max}}$ increases gastric emptying and fluid delivery. GLU + FRUC also attenuated rise in heart rate and lowered perceived exertion compared with GLU.

The result of this present study may be explained by the possibility that the participants did not benefit from the GLU + FRUC mixture because adequate quantities of glucose was not ingested to saturate the glucose transporters in the intestine [27]. Ingesting CHO at rates of $0.8\text{ g}\cdot\text{min}^{-1}$ may not cause the saturation required for increased oxidation. Hence, further ingestion of fructose as part of the CHO may not result in increased CHO oxidation rates [13]. The “maximum” rate of exogenous CHO oxidation may be influenced by the amount of glucose and fructose available for absorption and the “maximum” intestinal transport capacity for glucose and fructose [25, 28]. Thus, the findings of no difference between GLU and GLU + FRUC in this present study was likely as exogenous CHO oxidation is primarily restricted by intestinal CHO absorption when high amounts of CHO are ingested [5]. When ingestion rates are low, availability of CHO is not restricted by intestinal absorption; thus, the addition of a second CHO (FRUC), which uses a second transport mechanism (GLUT-5), may not increase the amount of CHO available for oxidation. Furthermore, according to Jeukendrup [25] the relationship among exercise duration, fitness level, training intensity, and CHO concentration is crucial for the ergogenic effects of CHO consumption. Most studies that have demonstrated significant effects of GLU + FRUC had durations of 2 hours or longer and were performed on relatively well-trained cyclists who often exercised at high-power outputs and had high CHO oxidation rates and energy expenditures. These results are unlikely to be applicable to untrained females and indeed the general population who often exercise for shorter duration (~ 30 min to 1 hour), train

at low to moderate intensity ($50\text{--}60\%$ $\text{VO}_{2\text{max}}$), and have lower CHO oxidation rates. Thus, it is potentially difficult to replicate these studies and the proposed results of improved CHO oxidation from GLU + FRUC in individuals such as the participants reported in this present study.

The outcome of this present study and findings by Hulston et al. [13] both confirm that when moderate amounts ($30\text{ g}\cdot\text{hr}^{-1}$ compared to $48\text{ g}\cdot\text{hr}^{-1}$) of GLU + FRUC or GLU alone are consumed, there is no difference in CHO oxidation. However, in the study by Adopo et al. [10] moderate intake of GLU + FRUC ($50\text{ g}:50\text{ g}$) showed higher rates of exogenous CHO oxidation compared with GLU only (100 g). The apparent difference between the present study and [10] may be explained by differences in total amount of CHO consumed. The subjects ingested 100 g of glucose in 500 mL of water (20% CHO solution) at the start of exercise and the 20% CHO solution was more concentrated than the 7.5% and 6% solution ingested in the present study and the study by Hulston et al. [13], respectively. Hulston et al. [13] also reported that the amount of exogenous CHO oxidised remained the same, despite reducing the GLU in one trial and replacing it with FRUC which has been demonstrated to be oxidised at lower rates [29]. Nonetheless, the results in the present study and that by Hulston et al. [13] are similar to findings by Currell and Jeukendrup [26] showing that FRUC and exogenous GLU ingested during exercise can be oxidised at a similar rate after ingesting 100 g in 1000 mL water.

Walker et al. [12] showed that women maintain lower RER values than men, suggesting an increased reliance on fat oxidation during cycling and running at power outputs between 40 and 75% $\text{VO}_{2\text{max}}$. However, Romijn et al. [30] reported that there was no significant difference in RER at rest and different exercise intensities (25% , 65% , and 85% $\text{VO}_{2\text{max}}$) between endurance trained men and women with comparable training status. Similarly, Tarnopolsky [31] reported a marginal difference in RER and $\text{VO}_{2\text{max}}$ following a 15.5 km treadmill run at 65% $\text{VO}_{2\text{max}}$ in equally trained male and female subjects when results were normalised per

kilogram of body weight. Thus, it is fair to assume that there would be no significant difference between the females in this study and male subjects with matched training status.

CHO ingestion also enhances immediate recovery after exercise. Ivy et al. [32] reported that delaying ingestion of CHO after-exercise (>2 hours) causes reduction of muscle glycogen storage because the highest rates of muscle glycogen synthesis occur within the first hour after exercise. Due to glycogen phosphorylase activation from the preceding glycogen depleting exercise and greater postexercise insulin sensitivity it is suggested to utilise smaller doses of CHO (20–30 g), frequently (20–30 min) for an overall intake rate of $1.2\text{--}1.5\text{ g}\cdot\text{kg}^{-1}\cdot\text{BW}^{-1}\cdot\text{h}^{-1}$ to maximize postexercise glycogen resynthesis rates [33]. Wallis et al. [9] reported that GLU and GLU + FRUC (2:1 ratio) ingestion at a rate of $90\text{ g}\cdot\text{h}^{-1}$ are equally effective at restoring muscle glycogen in exercised muscles during recovery from exhaustive exercise. The present study also showed similar rates of reduction in postexercise CHO oxidation after ingesting 150 mL of both nutritional solutions at 15 min intervals and immediately after cessation of a 60 min cycling bout which suggests a similar rate of postexercise glycogen muscle storage. In the novel study by Wallis et al. [9] where a glycogen-depleting exercise bout was followed by a 4-h recovery period with ingestion of an 18% GLU or isoenergetic GLU + FRUC solution. It was concluded that GLU and GLU + FRUC (2:1 ratio) solutions, ingested at the start of exercise and every 30 min thereafter, are equally effective at restoring muscle glycogen in exercised muscles during recovery from exhaustive exercise. The rate of ingestion was $90\text{ g}\cdot\text{h}^{-1}$ during exercise, 460 mL (83 g of CHO) with a further 220 mL (40 g of CHO) every 30 min for the duration of the recovery period [9]. These findings demonstrate indirectly that FRUC is not detrimental to postexercise muscle glycogen synthesis when coingested with GLU.

Jeukendrup et al. [34] observed similar systemic glucose appearance rates with GLU or GLU + FRUC ingestion despite strong indirect evidence that total CHO delivery was augmented with GLU compared with GLU + FRUC during exercise. This implies that splanchnic glucose output was similar for GLU + FRUC and GLU during exercise. This could be attributed to the failure of GLU + FRUC to increase systemic GLU availability since glucose is the major precursor for postexercise skeletal muscle glycogen synthesis. However, splanchnic glucose output in response to a glucose load has been reported to be enhanced by exercise with the effect attributed to increased intestinal glucose absorption [35]. Thus, increased splanchnic glucose output in the post-exercise period could conceal potential differences in CHO availability and, therefore, muscle glycogen storage between trials. Based on current evidence, consuming large amounts of GLU, GLU polymers, sucrose, or GLU + FRUC (2:1 ratio) immediately and at regular intervals (approximately every 15–30 min) represents an effective nutritional strategy to promote rapid muscle glycogen storage during the initial 4 h of recovery from exhaustive exercise [9].

The rate of perceived exertion and cardiovascular response to exercise were not statistically significant between

the beverages. The fatigue and wellbeing subscales of the SEES were similar for both nutritional solutions while the distress component was significantly lower after GLU + FRUC. Exercises that are perceived more positively are likely to foster exercise adoption and adherence [36] and exercise intensity is negatively related to both pleasure [37] and adherence [38]. Ekkekakis and Petruzzello [37] showed that there were no significant differences in RPE among 3 modes of exercise: cycle ergometer, treadmill, and stair-stepper. Similarly, all subjects self-selected work rates within the moderate range of the guidelines of 50–85% $\text{VO}_{2\text{max}}$ for each mode of exercise [39]. Hence, the present study sought to determine the impact of GLU or GLU + FRUC on HR and RPE during cycle ergometry at moderate intensity. The findings of no difference in HR and RPE between the two conditions in this study are similar to results by Hamilton et al. [35] in sedentary women who completed a 60 min walk on a motorised treadmill with oxidation rates of $0.7\text{ g}\cdot\text{min}^{-1}$ to $0.86\text{ g}\cdot\text{min}^{-1}$. Also, Daley and Welch [40] observed no significant difference in RPE in endurance-trained men in four experimental trials with CHO ingestion rates each of $1.8\text{ g}\cdot\text{min}^{-1}$. Gastrointestinal (GI) discomfort was reported in all except the glucose plus sucrose trial.

Comparable findings of no difference in RPE were also reported by Glass and Chvala [39] in a study comparing GLU and GLU + FRUC at an ingestion rate of $1.2\text{ g}\cdot\text{min}^{-1}$ and $2.4\text{ g}\cdot\text{min}^{-1}$, respectively. However, there were no differences in GI discomfort between the two experimental trials apart from one subject who reported severe GI problems in the GLU + FRUC trial. Conversely, the study by Jeukendrup and Moseley [7] contradicts this present study finding as the authors reported that GLU + FRUC ingestion at the rate of $1.5\text{ g}\cdot\text{min}^{-1}$ attenuated the rise in heart rate and resulted in lower ratings of perceived exertion with no report of GI discomfort or nausea compared to GLU. None of the drinks caused any GI symptoms or nausea and the findings were attributed to GLU + FRUC attenuating the disturbances in the resting state that occurred with exercise.

Compared to males, there is a dearth of physical activity information for females and it is necessary to consider psychological exercise experience in females to gain insight into the underrepresentation of females in leisure activity [40]. Hence, this study compared the perceptions of exercise experience (SEES) two days after exercise. There was no significant difference in psychological wellbeing (PWB) and fatigue after ingesting GLU or GLU + FRUC, but a higher distress was demonstrated with GLU compared to GLU + FRUC 2 days after exercise. Further, comparison of SEES on GLU and GLU + FRUC for each subject revealed no significant difference in the three subscales. Daley and Welch [40] reported that exercise positively influences psychological states of both active and inactive females after 20 min low-intensity (50–55% age-adjusted HR maximum) and high-intensity (80–85% age-adjusted HR maximum) treadmill exercise. Both groups reported higher PWB scores in the low-intensity exercise but changes in PWB across time on SEES before exercise, 10 mins during, and 5 mins after, were only observed in the high-intensity condition. A study by

Kilpatrick et al. [41] showed no difference in fatigue with SEES for subjects after 30 mins of maximal cycling at 60% $\text{VO}_{2\text{max}}$ with assessment of participants 15 mins after exercise. However, there was a reported increase in PWB and decrease in fatigue. Kilpatrick et al. [41] reported that SEES was measured immediately after completion of exercise and after quiet rest for 15 mins. This is contrary to this present study which involved assessment of participant's subjective exercise experience 48 hours after completing 60 mins bout of cycling. In another study by Cox et al. [42], it was reported that 30 min aerobic exercise at 50% and 75% $\text{VO}_{2\text{max}}$ resulted in increased PWD and fatigue and reduced distress in male subjects during exercise. Furthermore, assessment with the SEES at 30 and 60 min after exercise revealed increased PWB and decreased fatigue and distress. This present study utilized 60 mins of cycling exercise with SEES assessment 48 hours later and it is difficult to draw a conclusion from comparison of the results of this present study and other studies [40–42]. There is a wide variation in reported exercise duration, intensity, and timing of postexercise effect assessment. However, it is suggestive that immediate postexercise effect may be positively influenced by aerobic exercise of short duration and low-to-moderate intensity. Also, recall problems may arise when assessment is not conducted after the exercise session.

Respondents on the telephone have been found to be slightly more likely to choose one of the extreme categories in the case of questions involving response scales [43] and this may account for the outcomes from this study. Although it cannot be confidently asserted that telephone methods systematically improve or damage data quality relative to face-to-face methods, there may be an interaction with whether the prospective respondent agrees to be interviewed in the first place. The respondents in this study agreed to be interviewed 48 hours after each of the experimental trials, but the timing of the interview was not agreed upon. However, studies specifically designed to assess multiple dimensions of effect may help understand the complex nature of adherence to exercise programmes [44]. Specifically, further studies in untrained individuals should measure constructs such as enjoyment and perception of exercise difficulty, since this category of subjects may require more motivation to maintain endurance exercise as recommended by the ACSM/AHA [45].

Generalising the findings of this study to the broader population may be difficult due to the narrow demographic of the current sample and the low-to-moderate fitness level of the subjects. However, this sample is quite representative of the general population in terms of fitness level. The result of this study may be due to lower rates of CHO ingestion compared with previous studies. However, the contribution of exogenous glucose to energy provision during prolonged high-intensity endurance exercise is limited to approximately $1.0\text{--}1.1\text{ g}\cdot\text{min}^{-1}$, even when ingested in quantities up to $\sim 3.0\text{ g}\cdot\text{min}^{-1}$ [5]. On the other hand, fructose when ingested in isolation or in combination with glucose is oxidised at rates of $\sim 0.38\text{ g}\cdot\text{min}^{-1}$ [34].

Also, a relatively small sample size could have contributed to the overall result and a larger number of subjects could have detected smaller differences between both groups. According to Bengtsson et al. [18] factors such as individual diet and training status contribute to differences in substrate utilisation in women. The subjects in this study were allowed to take a light breakfast on the day before each exercise trial. Although, exercising in the fasted state will maximise fat oxidation, this is not always a practical option for the general population and there are many health benefits of eating breakfast. Providing an isoenergetic breakfast that is weighed, prepackaged, and distributed to each subject may control potential confounders [28].

5. Conclusion

The present study has shown that combined ingestion of moderate amounts of glucose and fructose during 60 min cycling resulted in peak CHO oxidation rates of $0.8\text{ g}\cdot\text{min}^{-1}$ and did not increase total CHO oxidation compared to glucose alone in untrained females. The recovery period after exercise also revealed similar total CHO and fat oxidation in both trials. The heart rate response to exercise, perceived exertion, and postexercise experience of fatigue and wellbeing were similar in both trials. However, experience of distress was higher in the glucose alone compared to glucose plus fructose. The present findings support the suggestion that, in order to achieve high CHO oxidation rates ($\sim 1.7\text{ g}\cdot\text{min}^{-1}$), it may be necessary to consume a mixture of glucose plus fructose at higher intake rates ($1.2\text{ g}\cdot\text{min}^{-1}$ glucose + $1.2\text{ g}\cdot\text{min}^{-1}$ fructose).

Ethical Approval

The study protocol was approved by the Nottingham University Medical School Research Ethics Committee (approval no.B/03/2010).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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