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The Effects of Pre-Exercise Carbohydrate Supplementation on Resistance Training Performance During an Acute Resistance Training Session

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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Abstract

It appears that "carbohydrate loading" may enhance the performance of resistance training, but studies on CHO supplementation prior to a resistance-training bout are limited and have resulted in conflicting findings. PURPOSE: To investigate the effects of pre-exercise CHO supplementation on high-intensity (>75% 1RM) resistance training performance for resistance-trained women during an acute bout of resistance exercise. METHODS: Thirteen resistance trained female participants (21.9 ± 4.8 yrs; 64.5 ± 3.0 in; 137.0 ± 14.8 lbs) came to the Exercise and Performance Nutrition Laboratory on three separate occasions; the day of the Familiarization Trial (FT) and the two Exercise Testing sessions (ET1 and ET2, respectively) all separated by seven days. Familiarization testing determined each participant's 1RM of the bench press and leg press and then 75% of the bench press 1RM and 85% of the leg press 1RM was determined. The participants were then randomly assigned to either the CHO or P treatment session using a double blind, counterbalanced technique in a cross-over design with each participant consuming 1.0 g CHO/kg body weight or a non-caloric P beverage 60 minutes before beginning the exercise bout for each ET. The total volume of weight lifted during five sets of the bench press, the total volume of the weight lifted during five sets of the leg press, and whole body total lifting volume was analyzed by a two-way repeated measures within subjects ANOVA with significance set at $P < .05$. RESULTS: There was no statistically significant difference between the CHO and P treatments in the three variables analyzed.

Specifically total volume of weight lifted in pounds during five sets of the bench press was 3,200 (± 912) and 3,152 (± 852) ($p = 0.655$), total volume of weight lifted during five sets of the leg press was 44,004 (± 29,711) and 37,705 (± 19,681) ($p = 0.136$), and total lifting volume was 47,204 (± 30,399) and 40,857 (± 20,434) for the CHO and P treatment, respectively ($p = 0.138$). CONCLUSIONS: Pre-exercise CHO supplementation does not improve high-intensity resistance training performance for resistance-trained women during an acute resistance training session. PRACTICAL APPLICATIONS: It is evident that consuming CHO 60 minutes prior to performing resistance training exercises will not increase the number of sets, repetitions, or total work volume completed during acute high-intensity (>75% 1RM) resistance training sessions for women. During lower-intensity resistance training sessions, however, pre-exercise CHO supplementation may provide ergogenic effects and enhance resistance-training performance.

Chapter 1: Introduction

For quite some time research has shown that significant muscle glycogen depletion occurs following aerobic endurance-type exercise. Recently, there is evidence that similar effects on muscle glycogen occur during intermittent anaerobic- type exercise, such as resistance training (Roy & Tarnopolsky, 1998). Scientific literature supports the theory that intermittent activities stimulate significant glycogenolytic effects, and therefore it appears that a similar effect on muscle glycogen occurs during the performance of resistance training exercises (Haff, Lehmkuhl, McCoy, & Stone, 2003). Several studies have demonstrated a significant decrease in muscle glycogen after resistance training and other forms of high-intensity intermittent exercises (Lambert, Flynn, Boone, Michaud, & Rodriguez-Zayas, 1991). These studies have led to the belief that glycogenolysis seems to be an important energy source during high-intensity resistance training (Haff et al., 2003). Therefore, several studies have investigated the effects that resistance training has on skeletal muscle glycogen depletion, specifically the extent of muscle glycogen depletion following one bout of resistance training.

One study, for example, demonstrated that muscle glycogen content in the vastus lateralis was decreased by 17% following the completion of three sets of isokinetic leg extensions that were performed at 120 degrees per second (Haff et al., 2003). Similar investigations showed a reduction in muscle glycogen by 13% following 10 repetitions of bicep curls, a 25% decrease following three sets of 10 repetitions, and a 31% glycogen reduction in response to performing leg extensions to muscle failure (Haff et al., 2003).

Overall, these studies emphasize the importance of glycogen in providing energy "fuel" during resistance training and show that one bout of resistance training can significantly reduce glycogen stores within the body.

This resulting glycogen depletion significantly affects performance during resistance training. Gollnick, Armstrong, Sembrowick, Shepherd, and Saltin (1973) claim that such reduction in glycogen content, especially in fast-twitch fibers, significantly decreased the ability of the fibers to function during the heavy work involved in resistance training, which may ultimately hinder performance. Several negative outcomes of decreased muscle glycogen concentration can lead to a decrease in overall resistance training performance (Haff et al., 2000). Studies have also demonstrated decreased isokinetic force production and reduced isometric strength following a resistance-training bout, which resulted in diminished resistance training performance (Haff et al., 2003). There may be a way to combat these negative results and prevent significant glycogen depletion following resistance training with carbohydrate supplementation (Hargreaves, Hawley, & Jeukendrup, 2004).

It is known that carbohydrate stores within the body provide the major sources of energy or "fuel" necessary for exercise (Burke, Kiens, & Ivy, 2004). Much attention has focused on maximizing carbohydrate (CHO) stores and minimizing the negative effects of glycogen depletion (Hargreaves et al., 2004). Resistance training performance during a routine that results in significant muscle glycogen depletion may theoretically benefit from CHO supplementation prior to exercise (Haff et al., 2000). It appears that "carbohydrate loading" may enhance the performance of intermittent, high-intensity exercise, such as the performance of resistance training (Hargreaves et al., 2004).

Hatfield et al. (2006) explain that since glycogenolysis is an important source of energy during resistance training, the effects of CHO supplementation may enhance resistance-training performance. Several studies have shown that CHO supplementation prior to and during resistance training can decrease the rate of muscle glycogen depletion, help to maintain daily glycogen stores, and ultimately improve performance (Haff et al., 2003; Volek, 2003).

While substantial evidence exists for the use of CHO supplementation to restore glycogen concentration levels following an exercise bout, studies on CHO supplementation prior to a resistance-training bout are limited and have resulted in conflicting findings. The discrepancies between the conflicting results seem to be due to the differences between the duration and intensity of the resistance training bout as well as the type of resistance exercise (Haff et al., 2003). The studies that demonstrated ergogenic effects used resistance-training protocols that lasted longer than 50 minutes while the studies that failed to demonstrate ergogenic effects used protocols that lasted less than 40 minutes and isokinetic exercises. Haff et al. (2003) claim that while the data in existing literature seems to support the ergogenic benefits of CHO supplementation on resistance training performance, the relationship between pre-exercise CHO supplementation and resistance training performance is somewhat unclear.

Problem Statement

Of the few studies that do attempt to investigate the relationship between pre-exercise CHO supplementation and the performance of a resistance training bout, only one study has investigated the effect of CHO supplementation on the ability to perform work at intensities greater than 70% 1 repetition maximum (1RM) (Kulik et al., 2008).

The majority of studies have focused on the performance of multiple bouts of resistance exercises with low-to-moderate intensities (<70% 1RM) rather than higher-intensity training bouts commonly performed to achieve hypertrophic adaptations (Kulik et al., 2008). Furthermore, the previous investigations have only used male participants. No published studies have attempted to investigate the ergogenic effects of pre-exercise CHO supplementation on resistance training performance for female subjects. The limited investigations hinder the reliability of the evidence that supports the use of CHO supplementation prior to a resistance-training bout in order to enhance resistance-training performance. Therefore, the purpose of this study is to investigate the effects of pre-exercise CHO supplementation on high-intensity resistance training performance for resistance-trained women during an acute bout of resistance exercise.

Study Variables

The independent variable, or manipulation, in this investigation is the pre-exercise supplemental treatment given to the participants. There are two levels of the independent variable: the CHO supplement (GlycoCharge ®, a commercially available waxy maize starch) and the placebo (P) supplement (a non-caloric beverage identical in volume and similar in taste, texture, and color). Consuming the CHO beverage is similar to drinking Gatorade® or PowerAde® sports drinks and does not pose a significant risk to the participants. The P beverage is sugar-free Kool-Aid® that is commercially available. The dependent variables in this investigation are collectively referred to as resistance training performance, and are total lifting volume of the bench press performed at 75% 1RM (sets X repetitions X weight), total lifting volume of the leg press performed at 85% 1RM (sets X repetitions X weight), and total body lifting volume(sets X repetitions X weight). The effects of participant's resistance training experience level and neurological adaptations will be controlled for by ensuring that each female participant performed resistance training exercises at least twice a week for six months prior to testing. An extraneous variable that cannot be controlled for, however, is the amount of effort put forth by the participants during the testing sessions. If a participant does not put forth maximum effort during the experimental trials, the results may not be valid.

Hypotheses

Ho1: There will be no difference between the CHO supplement group and the P group in bench press total volume (sets X repetitions X weight).

Ho2: There will be no difference between the CHO supplement group and the P group in leg press total volume (sets X repetitions X weight).

Ho3: There will be no difference between the CHO supplement group and the P group in whole-body total volume (sets X repetitions X weight).

Conceptual Model

The theoretical foundation for this investigation is based on previous research studies that have investigated the effects of CHO supplementation on resistance training performance. It has been reported that acute resistance training sessions significantly decrease muscle glycogen stores by 24-40%, depending on the intensity, duration, and workload of the session (Kulik et al., 2008). It seems that the higher intensities (>70% 1RM) elicited an increased rate of muscle glycogenolysis and caused a deleterious effect on training performance and adaptations (Kulik et al., 2008). Lambert et al. (1991) further states that total muscle glycogen levels can be reduced by as much as 40-50% after six sets of six repetitions performed at 70% 1RM. This data serves as the foundation for selecting the resistance training protocol of five sets at 75% and 85% 1RM for the bench press and leg press, respectively, in the present investigation. Furthermore, this type of resistance training protocol is commonly used by resistance-trained individuals with resistance training experience to attain muscle hypertrophy (Lambert et al., 1991). The female participants in this present investigation are considered resistance trained and have resistance training experience, and any potential increases in resistance training performance with CHO supplementation may enhance their performance during the experimental session.

The overall workload or length of the training session also seems to play a large role in determining the extent of ergogenic effects of the CHO supplement (Kulik et al., 2008). It appears that the studies that demonstrated ergogenic effects of CHO supplementation lasted longer than 40 minutes due to an increased reliance on exogenous blood glucose from the supplement (Haff et al., 2003). Haff et al. (1999) suggested that the longer duration of the resistance exercise session used in their study may explain why the CHO supplement elicited an increase in overall performance compared to the shorter duration of the study by Conley et al. (1995), which did not elicit ergogenic effects. Based on these studies, the resistance training session in the present investigation will last longer than 40 minutes in order to elicit a need for exogenous blood glucose when muscle glycogen levels are significantly depleted. As previously mentioned, the negative effects of limited glycogen levels manifest as increases in muscle weakness and decreases in maximal force production, which ultimately hinder the performance of an individual. Any techniques that may attenuate glycogen levels, such as CHO supplementation, may result in maintenance or enhancement of resistance training performance (Kulik et al., 2008). Enhancing resistance training performance by attenuating muscle glycogenolysis will significantly benefit women who resistance train and female athletes who aim for increased muscular strength for improved athletic performance.

Operational Definitions

The term "resistance trained" women is defined as non-sedentary female participants who are physically active at least three days per week (or a total of 90 minutes per week) and have performed resistance training twice a week for at least six months prior to the investigation. "Resistance training performance" will be measured by the bench press total volume, leg press total volume, and the whole-body total volume of work (sets X repetitions X weight) completed during the bench press and leg press performed at 75% and 85% 1RM, respectively. "Muscular failure" will be achieved when the participant can no longer lift the weight, when the participant is unable to maintain appropriate technique due to muscular fatigue, or when the participant voluntarily terminates the exercise due to exhaustion.

Assumptions

The first assumption is that the selected CHO beverage (GlycoCharge®) actually does what the manufacturer claims and that "Drinking GlycoCharge® through your workout helps to provide immediate energy, minimize fatigue, maintains peak performance levels, acts as an anti-catabolic and keeps the muscles feeling full" (Scott, J., 2008)." Additionally, the manufacturer claims that "GlycoCharge® helps maximize glycogen energy storage, increases hydration and promotes increased muscularity" (Scott, J., 2008). It is also stated on the product label that amylopectin, the glucose polymer in GlycoCharge® is rapidly absorbed, recharging energy immediately. It is assumed that the supplement is capable of sufficiently enhancing muscle glycogen stores and will provide immediate energy in order to enhance resistance-training performance.

It is also assumed that the selected exercises in this experiment will elicit significant glycogen depletion in order to demonstrate glycogen maintenance with pre-exercise CHO supplementation compared to the placebo supplementation. Scientific literature demonstrates that the extent of glycogen depletion depends on the types of strength tests used (Leveritt & Abernethy, 1999). Muscle glycogen depletion has been shown to reduce isometric strength, while isokinetic strength is unaffected by glycogen depletion (Leveritt & Abernethy, 1999). Therefore, the bench press and leg press exercises that will be used in this investigation are isotonic, rather than isokinetic, in nature and are expected to significantly decrease muscle glycogen stores.

Lastly, it is assumed that each participant will be physically capable of completing five sets of repetitions to muscular failure of the bench press and of the leg press in order to complete the exercise protocol. If the participant is unable to initiate movement and overcome the inertial force at the beginning of a set, then the tester will assist the participant in lifting the weight in order to overcome inertia and increase the chance of completing five sets. It must also be assumed that each participant understands and will follow specific instructions involved in this investigation. The participants will be asked to record and follow a two-day pre-testing diet prior to both experimental trials, to refrain from alcohol and vigorous physical activity 48 hours before each experimental trial, and to put forth maximal effort throughout the experiment. To ensure that these instructions will be followed, each participant will be asked to record a two-day log and list their daily diet and physical activity 48 hours before the testing session each week throughout the length of the experiment.

Limitations

The limitations of this investigation pertain to sample and intensity of the exercises. For this study, resistance trained female participants will be recruited from the University of South Florida (USF) recreational center and Exercise Science and Physical Education classes, and they may not sufficiently represent the larger population of women who perform resistance training exercises. Since the sample may not accurately represent the population, the significance and generalizability of the results may be hindered. Additionally, the intensity level of the resistance exercises may be too high. Scientific literature supports the belief that the performance of six sets of a single exercise at 85% 1RM may not allow the participants to exercise for long enough to elicit a significant glycogenolytic effect and thus increase the need for CHO supplementation (Kulik et al., 2008). Nevertheless, it is highly likely that muscle glycogen stores will be significantly affected during the present investigation and that CHO supplementation will attenuate the rate of glycogen depletion. Furthermore, the participants may not be physically able to complete five sets of each exercise, which will hinder the validity of the performance measurements. If the participant is unable to initiate movement, then the tester will assist the participant in lifting the weight in order to overcome inertia and increase the chance of completing five sets.

Delimitations

The specific limitations, or delimitations, that are imposed by the research design pertain to participant selection and exercise selection. As previously mentioned, the participants are resistance-trained women who will be recruited from the USF recreation center and Exercise Science and Physical Education classes to represent the larger resistance trained female population. The participants will range in age, height, weight, body composition, relative strength, and physical activity level, which may increase generalizability. Each participant, however, will have participated in resistance training exercises at least twice a week for at least six months prior to testing in order to provide familiarization with specific resistance exercises while also reducing neurological adaptations. An additional delimitation was selecting only the bench press and leg press exercises to represent isotonic exercises. The bench press is a common exercise for upper body strength gains, as is the leg press for lower body strength gains, and both exercises are expected to elicit glycogen depletion during the performance of five sets of repetitions to muscular failure at 75% and 85% 1RM, respectively.

Significance

The effects of CHO supplementation on performance during an acute resistance training session have direct importance for individuals or athletes who perform resistance training in hopes of gaining or maintaining muscular strength. Research has shown that glycogen concentration is significantly decreased during an acute bout of resistance training, which then leads to reduced strength and force production and an overall reduction in resistance training performance (Haff et al., 2000). Based on the vast scientific literature, the implementation of CHO supplementation may counteract the decrease in muscle glycogen stores, which could then result in enhanced resistance training performance (Kulik et al., 2008). Theoretically, CHO supplementation may prevent these deleterious effects on may allow the individual or athlete to train at higher intensities, perform more work during a resistance training session, and potentially increase physiological adaptations associated with high-volume resistance training routines typically used in the hypertrophy phase (Haff et al., 2003). While it seems highly plausible that CHO supplementation will have ergogenic effects on the resistance training performance during an acute resistance training session, previous investigations have lead to equivocal findings and further research is needed to clarify the relationship between CHO supplementation and resistance training performance.

Only one study has investigated the effects of CHO supplementation on resistance training performed at intensities greater than 70% 1RM (Kulik, 2008). This particular study found that CHO supplementation does not enhance resistance training performance at 85% 1RM, which was an unexpected finding based on previous literature. No studies have investigated this relationship in women who participate in regular resistance training. Recent studies on “carbohydrate loading” have provided evidence that women respond differently than males and are less able to increase and maintain glycogen stores (Burke et al., 2004). Furthermore, women tend to restrict their daily caloric intake in general, which further reduces glycogen stores and hinders resistance training performance (Burke et al., 2004; Leveritt & Abernethy, 1999).

Since women are already at a disadvantage to counteract the deleterious effects of glycogenolysis during resistance training, it is important to investigate the potential ergogenic effects of CHO supplementation prior to a resistance training session. Therefore, this investigation aims to provide the necessary evidence to show whether women will benefit from CHO supplementation when performing a resistance training session at 75% and 85% 1RM. This information will be especially important for female strength and conditioning professionals or strength athletes who perform resistance training routines similar to those seen during the strength / hypertrophy phase of a periodization cycle (Kulik et al., 2008).

Chapter 2: Review of Literature

Muscle Glycogen Depletion Studies

For quite some time research has shown that significant muscle glycogen depletion occurs following aerobic endurance-type exercise. Studies have demonstrated that similar effects on muscle glycogen occur during anaerobic-type exercises as well (Roy & Tarnopolsky, 1998). Scientific literature supports the theory that intermittent, anaerobic activities, such as resistance training, stimulate significant glycogenolytic effects (Haff et al., 2003). While the magnitude of glycogen depletion is not as significant as that seen with endurance training, glycogenolysis seems to be an important energy source during high-intensity resistance training (Roy & Tarnopolsky, 1998; Haff et al., 2003). Therefore, several studies have investigated the effects that resistance training has on skeletal muscle glycogen depletion, specifically the extent of muscle glycogen depletion following one bout of resistance training.

One study in particular demonstrated that muscle glycogen content in the vastus lateralis was decreased by 17% following the completion of three sets of isokinetic leg extensions performed at 120 degrees (Haff et al. 2000). This investigation demonstrated a 26% decrease in muscle glycogen of the vastus lateralis during a multi-set resistance-training session. The multi-set session included back squats, speed squats, and single leg squats performed at 65, 45, and 10% of 1RM (Haff et al. 2000).

Similar investigations showed a reduction in muscle glycogen by 13% following 10 repetitions of bicep curls, a 25% decrease following three sets of 10 repetitions, and a 31% glycogen reduction in response to performing leg extensions to muscle failure (Haff et al., 2003). Another study reported a glycogen content degree of depletion of -40.6 and -44.3 mmol/kg wet weight following the performance of eight sets of six single leg knee extensions at 70% of 1RM (until 50% of full knee extension was no longer possible) (Pascoe, Costill, Fink, Robergs, & Zachwieja, 1993). Glycogen concentration was also reported to decrease by 20% in response to completing five sets of 10 repetitions of 45% of 1RM, by 39% after completing six sets of six repetitions of leg extensions performed at 70% of 1RM, and by 38% when the six sets of six repetitions were performed at 35% of 1RM (Haff et al., 2003).

A handful of these investigations also demonstrated a fiber-type specific reduction in glycogen content during the resistance training. These studies show a Type II fiber bias with greater glycogen content depletion in the Type II fibers compared to Type I fibers. In a study conducted by Tesch, Ploutz-Snyder, Ystrom, Castro, & Dudley (1998), a 40% decrease in muscle glycogen occurred following the performance of five sets of 10 repetitions at 45% of 1RM, with a 30% decrease in glycogen content of Type IIa and IIb fibers. The majority of studies investigated by Volek (2003) demonstrated a decrease in muscle glycogen by approximately 30-40%, especially in Type II fast-twitch muscle fibers. This phenomenon is due to the fact that fast-twitch muscle fibers are more heavily recruited during resistance training due to its short-term, high-intensity nature. Evidence shows that the first fibers to undergo glycogen depletion during heavy resistance training are the slow-oxidative, high-glycolytic, fast-twitch fibers (Gollnick et al., 1973). Pascoe and Gladden (1996) further explain this idea by stating that the Type II fast-twitch fibers have greater levels of glycogen phosphorylase activity than Type I slow-twitch fibers and, thus, promotes greater depletion in glycogen concentrations.

Importance of Glycogen as Fuel

These studies emphasize the importance of glycogen in providing energy during resistance training. Haff et al. (2003) further concludes that these studies suggest that the amount of glycogen depletion depends on the amount of work completed during the resistance-training bout. It has been reported that the rate of glycogenolysis is dependent on load and magnitude of muscle force development (Hatfield et al., 2006). It seems that a resistance training bout that is designed for muscle hypertrophy with high repetitions (8-12) and moderate-to-high loads may result in greater glycogen depletion than a resistance training bout designed for endurance training with lower loads (Haff et al., 2003). Furthermore, it appears that higher-volume resistance training (involving moderate-to-heavy loads) significantly depletes Type II fibers with higher glycolytic enzyme activity.

Effects on Performance

This glycogen loss significantly affects performance during resistance training. Gollnick et al. (1973) claim that such a reduction in glycogen, especially in fast-twitch fibers, significantly decreased the ability of the fibers to function during the heavy work involved in resistance training, which may ultimately hinder performance. Haff et al. (2003) add to this theory. They claim that the "preferential depletion of Type II fibers during high-intensity exercise…may compromise the performance of resistance training and ultimately lead to a decrease in performance" (p.188). Several negative outcomes of decreased muscle glycogen concentration, including decreased isokinetic force production, reduced contractile force necessary to sustain exercise load, reduced isometric strength, and accentuated muscle weakness, led to a decrease in overall resistance training performance (Haff et al., 2000). There may be a way to combat these negative results and prevent significant glycogen depletion following resistance training with proper nutritional supplementation.

Use of Carbohydrate Supplementation

Investigators have suggested the use of CHO supplementation to reduce the muscle glycogen loss that results from a resistance-training bout (Haff et al., 2003). It appears that "CHO loading" may enhance the performance of intermittent, high-intensity exercise, such as the performance of resistance training (Hargreaves et al., 2004). Glycogen stores are significantly influenced by daily CHO in the diet, and CHO supplementation is very important in maintaining daily glycogen levels, which can potentially increase the benefits of training (Haff et al., 2003). Furthermore, Hatfield et al. (2006) explain that since glycogenolysis is an important source of energy during resistance training, the effects of CHO supplementation may enhance resistance-training performance.

Reasons for Improved Performance

There may be several reasons for why CHO supplementation improves resistance-training performance when taken prior to a resistance-training bout. Ingestion of CHOs before exercise has been shown to increase muscle glycogen, which serves as an explanation for increased performance (Hargreaves et al., 2004). While the exact mechanism is unclear, it is likely related to the maintenance of blood glucose and insulin concentrations. One study observed higher blood glucose levels prior to and immediately after resistance training exercises when participants consumed CHOs, while another study observed similar elevations in blood glucose levels before and after a resistance-training bout in the CHO supplemented group compared to the placebo group (Haff et al., 2003). Haff et al. (2003) conclude that the elevation in blood glucose levels with CHO supplementation “result in … a reduction in muscle glycogen utilization during an exercise bout…and that blood glucose plays a critical role in fueling glycolysis” (p.189).

Elevations in blood glucose also impact the hormonal response to resistance training and may result in an enhanced anabolic environment, thus, ultimately enhance performance (Haff et al., 2003). Insulin, for example, is a hormone that functions to enhance the storage of glycogen. CHO ingestion prior to resistance training might be expected to increase insulin concentration, which then should theoretically increase muscle glycogen stores and resistance training performance (Haff et al., 2003). Another hormone, known as Growth Hormone, is involved with the growth process of skeletal muscle and stimulated through hypoglycemia induced by insulin (Haff et al., 2003). With this knowledge, it can then be said that the “CHO-induced” increased insulin may increase growth hormone levels and may enhance hypertrophy and resistance training performance (Haff et al., 2003). One study demonstrated that compared to a placebo, a CHO supplement consumed before and immediately after a resistance training bout enhanced the acute growth hormone response (Volek, 2003).

Conflicting Findings

While substantial evidence exists for the use of CHO supplementation to restore glycogen concentration levels following an exercise bout (Pascoe et al., 1993; Roy &

Tarnopolsky, 1998; Costill, 1991; MacDougall, Ward, Sale, & Sutton, 1977; Burke et al., 2004), several studies on CHO supplementation prior to a resistance training bout have resulted in conflicting findings. Several studies have demonstrated the potential ergogenic effects of consuming CHOs just prior to a resistance-training bout (refer to table 1 at the end of chapter 2) while others have shown no ergogenic effects whatsoever (refer to table 2 at the end of chapter 2) (Dalton, Walberg, Rankin, Sebolt, & Gwazdauskas, 1999). One case examined the effects of pre-exercise liquid high CHO feeding prior to a weight training session on work, power, and fatigability (Vincent, Clarkson, Freedson, & DeCheke, 1993). In order to stress the glycolytic energy system, the exercise session consisted of 12-15 repetitions with 60 seconds of rest in between sets, but the results showed no difference in performance between the liquid CHO treatment or the placebo treatment. Thus, the investigators concluded that liquid high CHO ingestion did not increase resistance-training performance (Vincent et al., 1993).

Conley et al. (1995) investigated the effects of CHO supplementation on resistance training performance during set of 10 repetitions performed at 65% 1RM. Participants consumed either a CHO or a placebo supplement 15 minutes before and after every successful set. The results showed no significant increase in number of sets, repetitions, or total work in the CHO group compared to the placebo group, and therefore the CHO supplementation did not enhance performance during the resistance training session (Conley et al., 1995). Another study resulted in similar findings. Kulik et al. (2008) investigated the effects of supplemental CHO ingestion on the performance of squats to exhaustion (STE), which consisted of sets of five repetitions at 85% 1RM. The participants consumed 0.3g/kg of a CHO or placebo supplement (approximately 20.5

grams for a 150lb person) immediately before exercise and after every successful STE, and performance was measured in total sets, repetitions, volume load, and total work (Kulik et al., 2008). There was no statistical difference between treatments, and therefore the results suggest that CHO supplementation does not enhance resistance-training performance during the performance of STE (Kulik et al., 2008).

Other investigations, on the other hand, have demonstrated reduced muscle glycogen depletion and resistance training performance enhancement following CHO supplementation. One study explored the effects of CHO supplementation on muscle glycogen loss during a bout of resistance training (Haff et al., 2000). This study found that the consumption of a CHO beverage prior to and during an acute bout of resistance training can decrease the rate and amount of muscle glycogen loss. The exercise protocol consisted of three sets of 10 repetitions of back squats at 65% 1RM, speed squats at 45% 1RM, and single-leg squats at 10% 1RM (Haff et al., 2000). The training bout resulted in a 26.7% decrease in muscle glycogen content in the placebo treatment, but only a 13% decrease when the CHO beverage was implemented (Haff et al., 2000). Haff et al. (2000) claim that the decreased rate of glycogenolysis is related to an increase in glycogen synthesis during the rest periods between set, which indicates that the consumption of a CHO beverage can attenuate the muscle glycogen depletion associated with isotonic resistance training (Haff et al., 2000).

Another study conducted by Lambert et al. (1991) investigated the effects of CHO supplementation on the performance of multiple-sets performed at 80% of 10RM until muscular failure. The results suggest that pre-exercise CHO supplementation “elevates glucose and lactate levels in the blood and tends to enhance resistance training performance during a multiple-bout resistance session" (Lambert et al., 1991, p.192). The elevated lactate was thought to be the result of an increase in the rate of glycolysis due to the enhanced substrate availability from the CHO supplementation (Lambert et al., 1991). Another study examined the effects of CHO supplementation or a placebo on the ability to perform multiple sets of squat exercises. The results showed that, compared to the placebo, the CHO supplementation significantly increased the mean number of sets, number of repetitions, and duration completed (Volek, 2003).

Haff et al. (2003) describe another study that supports enhanced resistance training performance with CHO supplementation. The subjects participated in a multiple session resistance exercise program consisting of a morning resistance session, four hours of recovery, and then the performance of sets of squats to exhaustion (STE) (Haff et al., 1999). A CHO supplement or a placebo beverage was consumed during the morning session, recovery period, and the STE and performance measured in number of sets, repetitions, and duration were statistically different between treatment trials. The results showed that the CHO supplement increased performance compared to the placebo supplement, which suggests that "CHO supplementation enhances the performance of multiple STEs during the second workout on a given day" (Haff et al., 1999, p.116). In summary, evidence shows that CHO supplementation prior to and during a resistance training bout can attenuate the rate of muscle glycogen depletion, help to maintain daily glycogen stores, and ultimately improve performance (Haff et al., 2003; Volek, 2003).

The discrepancies between the previous studies seem to be due to the differences between the duration and intensity of the resistance training bout as well as the type of resistance exercise (Haff et al., 2003). The studies that demonstrated ergogenic effects used resistance-training protocols that lasted longer than 40 minutes while the studies that failed to demonstrate ergogenic effects used protocols that lasted less than 40 minutes and isokinetic exercises. Haff et al. (2003) claim that while the data in existing literature seems to support the ergogenic benefits of CHO supplementation on resistance training performance, the relationship between pre-exercise CHO supplementation and resistance training performance is somewhat unclear.

Of the previous studies that attempted to investigate the relationship between pre-exercise CHO supplementation and the performance of a resistance-training bout, none have discovered the effect of CHO supplementation on the ability to perform work at intensities greater than 70% 1RM (Kulik et al., 2008). The majority of studies have focused on the performance of multiple bouts of resistance exercises with low-to-moderate intensities (<70% 1RM) rather than higher-intensity resistance training bouts commonly performed to achieve hypertrophic adaptations (Kulik et al., 2008). Previous studies have also investigated the effects of CHO supplementation on the performance of lower body *or* upper body resistance exercises, rather than the performance of lower body *and* upper body resistance training exercises performed in one resistance-training bout.

The previous investigations have only used male participants. No published studies have attempted to investigate the ergogenic effects of pre-exercise CHO supplementation on resistance training performance for female subjects. The limited investigations hinder the reliability of the evidence that supports the use of CHO supplementation prior to a high-intensity resistance training session in order to enhance resistance-training performance. Therefore, the purpose of this study is to investigate the effects of pre-exercise CHO supplementation on high-intensity resistance training performance for resistance trained women during an acute resistance training session.

Table 1: Studies that demonstrate the ergogenic effects of consuming CHOs just prior to a resistance training bout.

Study	**CHO Dosage/ Timing**	**Exercise Bout**	**Duration of Exercise Bout**	**Performance Outcome**
Haff et al. (1999)	.3kg/kg during morning session, 4 hrs of recover, and during sets of STE	Sets of 10 repetitions of squats performed at 55% 1RM (to failure)	~ 77 minutes	Increased # of sets, repetitions, and duration. CHO enhances performance of multiple STE's during 2nd workout of the day.
Lambert et al. (1991)	1g/kg immediately before and .17g.kg after the 5th, 10th, and 15th sets	Leg extensions Sets of repetitions to failure with 80% 10RM	~ 56 minutes	Performance (# of sets and repetitions) was greater for CHO group and approached significance.
Haff et al. (2001)	.3kg/g immediately before	16 sets of 10 repetitions of isokinetic leg extensions (120˚s)	~57 minutes	Increase in amount of work performed with significantly greater torque generated by the quadriceps for CHO group.

Table 2: Studies that failed to demonstrate the ergogenic effects of consuming CHO's just prior to a resistance training bout.

Study	**CHO Dosage / Timing**	**Exercise Bout**	**Duration of Exercise Bout**	**Performance Outcome**
Kulik et al. (2008)	.3g.kg immediately before and after every other set of 5 reps	STE of sets of 5 reps to exhaustion at 85% 1RM	~ 29 minutes	No statistical improvements in sets, reps, volume load, or work performed
Haff et al. (2000)	1g/kg 10 min prior and .3g/kg every 10 min	Initial isokinetic leg ext before and after 3 isotonic leg exercises	~ 39 minutes	CHO group decreased muscle glycogen depletion but did not improve performance
Conley et al. (1995)	15 minutes before and after every set	Sets of 10 repetitions at 65% 1RM to failure	~ 35 minutes	No significant difference in # of sets, reps, or total work
Vincent et al. (1993)	16 oz. beverage (100g CHO) immediately before	Pre-&post-isokinetic tests after (Sets) exercise: (5) squats, (5) leg press, (4) leg curls, (3) leg ext, (3) calf press, (4) barbell curl, (3) preacher curl, and (3) dumbbell curl (all 12-15 reps)		No significant improvements in total work, average power, peak torque, or work fatigue

Chapter 3: Methods

Participants

Fourteen resistance trained female participants between the ages of 18 and 35 years-old were recruited from the USF Exercise Science and Physical Education classes and the USF Campus Recreation center in Tampa, Fl. Participants varied in age, height, weight, relative strength, physical activity level, and resistance training experience level. Descriptive characteristic are presented in Table 3 in the results section. Prior to the investigation, each participant was informed of the potential benefits and risks associated with participation and signed an informed consent in accordance with the Institutional Review Board (IRB). Each participant was cleared by a physician and met the specific criteria in order to participate. Each participant underwent a medical examination by a physician from Bayfront Medical Center in St. Petersburg. The physician signed a medical clearance form for each participant and indicated whether the participant had been cleared (or not cleared) to participate in this study. Additionally, each participant was required to fill out a USF Exercise Science Program Pre-Activity Screen Questionnaire (PASQ) form. From the responses on the form, the physician determined whether the participant was “low, moderate, or high risk” and only those classified as “low risk” were cleared to participate. Participants were all healthy, resistance trained collegiate women that are physically active at least three days per week (or for a total of 90 minutes per week) and have performed resistance training exercises at least twice a week for at least six months prior to testing to control for neurological adaptations and to ensure familiarization with the specific exercises (i.e. bench press and leg press).

Instrumentation

Height and weight were measured to the nearest half inch and pound (lb) respectively, on a Health' O Meter Professional ® scale. 1RM bench press and leg press was determined based on standard National Strength and Conditioning (NSCA) guidelines for 1RM testing.

Equipment

The bench press was performed using a Valor BF-3 Olympic Bench Max (St. Petersburg, Fl) bench and a completed repetition was determined from a straight-arm starting position until the bar touched the participant's chest and then back to the starting position. The leg press was performed using a Nebula 6000-A 35˚leg press (Russia, OH) and a completed repetition was determined from a starting position (with the weight resting and knees in full extension) to knees bent at 90˚ and the sled touched the springs, and then back to starting position. Statistical analyses were performed using IBM® SPSS® Statistics (version 19).

Procedures

The following procedures were based off previous studies conducted by Lambert et al. (1991), Haff et al. (2000), and Kulik et al. (2008). Testing consisted of a familiarization trial (FT) and two experimental trials (ET1 and ET2). The participants came to the Exercise and Performance Nutrition Laboratory after an overnight fast at the same time in the morning on three separate occasions; the day of the FT and the two different ETs (ET1 and ET2, respectively). Each testing session was separated by seven days. Familiarization testing determined each participant's 1RM of the bench press and leg press following the NSCA guidelines for 1 RM testing. After a period of familiarization with the bench press, the participant performed a light warm-up with a resistance that easily allowed five to 10 repetitions. After a one-minute rest, 10-20 lbs was added to allow the participant to complete three to five repetitions. After a two-minute rest, another 10-20 lbs was added to allow the participant to complete two to three repetitions. After three minutes of rest, another 10-20 lbs was added and the participant then attempted a 1RM. If the participant was successful at lifting that weight, she was allowed a rest period of three minutes and another 10-20 lbs was then added. This process continued until the participant completed only one repetition with proper exercise technique (Baechle & Earl, 2000). The same process was repeated for the leg press, with 30-40 lbs added each time. Then the 1RM bench press and leg press measurements were used to determine 75% and 85% 1RM weight, respectively, for each participant. The FT was also used as a familiarization session for the experimental protocol and to reduce the probability of a learning effect (Lambert et al., 1991). After the 1 RM testing, the participants performed a familiarization trial with three sets of the bench press at 75% of their 1RM and then three sets of the leg press at 85% of their 1RM.

The participants were then randomly assigned to either the carbohydrate (CHO) or placebo (P) treatment session. All treatments were administered using a double blind, counterbalanced technique in a cross-over design with each participant receiving only one of the treatments on each of the ETs (Haff et al., 2000). During the ETs, the participants consumed either a CHO or P beverage 60 minutes before beginning the exercise session. The ETs were conducted on the second and third visits to the laboratory following the protocol from the FT, all separated by approximately one week. Participants were also required to record their diet and total calories consumed two days prior to the first ET and to eat the same diet and amount of calories during the two days prior to the second ET to maintain pre-exercise glycogen levels (Haff et al., 2003). The research designed is outlined in Figure 1 (Appendix A).

Familiarization Trial

During the FT, each participant's 1RM bench press and leg press was measured. Then 75% of the bench press 1RM and 85% of the leg press 1RM was determined for each participant for each exercise and remained constant throughout each trial. Subjects then participated in a FT consisting of only three sets of each exercise to become familiarized and to reduce a learning effect (i.e. a measurable improvement in performance from ET1 to ET2 regardless of treatment) (Lambert et al., 1991). All testing sessions were conducted with the participant's safety as a priority, under the supervision of a trained study staff member and spotter. The trained spotter assisted the participant with safely returning the bar to the stacks when she was no longer able to lift the weight. The leg press exercise was performed on a Nebula 6000-A 35˚leg press (Russia, Oh) equipped with a safety lock and under the supervision of at least one spotter to ensure the participant's safety.

Participants then performed a set of as many repetitions at 75% 1RM on the bench press as they could until they reached fatigued and were no longer able to lift the weight. The trained spotter assisted the participant with safely returning the bar to the stacks when she was no longer able to lift the weight. The recovery period between each set was three minutes, during which the participant was permitted to sit up, walk around, or drink water as she wished. The participants then repeated this process for a total of three sets with a three-minute rest interval between each set. Next, the participants rested for five minutes before repeating the same process on the leg press performed at 85% of the leg press 1RM. The leg press exercise was performed on a Nebula 6000-A 35˚leg press (Russia, Oh) equipped with a safety lock and under the supervision of at least one spotter to ensure the participant's safety. Each participant performed the leg press for a total of three sets and was permitted to sit up, walk around, or drink water as she wished during the three-minute recovery intervals. The resistance training protocol design is outlined in Table 5 in appendix A. The exercise testing was stopped for a participant if it appeared that the beverage or exercise tests were harming the individual. The testing was also stopped at anytime if requested by the participant for any reason. If a participant became severely ill or injured during the exercise testing, the session was stopped immediately.

Experimental Testing

Each participant arrived at the USF Exercise and Performance Nutrition Laboratory in the morning after an overnight fast without eating or drinking anything for breakfast besides water. During each ET session, participants ingested either a CHO supplement (commercially available waxy maize starch) consisting of 1.0 g CHO/kg body weight or a non-caloric placebo beverage (sugar-free Kool-Aid, which is identical in fluid ounces and similar in taste, texture, and color) approximately 60 minutes before beginning the exercise bout. The dosage of the CHO supplement is based on a relative amount per body weight in kilograms (1.0 g CHO/kg) with 10 oz of water per 30 g CHO. For example, an average female weighing 130 lbs (59 kg) would consume about 60 g CHO mixed into 20 oz of water (or 20 oz of the P beverage) 60 minutes before beginning the exercise session. The participant consumed either supplement A or B out of a Styrofoam cup with a lid and straw, one being the CHO supplement and the other being the P supplement. Approximately 60 minutes after ingestion, the participant performed the designated resistance training protocol from the FT (outlined in Table 5). Again, each set was performed at 75% of the bench press 1RM and 85% of the leg press 1RM until muscular fatigue with three minutes of rest between sets. Number of completed repetitions to failure was recorded for the five sets of the bench press and then the participant rested for five minutes. The participant then walked over to the leg press machine and the process was repeated for the leg press exercise performed at 85% of the leg press 1RM. This whole process was then be repeated for each participant approximately one week later, with the only difference being the supplementation given prior to the exercise session (i.e. those participants who received supplement A during ET1 then received supplement B and vice versa).

Pretreatment Dietary Controls

Participants were required to record their food intake in a daily journal for two days prior to the first ET and to attempt to repeat this diet for the two days prior to the second ET. Participants were also instructed to refrain from consuming alcohol or engaging in vigorous physical activity during these two days and received detailed descriptions on methods of measuring and recording dietary intake in their daily journal (Kulik et al., 2008).

Supplement Schedule

During each ET session, participants ingested either a CHO supplement consisting of 1.0 g CHO/kg body weight or a non-caloric P beverage approximately 60 minutes before beginning the exercise bout. The dosage of the CHO supplement is based on a relative amount per body weight in kilograms (1.0 g CHO/kg) with 10 oz of water per 30 g CHO. This supplementation schedule is based off previous studies that involved CHO supplementation and resistance training (Kulik et al., 2008; Lambert et al., 1991; Haff et al., 1999). Additionally, the peak glucose concentration of the slow digesting starch waxy maize has been shown to occur after 60 minutes of ingestion (Sands, Leidy, Hamaker, Maguire, & Campbell, 2009). Waiting 60 minutes after ingesting either the CHO supplement ensured peak glucose concentration for optimum energy source during the exercise bout.

Performance Measurements

Total number of completed repetitions to muscular failure during five sets of the bench press at 75% 1RM, as well as the total number of completed repetitions to muscular failure during the five sets of the leg press at 85% 1RM was recorded and analyzed. The whole-body total volume from the combined exercises was also analyzed to determine resistance training performance during the ET's. Repetitions were determined by the total number completed to muscular failure (Kulik et al., 2008).

Statistical Analysis

Resistance training performance was analyzed to determine the ergogenic effects of CHO supplementation compared to the P supplementation via three primary parameters – the total volume of weight lifted during five sets of the bench press, the total volume of the weight lifted during five sets of the leg press, and whole body total lifting volume (the sum of bench press total weight lifted and leg press total weight lifted). Mean differences in performance between trials was analyzed by a two-way repeated measures within subjects ANOVA with significance set at $P < .05$. Statistical analysis was performed using IBM® SPSS® Statistics (version 19). All values are expressed as mean ± standard deviation. Effect size was also calculated using the partial eta squared formula and all values are reported in the results section.

Chapter 4: Results

Participants

Fourteen resistance-trained women between the ages of 18 and 35 were recruited for this study, with 13 participants completing the experimental testing. One participant become ill immediately after ingesting the supplemental beverage and was excused from the exercise testing. Her data was not included in the analysis or results. Descriptive characteristics for the 13 participants are presented in Table 3.

Table 3: Participant Descriptive Characteristics

Characteristic	**Mean (Standard Deviation ±)**
Age	21.9 (4.8)
Height (in)	64.5 (3.0)
Weight (lbs)	137.0 (14.8)
Bench Press 1RM	94.6 (15.5)
Leg Press 1RM	443.8 (110.8)

Resistance Training Performance

Table 4 presents a summary of the resistance training performance measures for both the CHO and P treatments for the three primary parameters. Ho1 stated there would be no difference between the CHO supplement treatment and the P treatment in bench press total volume. There was no statistically significant difference between the CHO and P treatments when examining the total volume of weight lifted during five sets of the bench press (p = 0.655). Therefore, the Ho1 could not be rejected. Ho2 stated there would be no difference between the CHO supplement treatment and the P treatment in leg press total volume. There was no statistically significant difference between the CHO and P treatments when examining the total volume of weight lifted during five sets of the leg press (p = 0.136). Therefore, the Ho2 could not be rejected. Ho3 stated there would be no difference between the CHO supplement treatment and the P treatment in total body lifting volume. There was no statistically significant difference between the CHO and P treatments when examining total lifting volume (p = 0.138). Therefore, the Ho3 could not be rejected.

Table 4: Resistance Training Performance. Data is presented as mean (± sd).

Variable	**Carbohydrate**	**Placebo**	**P value**	**Partial Eta Squared**
Bench Press Total Volume (lbs.)	3,200 (912)	3,152 (852)	.655	.017
Leg Press Total Volume (lbs.)	44,004 (29,711)	37,705 (19,681)	.136	.176
Total Body Lifting Volume (lbs.)	47,204 (30,399)	40,857 (20,434)	.138	.174
# of Repetitions Completed for the Bench Press	45.2 (11.0)	44.5 (9.7)	.644	.018
# of Repetitions Completed for the Leg Press	112.4 (59.3)	97.5 (38.1)	.118	.191
Exercise Duration (min.)	46.15 (3.65)	45.69 (3.12)	.539	.032

Chapter 5: Discussion

The primary finding of the present investigation is that pre-exercise CHO supplementation does not improve high-intensity resistance training performance for resistance-trained women during an acute resistance training session. Compared to the placebo, the CHO supplement did not offer any ergogenic effects on resistance training performance during five sets of repetitions to failure of the bench press performed at 75% 1RM or during five sets of repetitions to failure of the leg press performed at 85% 1RM for the resistance trained female participants. These findings contradicted the findings from other investigations that have shown that CHO supplementation prior to and during an acute resistance training session elicits an ergogenic effect. In addition, several investigators have demonstrated reduced muscle glycogen depletion and resistance training performance enhancement following CHO supplementation (Haff et al., 1999; Haff et al., 2001, and Lambert et al., 1991).

The study by Haff et al. (2000) explored the effects of CHO supplementation on muscle glycogen loss during a bout of resistance training and found that the consumption of a CHO beverage prior to and during an acute bout of resistance training can decrease the rate and amount of muscle glycogen loss. Similarly, Lambert et al. (1991) investigated the effects of CHO supplementation on the performance of multiple-sets performed at 80% of 10RM until muscular failure. It was reported that pre-exercise CHO supplementation elevated blood glucose and tended to enhance resistance-training performance, but did not reach statistical significance, during a multiple-bout resistance session (Lambert et al., 1991). Evidence from other investigations shows that CHO supplementation prior to and during a resistance training bout can attenuate the rate of muscle glycogen depletion, help to maintain daily glycogen stores, and ultimately improve performance (Haff et al., 2003; Volek, 2003).

It has been speculated that the ergogenic effects of pre-exercise CHO supplementation are linked to the amount of glycogenolysis that results during resistance training (Kulik et al., 2008). Haff et al. (2000) demonstrated that muscle glycogen content in the vastus lateralis was decreased by 17% following the completion of three sets of isokinetic leg extensions. Glycogen concentration was also reported to decrease by 20% in response to completing five sets of 10 repetitions of 45% of 1RM and by 39% after completing six sets of six repetitions of leg extensions performed at 70% of 1RM (Haff et al., 2003). These results suggest that higher intensity (>70% 1RM) bouts of resistance training have the potential to increase the rate of glycogenolysis (Kulik et al., 2008). While muscle glycogen content was not measured in the present investigation, it can be assumed that significant glycogenolysis occurred during the five sets of repetitions to failure of the bench press and the five sets of repetitions to failure of the leg press performed at 75% and 85%, respectively. Theoretically, it is likely that the inclusion of a pre-exercise CHO supplement should have attenuated muscle glycogen depletion.

The present investigation, however, did not demonstrate enhanced performance with pre-exercise CHO supplementation during an acute resistance training bout and this finding is similar to other studies that did not support this theory. Conley et al. (1995) investigated the effects of CHO supplementation (a 20% maltodextrin and dextrose solution) on resistance training performance during set of 10 repetitions performed at 65% 1RM. The results showed no significant increase in number of sets, repetitions, or total work in the CHO group, and therefore the CHO supplementation did not enhance performance during the resistance training session (Conley et al., 1995). Kulik et al. (2008) investigated the effects of supplemental CHO ingestion (0.3g CHO/kg) on the performance of squats to exhaustion (STE), which consisted of sets of five repetitions at 85% 1RM. There was no statistical difference between treatments, and therefore the results suggest that CHO supplementation does not enhance resistance-training performance during the performance of STE (Kulik et al., 2008).

It seems that the disagreement between the conflicting findings of previous scientific literature and the results of this present investigation may be a result of several factors. As previously mentioned, the discrepancies seem to be due to the differences between the duration and intensity of the resistance-training bout (Haff et al., 2003). As stated by Kulik et al. (2008), the studies that demonstrated enhanced resistance training performance with pre-exercise CHO supplementation used protocols with lower intensities (<75% 1RM), larger workloads (greater number of sets and repetitions), and longer exercise duration (greater than 55 minutes) compared to the present study. The resistance training protocol in the present study required the participants to perform at 75% 1RM for the bench press exercise and 85% 1RM for the leg press. It seems that lower intensity protocols allow the participants to perform larger workloads for a longer duration and ultimately results in enhanced resistance training performance. For example, Haff et al. (1999) used a resistance training protocol with an intensity of 55% 1RM, and the CHO supplement elicited a significant enhancement of performance and allowed for a larger workload and exercise duration when compared to the P supplement. In the study by Lambert et al. (1991), the CHO supplement elicited a non-significant greater workload (increased number of sets and repetitions) compared to the P supplement ($p=0.067$ and $p=0.056$, respectively) during an exercise protocol that required an intensity of 70% 1RM. Furthermore, when resistance training is performed to exhaustion or muscular failure, total muscle glycogen is not reduced to levels thought to be a limiting factor (Lambert et al., 1991). It may be that at the higher intensities, other fuel sources are being depleted, such as phosphocreatine and ATP stores, rather than glycogen. These studies support the idea that high workloads that last for a longer duration and are performed at lower intensities (<75% 1RM) are needed to result in sufficient glycogenolysis to allow CHO supplementation to be an ergogenic aid (Kulik et al., 2008).

It is possible that the higher intensities (>75% 1RM) and shorter exercise duration (mean exercise duration of 45.02 minutes) used in the present investigation did not allow for a large enough workload to be performed in order to elicit a large enough glycogenolytic effect and thus increase the reliance on carbohydrates as a fuel source. While this may be true, the exercise intensities and duration of the present resistance training protocol are similar to those seen in more realistic resistance training regimens designed to increase muscle mass and strength during the strength / hypertrophy phase of a periodization cycle (Kulik et al., 2008).

A limitation of the present investigation is that each participant may not have put forth maximal effort and may have ended each set prematurely due to increased discomfort rather than true muscular failure. If muscular failure was not reached during the exercise testing protocols, then the validity of the results would be reduced. The participants, however, were resistance trained and are accustomed to eliciting muscular fatigue and failure during their typical resistance-training regime. It is therefore assumed that each participant put forth a maximal effort during the familiarization trial, 1RM testing, and both exercise testing sessions.

In conclusion, pre-exercise CHO supplementation does not improve high-intensity (>75% 1RM) resistance training performance for resistance trained women during an acute resistance training session. This finding suggests that CHO supplements do not provide ergogenic effects during high-intensity, shorter-duration resistance training bouts that do not induce large workloads for resistance trained women. Although it is reasonable to assume that muscle glycogen stores are reduced during high-intensity, shorter-duration resistance training sessions, it seems that other factors may have a greater impact on muscular fatigue in response to the training session. Further research is needed to investigate the influence of other factors (such as local muscular fatigue, increase lactate accumulation, and decreased phosphocreatine levels) on the resistance training performance during a high-intensity resistance training bout for resistance trained women.

Practical Applications

To the author's knowledge, this is the first study that has examined the effects of pre-exercise CHO supplementation on high-intensity resistance training performance during an acute resistance training session for resistance trained women. In addition, to the author's knowledge, this is the first study to use waxy maize as a CHO source and investigate its affect on resistance training performance during an acute resistance training session. Based on these results, it is evident that consuming waxy maize 60 minutes prior to performing resistance training exercises will not increase the number of repetitions or total work volume completed during acute high-intensity (>75% 1RM) resistance training sessions, similar to those performed during the strength / hypertrophy phase of the periodization cycle, for women. In short, women who ingest waxy maize prior to an acute resistance training bout will not experience an increase in resistance training performance compared to those who do not consume waxy maize prior to exercise. During lower-intensity (<75% 1RM) resistance training sessions, similar to those performed during the muscular endurance phase of a periodization cycle, however, pre-exercise CHO supplementation may provide ergogenic effects and enhance resistance-training performance.

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Appendices

Appendix A: Research Design and Resistance Training Protocol

Figure 1: Research Design

Table 5: Resistance Training Protocol with 3 minute rest intervals between each set and 5 minute rest interval between exercises

Bench Press (BP)Sets	Repetitions Completed	% 1RM
Warm Up 1	10	45
Warm Up 2	5	65
BP Set 1		75
BP Set 2		75
BP Set 3		75
BP Set 4		75
BP Set 5		75
5 Minute Rest	**5 Minute Rest**	**5 Minute Rest**
Leg Press (LP) Sets	Repetitions Completed	% 1RM
Warm Up 1	**10**	45
Warm Up 2	**5**	65
LP Set 1		85
LP Set 2		85
LP Set 3		85
LP Set 4		85
LP Set 5		85