



Research Paper

Effects of carbohydrate and protein supplementation during resistance exercise on respiratory exchange ratio, blood glucose, and performance

David M. Laurenson^{a,*}, Danielle Jane Dubé^b^a Department of Exercise Science and Sport Studies, Springfield College, Springfield, MA, USA^b Department of Business, University of Connecticut, Hartford, CT, USA

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ABSTRACT

Introduction: Athletes must determine whether they will benefit most from exercise in the fasted or fed state when discussing variables such as substrate oxidation, muscle anabolism, and performance.

Objective: To determine the effects of a carbohydrate plus protein (C + P) beverage consumed during resistance exercise on respiratory exchange ratio (RER), blood glucose, and performance.

Methods: Ten resistance trained male subjects completed two bouts of exercise consisting of seven sets of squats and bench presses using 60% of their one repetition maximum (1RM). Subjects consumed C + P during one trial, and a non-caloric placebo (P) in the other. Six sets of each exercise were performed for a predetermined number of repetitions, followed by a seventh set of each exercise for as many repetitions as possible, performed as explosively as possible. Power was measured during the final set of each exercise. Glucose was measured pre, during, and post exercise. RER was measured seven times during each session. **Results:** No significant difference in power was found. C + P resulted in significantly greater work in the bench press ($p < 0.05$), with no difference in the squat ($p = 0.10$). Post-exercise glucose was significantly greater ($p < 0.05$) in C + P vs. placebo. In C + P, post-exercise glucose was significantly greater ($p < 0.05$) than before or during exercise. For RER, a significant effect was found for time ($p < 0.05$), with no difference between conditions.

Conclusion: In active males, C + P ingestion during resistance exercise improved bench press performance and increased blood glucose, but does not appear to affect RER.

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Introduction

Many athletes consume nutritional supplements in an effort to maximize the results from their exercise training. Proper nutrient intake is vital in attaining optimal adaptations to exercise, with the greatest benefits seen when nutrients are ingested in close proximity to the exercise bout [1–3]. When carbohydrates and amino acids are consumed immediately before resistance exercise, protein

synthesis following exercise is greater compared to when carbohydrates and amino acids are consumed immediately following resistance exercise [4]. Consuming a pre-workout supplement containing carbohydrate and protein provides additional fuel for the athlete while simultaneously increasing levels of blood glucose and insulin [5]. Insulin serves several roles in the body, including the stimulation of cellular glucose uptake [6], increasing the rate of protein synthesis [7], and inhibiting protein breakdown [8]. Such effects may be viewed as positive among athletes, especially those involved in strength and power sports.

Another role of insulin is to inhibit lipolysis [9], which may be viewed as a negative consequence among individuals attempting to decrease body fat as a primary objective of their exercise program. Carbohydrate supplementation 1 h prior to endurance exercise [10], or 4 h prior [11] results in increased insulin along with increased carbohydrate availability, which causes the body to favor carbohydrate over lipid as a fuel source. A beverage containing a 4:1 carbohydrate to protein ratio administered immediately before and during endurance exercise leads to higher rates of carbohydrate

Abbreviations: RER, respiratory exchange ratio; C + P, carbohydrate plus protein.

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Dr. David Laurenson contributed to the study design, subject recruitment, and ran all exercise testing sessions. Danielle Dube was responsible for data recording, instrumentation, and preparation and administration of the test beverages.

* Corresponding author. 219 York St. Stoughton, MA 02072, USA. Tel.: +1 781 975 1202.

E-mail address: DaveLaurenson@hotmail.com (D.M. Laurenson).

oxidation and lower rates of lipid oxidation [12]. Miller et al. demonstrated an attenuated rise in plasma free fatty acids when subjects ingested carbohydrate or non-fat milk during endurance exercise, compared to placebo [13]. Athletes and recreational exercisers may experience a dilemma in deciding whether or not to supplement during their workout, depending on their priorities regarding promoting muscle anabolism and accelerating recovery from exercise, or maximizing lipolysis and lipid oxidation in an effort to decrease body fat. The purpose of the present investigation was to examine differences in performance, blood glucose, and respiratory exchange ratio (RER) which may occur when carbohydrates and protein are consumed during an acute bout of resistance exercise compared to when the same exercise bout is conducted while consuming a non-caloric placebo. Variables measured included power output, total volume of work, blood glucose, and RER. Blood glucose measurements were taken immediately before, once during, and immediately after two identical resistance training protocols. RER was measured during each of the two exercise sessions (supplement vs. placebo) at seven time points.

Methods

Subject characteristics are presented in Table 1. Subjects completed an informed consent and medical history questionnaire and were free of any medical conditions including diabetes. RER was measured using the Cosmed K4B2 portable metabolic system (Cosmed USA, Chicago, IL). Blood glucose was measured using the Bayer Contour blood glucose monitor (Bayer Health Care, Mishawaka, IN). Blood samples were taken from the fingertip via capillary puncture. Power output was measured using the Tendo Unit (Tendo Sport Machines, Trencin, Slovak Republic). The supplement used in the present study was an 8% solution of glucose and hydrolyzed whey protein at an approximate 3:1 carbohydrate to protein ratio. The serving administered during the supplement trial (48 g dissolved in 600 mL of water) provided approximately 36 g of carbohydrate and 12 g of protein (approximately 392 kcal). During the placebo trial, subjects ingested the same volume of a non-caloric naturally flavored placebo beverage. Both the supplement and placebo were flavored with non-caloric natural orange cream flavoring. The beverages were consumed in two equal doses of 300 mL each at 12 and 26 min into exercise. Both the supplement and placebo were manufactured by True Protein Laboratories Inc. (Oceanside, CA).

Exercise protocol

Subjects completed three visits to the laboratory for testing. The first session was to determine their 1RM on the back squat and bench press. 1RM refers to the maximum resistance with which an individual can perform a single repetition. The other two testing sessions involved multiple sets with 60% of their predetermined 1RM, once while consuming C + P, and once while consuming a placebo. Glucose was measured before, during, and following exercise. RER was measured before, three times during, and three times following exercise, for a total of 7 RER measurements. Power and work were measured during the final set of each exercise.

Table 1
Descriptive statistics for subjects

Variable	Mean	s	N
Age (yrs)	25.3	6.07	10
Weight (lbs)	184.2	28.86	10
Height (in)	70.0	3.71	10
1RM squat (lbs)	300.5	70.65	10
1RM bench (lbs)	236.5	52.50	10

Power was calculated with the Tendo unit, and work was calculated by multiplying resistance by repetitions.

The exercise protocol was as follows:

- 10:00 Pre-exercise RER measurement (RER T1)
- 07:00 Pre-exercise glucose measurement (glucose T1)
- 05:00 Dynamic warm-up

(All exercises performed using 60% 1RM; each set was estimated to be approximately 30 s in duration; subjects rested for 2 min between sets unless otherwise noted)

- 00:00 Squats × 12
- 02:30 Bench × 12
- 05:00 Squats × 11
- 07:30 Bench × 11
- 08:00 Six Minute rest – RER measured over min 1–4 (RER T2)
- Glucose measured at minute 4 (glucose T2)
- First half of the beverage consumed during minutes 4–6
- 14:00 Squats × 10
- 16:30 Bench × 10
- 19:00 Squats × 9
- 21:30 Bench × 9
- 22:00 Six Minute rest – RER measured over min 1–4 (RER T3)
- Second half of the beverage consumed during minutes 4–6
- 28:00 Squats × 8
- 30:30 Bench × 8
- 33:00 Squats × 7
- 35:30 Bench × 7
- 36:00 Six Minute rest – RER measured over min 1–4 (RER T4)
- 42:00 Squats × Max Power and Reps (up to 15) (5 min rest)
- 48:00 Bench × Max Power and Reps (up to 15) (exercise concluded)
- RER measurement over min 1–4 post-exercise (RER T5)
- Glucose measured at min 4 post-exercise (Glucose T3)
- RER measurement over min 12–15 post-ex (RER T6)
- RER measurement over min 27–30 post-ex (RER T7)

Statistical analyses

Two repeated measures *t*-tests were performed to examine differences in power output during the final set of squats and bench presses between the supplement and placebo conditions. Two additional repeated measures *t*-tests were performed comparing the total volume of work (resistance in kg × number of repetitions) subjects were able to complete during the final set of each exercise between the two conditions. A 2 × 3 repeated measures Analysis of Variance (RM-ANOVA) was used to assess differences in blood glucose between conditions and across time periods. The three time periods were pre, during (12 min into exercise), and post exercise (53 min from the start of exercise; or 4 min post exercise). A 2 × 7 RM-ANOVA was performed to assess differences in RER between conditions and across time. RER was measured at seven time points during each exercise session. One measurement was taken pre-exercise; three measurements were taken during exercise (min 12, 26, and 40); and three measurements were taken during recovery from exercise (min 4, 15, and 30 post exercise).

Results

Power

No significant mean difference was found in peak power for squats between the supplement ($M = 1083 \pm 290$) and placebo ($M = 1061 \pm 271$) conditions ($p = 0.45$). No significant mean

Table 2
Descriptive statistics of mean values of muscular power output for the squat and bench press^a

Exercise	Placebo		Carbohydrate + protein	
	Mean	SD	Mean	SD
Squat	1060.8	271.3	1082.9	289.6
Bench press	543.6	138.0	552.1	150.7

^a Power represents the average of the best 3 repetitions performed in each set reported in Watts.

difference was observed in peak power for bench presses between the supplement ($M = 552 \pm 151$) and placebo ($M = 544 \pm 138$) conditions ($p = 0.70$). Results for power are presented in Table 2.

Work

When comparing the volume of work between conditions, no significant difference was found in total work (resistance in $\text{kg} \times \text{reps}$) for squats between the placebo ($M = 909 \pm 472$) and supplement ($M = 1009 \pm 433$) conditions ($p = 0.10$). However, subjects performed significantly more work in the bench press in the supplement ($M = 921 \pm 365$) vs. the placebo ($M = 783 \pm 332$) condition ($p = 0.01$). Results for work are presented in Table 3.

Blood glucose

A 2×3 RM-ANOVA was used to examine differences in blood glucose between conditions (supplement vs. placebo) and across time points (pre, during, and post exercise). The supplement was distributed following the second blood glucose measurement. A significant interaction was found between condition and time period for blood glucose ($p = 0.008$). A simple effects test was computed to determine where the significant mean differences occurred. When comparing time differences for the supplement condition, no significant mean difference was found between pre vs. mid exercise ($p > 0.05$). In contrast, blood glucose was significantly higher post exercise compared to both pre ($p = 0.003$) and during ($p = 0.001$) exercise. No significant mean differences were found when comparing differences in blood glucose among the three time points for the placebo condition ($p > 0.05$). No significant mean difference in blood glucose was found between conditions for pre ($p = 0.63$) or during ($p = 0.21$) exercise. However, blood glucose was significantly higher following exercise in the supplement compared to placebo condition ($p = 0.01$). Results for blood glucose are presented in Table 4.

RER

A 2×7 RM-ANOVA was computed to examine differences in RER over time and between conditions. RER was measured pre-exercise, three times during exercise, and three times following exercise. No

Table 3
Descriptive statistics of mean values for total volume of work completed (resistance in $\text{kg} \times \text{number of repetitions}$) in the squat and bench press

Exercise	Placebo		Carbohydrate + protein	
	Mean	SD	Mean	SD
Squat	909	472	1009	433
Bench press	783	332	921 ^a	365

^a Total volume of work in the bench press significantly higher in the supplement condition ($p = 0.01$).

Table 4
Descriptive statistics of mean values for blood glucose^a

Time	Placebo		Carbohydrate + protein	
	Mean	SD	Mean	SD
Pre exercise	75.7	7.8	76.9	9.3
Mid exercise	81.3	12.9	77.5	11.3
Post exercise	84.9	18.9	110.1 ^{b,c,d}	21.2

^a Glucose = mg/dL .

^b Significantly greater than pre exercise in the C + P condition ($p = 0.003$).

^c Significantly greater than mid exercise in the C + P condition ($p = 0.001$).

^d Significantly greater than post exercise values during the placebo condition ($p = 0.01$).

significant interaction was found between condition and time for RER ($p = 0.51$). No significant mean difference was found between conditions for RER ($p = 0.44$). A significant mean difference for RER was found across time points ($p = 0.00$). RER was significantly higher at time 1 compared to time 7 ($p < 0.05$), and significantly lower than times 2, 3, 4, and 5 ($p < 0.05$). RER at time 1 was not significantly different from time 6 ($p > 0.05$). RER at time 2 was significantly higher than times 3, 4, 5, 6, and 7 ($p < 0.05$). RER at time 3 was significantly higher than times 4, 6, and 7 ($p < 0.05$), and not significantly different from time 5 ($p > 0.05$). RER at time 4 was not significantly different from time 5 ($p > 0.05$), but was significantly higher than times 6, and 7 ($p < 0.05$). RER at time 5 was significantly higher than times 6 and 7 ($p < 0.05$). RER at time 6 was not significantly different from time 7 ($p > 0.05$). Results for RER are presented in Table 5.

Discussion

Some researchers have reported no performance benefit of supplementation during an acute bout of resistance exercise [14,15], whereas Haff et al. suggested an ergogenic benefit of consuming nutrients during resistance exercise [16]. In the present study, the only performance benefit seen was an increase in work capacity for the bench press. The additional fuel provided by the supplement may have aided performance, perhaps by sparing muscular glycogen. The difference in work capacity for the squat did not reach statistical significance ($p = 0.10$). Perhaps the results would have been different if the timing and amount of supplement ingested were changed. Also, the exercise type and duration, as well as initial glycogen levels, are likely to impact whether or not performance differences can be seen with supplementation.

Blood glucose was well maintained during exercise in the placebo condition, and increased in response to C + P ingestion. Blood glucose is regulated by glucose release into the blood stream, either from digested carbohydrates or hepatic glucose production, and glucose disposal, or uptake by cells. Glucose was measured via capillary puncture. Having subjects consume a beverage containing labeled glucose would have provided a more detailed picture of the contribution of the ingested beverage to changes in blood glucose. Since blood glucose was well maintained during the placebo condition, one may infer that the exercise protocol was not long or intense enough to threaten blood glucose homeostasis. In the present study, liver glucose output, whether from glycogenolysis or gluconeogenesis, was able to meet the demands of exercise during the placebo condition. Subjects were instructed to fast for at least 8–10 h prior to testing, and to record and match their food intake for 72 h prior to each testing session. Perhaps if the exercise bout had been greater in duration and/or volume, and if subjects were glycogen depleted at the beginning of exercise, a greater performance difference may have been observed. Also, the addition of an aerobic portion following the resistance exercise protocol would

Table 5
Descriptive statistics of mean values for respiratory exchange ratio^a

Time	Placebo		Carbohydrate + protein		Overall	
	Mean	SD	Mean	SD	Mean	SD
1. Pre Ex	0.79	0.05	0.82	0.05	0.81 ^b	0.01
2. Min 12 Ex	1.31	0.08	1.28	0.13	1.30 ^c	0.03
3. Min 26 Ex	1.16	0.09	1.20	0.11	1.18 ^d	0.02
4. Min 40 Ex	1.10	0.09	1.11	0.10	1.10 ^e	0.02
5. Min 4 Rec	1.08	0.12	1.12	0.09	1.10 ^f	0.03
6. Min 15 Rec	0.77	0.11	0.78	0.10	0.77	0.02
7. Min 30 Rec	0.70	0.10	0.76	0.09	0.73	0.02

All $p < 0.05$.

^a Respiratory exchange ratio average values over one minute.

^b Time 1 significantly less than times 2, 3, 4, 5, and 7.

^c Time 2 significantly greater than times 3, 4, 5, 6, and 7.

^d Time 3 significantly greater than times 4, 6, and 7.

^e Time 4 significantly greater than times 6, and 7.

^f Time 5 significantly greater than times 6, and 7.

have offered another way to compare performance differences. During the placebo condition, no nutrients were consumed and thus blood glucose was maintained by glycogenolysis and gluconeogenesis. The increase in blood glucose seen after subjects consumed the supplement may have been due to increased glucose release from splanchnic tissue. In retrospect, a fourth glucose measurement taken 30 min following exercise may have helped to determine if glucose levels would return to baseline after 30 min of recovery in the supplement condition, and if 30 min of recovery would have led to any glucose changes in the placebo condition.

RER is a widely used measure in studies examining aerobic exercise, and has been examined less in studies involving resistance exercise [17–20]. In the present study, RER was measured throughout exercise in an effort to examine potential differences in fuel oxidation when nutrients are consumed during resistance exercise vs. when no nutrients are ingested. One aim of the study was to examine if the supplement would improve performance at the expense of limiting lipid oxidation. Many people who engage in physical activity are concerned more with changing body composition than with exercise performance. RER can provide us with an estimate of how much relative fuel is being oxidized from carbohydrates vs. lipids. RER changed significantly over time in both conditions, although the conditions were not statistically different from one another. The first RER measurement was taken before the start of exercise. The second was taken after two sets of each exercise, but before any beverage was consumed. The third was taken following two more sets of each exercise, and one half of the beverage. The fourth was taken following two more sets of each exercise, and the second half of the beverage. The fifth was taken following the final (7th) set of each exercise (conclusion of exercise). The sixth and seventh RER measurements were taken following 15 and 30 min of recovery from exercise, respectively. As expected, RER rose from rest to exercise during both the supplement and placebo trials, and returned toward normal during recovery. However, no differences in RER between conditions were found, suggesting that the supplement did not cause a statistically significant difference in fuel oxidation between the two conditions.

Results from the present study are in agreement with Ormsbee et al., who reported a decrease in RER from before to after resistance exercise, indicating a shift toward greater lipid oxidation during recovery from exercise compared to pre-exercise [20]. In the present study, RER was significantly lower 30 min following exercise compared to pre-exercise. At 30 min post-exercise, RER in the placebo condition was 0.70 ± 0.032 compared to 0.76 ± 0.029 in the supplement trial, suggesting a greater reliance on lipid oxidation during recovery in the placebo trial, however no statistical significance was found. Following the 2×7 ANOVA, a repeated measures

t-test was used to examine for differences at time 7 only. However, no significant difference was found. Perhaps if a third portion of the beverage had been consumed immediately following exercise, or if RER was measured beyond 30 min of recovery, perhaps for 1–2 h post exercise, we may have witnessed an elevated recovery RER compared to placebo by allowing ample time for the ingested glucose to be metabolized. Although RER during exercise was not statistically different between trials, RER values during exercise were higher in the present study compared to other studies. Other researchers have reported slight differences in respiratory measurements when comparing the portable Cosmed K4b2 system to laboratory based metabolic carts [21–23].

Several possibilities exist for future research. Measuring insulin and indicators of lipolysis such as glycerol would help to determine the effects of nutrient ingestion during resistance exercise on lipolysis. A longitudinal study would be interesting as well. Subjects could be divided into two groups and perform identical exercise programs for several weeks. One group could exercise while fasted, while the other group could supplement during exercise. Researchers could compare differences in body composition and performance improvements over time, as well as indicators of overall health such as insulin sensitivity, and markers of inflammation. Also, similar studies on diabetic and pre-diabetic patients could provide information regarding proper dietary and exercise prescriptions in order to manage blood glucose during and following exercise. In conclusion, in healthy active males, nutrient ingestion during resistance exercise improved upper body muscular endurance, but had no effect on power or substrate use as indicated by RER. The question remains as to whether supplementation during exercise will improve performance at the expense of lipid oxidation, and whether exercise in the fasted state will enhance lipid oxidation at the expense of limiting performance.

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