Human Performance Enhancement in Sports and Exercise: Nutritional Factors - "Carbohydrate Loading"

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Summary The nutritional dietary procedure known as "carbohydrate loading" has been shown to substantially increase muscle glycogen levels. Increased muscle glycogen has a positive ergogenic effect on exercise performance in sporting events longer than 90 minutes in duration. However, the efficacy of the carbohydrate loading procedure is somewhat variable. This variability may be attributable to factors that influence the ability of the muscle to super-compensate with glycogen. This article discusses those factors and aspects of the procedure that add to the variability in an attempt to improve the success of sportsmen and women (i.e., athletes) attempting to perform the carbohydrate loading procedure and improve their exercise performance.

INTRODUCTION

The nutritional practice of carbohydrate loading (also known as muscle glycogen loading or muscle glycogen super-compensation) is a performance enhancement procedure frequently used by endurance athletes before key competitive events. It is well established that increased dietary intake of carbohydrate (CHO) through proper food selection can substantially increase muscle glycogen storage (2,9,10,16) and these increases in glycogen stores can result in enhanced exercise performance during prolonged endurance events (8,9).

A multitude of studies support the importance of CHO as a metabolic fuel for prolonged endurance performance (2,8,9,10,12). It is important, however, for athletes and coaches to realize that just consuming a high CHO dietary intake will not always result in increased glycogen levels and improved performance. That is, the degree to which muscle glycogen can be super-compensated varies considerably within individuals (8,9,16) as does the level of performance enhancement capacity from the procedure (9,16).

Since CHO loading can be an effective nutritional performance enhancement aid in some circumstances, but not always in others, it is important for athletes and coaches to be aware of those factors that can influence the outcome of the procedure (8,16). Research findings point to several critical factors as effecting the procedure, these key factors are: CHO loading strategy, type of CHO consumed, competitive event (i.e., exercise) features, the utilization of a pre-loading depletion exercise phase, the timing of the loading procedure prior the specific competitive event, and the gender of the individual performing the procedure.

The purpose of this brief article is to discuss aspects of these key factors noted above that influence the efficacy of the CHO loading procedure. The intent is to provide guidance to athlete and coaches on steps and actions they should consider to improve the likelihood that the CHO loading procedure will be successful and improve exercise performance.

CHO LOADING STRATEGIES

The CHO loading strategies consist of either the "classic" or "modified" approaches. The classic approach was first reported by Scandinavian researchers (2,10) in the late 1960s and involved either a 3- or 6-day exercise and dietary manipulation period. The 3-day procedure involved performing a single prolonged glycogen-depleting exercise (i.e., exhausting exercise) followed by 3 days of a high-CHO diet (~90% of daily caloric intake) with minimal to no training, and on the 4th day a competitive event; or the 6-day procedure involving glycogen-depleting exercise, then 3 days of low CHO diet (~10% daily caloric intake) and then 3 days of a high-CHO diet (~90%) followed by a competitive event on the 7th day.

These classic approaches most certainly have been shown to lead to substantial enhanced muscle glycogen levels and a prolonged the onset of muscle fatigue and improve exercise performance. These approaches do, however, have their draw backs. The exercise phase and diet manipulation can be difficult to execute. The glycogen-depleting exercises, as well as 3 consecutive days of inactivity immediately before an endurance competition can be disruptive to the sports-man or woman. The low dietary CHO phase of the procedure can result in hypoglycemia, listlessness, irritability, and reduced mental acuity, all of which can be stressful. Conversely, bloating, gastrointestinal distress, and weight gain can occur during the high CHO caloric intake phase and this can be disruptive or distracting the sports-man and woman (11).

Because of the difficulties just noted, researchers in the 1980's developed modified approaches to the classic procedures. It was found that muscle glycogen levels could almost be doubled by undergoing a 3-day exercise taper period starting approximately 1 week before the competitive event while consuming a normal mixed diet (~50% of energy as CHO), then ingesting a high (~ ≥70%) CHO diet for the remaining 3 days with approximately ~20 minutes of low-intensity exercise during the first 2 days and then complete rest on the last day before the event (12,17). This modified procedure not only increased muscle glycogen substantially, but eliminated or reduced many of the difficulties associated with the classic procedures as noted above. For these reasons, the modified approach tends to be the preferred contemporary means of CHO loading. Although, some coaches still prefer the classic approaches to the procedures for their athletes (see Pre-loading depletion exercise section below).

TYPE OF CHO CONSUMED

Sports-men and women typically use combinations of simple, complex, solid, and/or liquid CHO in their diets when performing the CHO loading procedure. Research suggests that the specific type or form of CHO ingested is not a critically important factor in the loading if the overall amount of CHO is adequate. The quantity of food that must be ingested to attain the proper dose of CHO depends on the CHO content of the foods, with a smaller amount required if the food has a relatively high-CHO content (e.g., pasta or rice) versus a relatively low-CHO content food (e.g., some dairy and meats) which requires large amounts to be consumed. Alternatively, high-CHO beverages can provide much of the additional CHO needed for loading without adding extra "bulk" to the diet. The reader is directed to an earlier discussion by this author in this journal about CHO rich foods (6). The typical CHO consumption during the "loading phase" of the procedure represents ~70-90% of the daily caloric intake (based upon a 2500-4000 kcal·day total consumption) (8,9,12). This would represent an intake need of about 8-10 g of CHO per kilogram of body mass in a 50-80 kg women or man per day.

The glycemic index (GI) of the CHO consumed may, however, influence some aspects of the loading procedure too. The GI is an indicator of the ability of different types of foods that contain carbohydrate to raise the blood glucose (i.e., sugar) levels within ~2 hours following ingestion. Foods containing carbohydrates that break down more quickly during digestion have the highest GI value. High-GI foods cause the largest increase in blood sugar and are reported to result in a greater restoration of glycogen than low-GI food within the first 24 hour after a glycogen depleting exercise (3,12). This suggests that the GI of food may be an important consideration when relatively rapid glycogen repletion is necessary and useful. See reference 12 for suggestions of high- and low-GI foods.

COMPETITIVE EVENT FEATURES

Currently there are a multitude of different types of competitive endurance sporting events in which men and women participate. These events can be multi-mode (e.g., involving cycling, swimming and/or running - duathlons or triathlons) or single mode (e.g., just cycling or running), with durations ranging from a few minutes (e.g., sprints triathlons) to hours (e.g., ultra-endurance) or even days (e.g., cycling tours). Most research supports that the benefits of CHO loading on performance occurs in competitive events lasting 90 minutes or more in duration (8,9,16). If the event is shorter in duration than 90 minutes, the procedure is not effective in improving performance, as typically normal dietary practices results in more than adequate amounts of muscle glycogen to perform the activity. It is also important to remember that muscle glycogen is stored with water in a ratio of approximately 1:3-5 (8). This results in some extra body mass and feelings of "fullness" and/or "heaviness" in the individual. This extra body mass might be a consideration if the competitive event is, or involves, weight-bearing (e.g., running) as opposed to non-weight-bearing activities (e.g., cycling or swimming). The carrying of extra mass can lead to an elevation in the energy cost of weight bearing activities and potentially increased relative workloads, which can be counter productive.

PRE-LOADING DEPLETION EXERCISE

One of the most stressful aspects of the "classic" loading procedures for athletes is performing the depleting exercise bout, which is physically taxing, especially so close to a key competitive event. The removal of this step within the "modified" procedure is one of the reasons for its more prevalent usage by athletes and coaches. However, findings from some research studies suggest that a greater amount of glycogen storage occurs after performing the glycogen depleting bout of exercise rather than lighter exercise bouts (e.g., exercise tapering - "modified" procedure approaches) before proceeding to the high-CHO diet phase of loading (4,15,17). This research points to the depleting bout of exercise seeming to enhance muscle sensitivity to CHO and allowing for a greater degree of re-synthesis and thus super-compensation. Although, as noted in above sections, the "modified" loading protocol has been reported in some research to produce muscle glycogen levels similar to the "classic" procedure involving depleting exercise. Thus the question of whether this depletion exercise aspect of the CHO loading procedure results in a maximal increase in glycogen storage is one of debate among physiologists and the sports science community. This question is obviously in need of further research.

TIMING OF LOADING PROCEDURE

Either the "classic" or "modified" CHO loading procedures typically involve 3 days of high-CHO dietary intake, and then participation in a competitive event on the subsequent 24-hour period. In actuality, evidence suggests muscle glycogen increases from the loading may persist for up to 5 days following the procedure (1). This gives the athlete a variety of strategies to potentially explore regarding the timing of the CHO loading procedure and when exactly to compete in an event. This may allow the athlete to incorporate an additional day or two of rest into the regime before competing if the coach feels that would be useful. Research does not suggest, however, that extending the high-CHO dietary intake phase of loading beyond 3 days results in any substantially greater compensation in the glycogen storage levels (8,9,12). Neither does it potentially result in any significance detrimental effect on the glycogen already stored.

GENDER

Most of the research on the CHO loading procedure has been done in men. Regrettably, far less research has examined the efficacy of CHO loading in women and the limited numbers of existing studies are somewhat contradictory and reveal equivocal findings. Some researchers reported no significant increase in muscle glycogen or performance after CHO loading in women (18). Other researchers have shown women to significantly increase glycogen and improve performance in response to CHO loading in a very similar fashion to men (20). Still others reported significant increases in muscle glycogen from CHO loading in women, but no subsequent substantial increase in performance (13,14).

There are several factors that potentially could influence the efficacy of CHO loading in women and cause these conflicting results. These factors are: total caloric energy intake, amount of CHO ingested, and menstrual cycle phase hormonal changes. For example, in order for women to increase their capacity to store glycogen it may be necessary during loading to increase their daily caloric intake (i.e., kcal·day) to substantially higher than normal levels and with a daily CHO intake exceeding approximately 8 g·kg body mass. From a caloric perspective this is an especially large amount of CHO for smaller women (‹ 60 kg body mass) to consume and may be difficult to achieve (19). Menstrual cycle hormones may also play a role in the effectiveness of CHO loading procedure in women. Research has demonstrated women have a greater capacity for storing glycogen (5,13,14) during the luteal phase than the follicular phase of their menstrual cycle and is related to direct and indirect effects of estrogen level changes. It appears that not only is the glycogen re-synthesis process affected by the female reproduction hormones, but also the energy metabolism during exercise (e.g., luteal phase exercise utilizes a greater fat than CHO energy component) (7). Thus, the natural fluctuations of female reproductive hormones throughout the menstrual cycle can be a critical factor for inducing the differences in CHO metabolism and glycogen storage seen in some women.

CONCLUSIONS

The ergogenic benefits of CHO loading for endurance exercise performance exceeding 90 min in duration is widely accepted by many physiology researchers, athletes and coaches. A variety of strategies in the CHO loading procedure to enhance muscle glycogen levels exist – involving variations in overall procedure duration, extend of dietary CHO manipulation, and amount-intensity of accompanying exercise activity. The efficacy of these various strategies and the resulting success in improving performance is related to how well the athlete executes and completes the necessary steps involved within the specific procedure they employ. For women athletes, successful elevation of muscle glycogen also seems influenced by the ability to ingest an appropriate amount of CHO, maintain adequate daily caloric intake, and be mindful of menstrual cycle hormonal influences. Performing the CHO loading procedure(s) can not guarantee an athlete improves their endurance exercise performance, nevertheless, if care is taken in executing the procedure correctly the athlete certainly maximizes their potential for improvement physiologically and can have a distinct advantage over competitors who do not use the procedure.

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