The Effects of Carbohydrate, Caffeine and Protein on Endurance Performance

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Introduction

If you were in the latter stages of your cycling race and nearing the "wall" that seems to be getting closer, would you believe someone if they told you to crack open a Coke to get just enough boost to finish strong? You should. During an endurance event, one may commonly observe a widespread practice where competitors actually drink defizzed Coke during later stages of an event. This consumption of Coke replaces the earlier use of a carbohydrate-electrolyte drink (Cox, Desbrow, Montgomery, Anderson, Bruce, Macrides, Martin, Moquin, Roberts, Hawley & Burke, 2002). Sports gels containing both caffeine and carbohydrate are a hot topic in the endurance sports world. As an endurance athlete, I can confirm that there is a lot of discussion amongst the athletes that revolves around supplement use. Gels and powders that consist of both caffeine and carbohydrate are the most commonly used. This is in fact the supplement that I use as an ergogenic aid, or a substance that can enhance performance by eliminating or decreasing symptoms of fatigue. In this literature review, conclusive evidence will be reported that supplements containing carbohydrate, caffeine, and protein are effective ergogenic aids.

Carbohydrate Ingestion During Endurance Exercise

Fatigue is often associated with glycogen depletion. Once the body has used all of its glycogen stores, it begins metabolizing fat which is much less efficient for producing Adenosine Triphosphate (ATP). This is the high-energy molecule that stores the energy an individual needs to complete just about anything they do (Williams, 2010). A drink containing 5–8% carbohydrate (CHO) could both contribute to fluid balance and help maintain available or exogenous glucose in order to spare glycogen or endogenous stores. An individual would need these endogenous stores after reaching 60–90 minutes of an endurance event. Exogenous glucose is the glucose individuals ingest from outside dietary sources. Items containing CHO are metabolized into glycogen to enter glycolysis, which is the major energetic process in living cells where CHO are eventually broken down into ATP. Endogenous glucose are the body's glycogen stores which is stored in three ways; as liver glycogen, blood glycogen, and muscle glycogen, with muscle glycogen as the largest store. Ingesting adequate amounts of CHO during an endurance event is vital, however, athletes need to be aware that a drink containing over 8% carbohydrate is commonly known to cause Gastrointestinal (GI) distress (Lacerda, Alecrim, Damaceno, Gripp & PintoSilami-Garcia, 2009). Signs and symptoms of GI distress entail delayed emptying of the stomach and small intestines which leads to cramping, nausea, bloating, vomiting and diarrhea (Williams, 2010). In essence, by taking in more CHO than their body can tolerate, the athlete is actually inhibiting their performance.

Some studies have suggested that CHO supplementation can improve performance by delaying fatigue and improving power output during exercise of more than sixty minutes, however, best results are typically found in exercise lasting over ninety minutes. Sufficient CHO should be ingested for an exogenous glucose supply at a rate of 1.0 g/min late in exercise, which likely represents the maximum rate at which the body can oxidize both ingested CHO and blood glucose (Coyle, Coggan, Hemmert & Ivy, 1986). If more than 1.0 g/min of CHO is ingested during exercise the body will not be able to metabolize it fast enough, leaving the athlete more likely to develop GI distress. During prolonged intense endurance exercise the body uses 30–60 g of CHO per hour, they need to be replaced for available CHO oxidation and to delay glycogen depletion or deny the reliance of endogenous sources (Yeo, Jentjens, Wallis & Jeukendrup, 2005). Athletes should refrain from ingesting over 60 g/hour of CHO, as this rate can be looked at as the maximum exogenous CHO rate for most athletes to avoid the onset of GI distress.

Several studies on soccer players found CHO to be an ergogenic aid for a 60-minute exercise performance at 75% of their VO_2 max. A study by Currell, Conway, and Jeukendrup (2009) found that in the soccer players who ingested a CHO solution, body mass losses through sweat were significantly lower, as were their heart rates in the second half of simulated play. As for performance, there was a significant improvement for dribbling, agility and shooting for the group that ingested the CHO solution.

There were cautions for CHO supplementation found in numerous studies, which had to do with dosage and timing of ingestion. Foods that are high on the Glycemic Index (70 and above) typically contain over 70% CHO which is a great fuel source for the body. However, ingesting a food this high on the Glycemic Index within an hour before activity can hinder performance. Foods high on the glycemic index, though high in glucose, can actually decrease blood glucose because they increase the insulin response (Thomas, Brotherhood & Brand, 1991). Insulin is responsible for the uptake of glucose (CHO) from blood, moving it to endogenous stores or into glycolysis. The rapid uptake of glucose from the blood may leave the athlete in a hypoglycemic state (low blood sugar, results in sweating, anxiety, shakiness, headache, GI distress), an inhibitor to performance (Williams, 2010). As stated previously, blood glucose is one of the endogenous stores of glycogen and is important to have in the latter stages of endurance performance.

There are various things that one must keep in mind when supplementing with CHO. In events lasting one hour or less there is little evidence that a sports drink or CHO supplementation will provide any ergogenic benefit, especially in glycogen-sufficient athletes. Carbohydrate supplementation is not recommended for events lasting 30–45 minutes or less because the CHO ingested will not have had enough time to metabolize and aid in performance. Athletes who do choose to ingest a CHO supplement in a short event are only enhancing their likelihood of GI distress. Instead, their main focus should be on fluid and electrolyte imbalance rather than concerns about CHO depletion (Bachle, et al., 2001).

Carbohydrate Supplementation in Research

Carbohydrates have been found to enhance performance the most when solutions are 5–8% CHO because blood glucose levels are usually elevated by only 0.5–1.0 mmol/L. An increase in blood glucose in that range is not significant enough to trigger too high of an insulin response (Cox et al., 2002). Some studies have used 40–50% CHO solutions, or mandated a 10–12 hour fast prior to exercise testing to deplete the athlete of glycogen; both protocols are impractical and a more practical four-hour fast can give just as significant results. Many studies incorporate high CHO concentration doses of over 20% CHO, low CHO concentration is defined as $\leq$10%; low concentration CHO is what is found in sports drinks and should be researched more than impractical high concentrations that athletes are not ingesting during endurance exercise (Coombes, & Hamilton, 2000).

Most studies administer CHO in split doses ranging anywhere from 0.5–1.5 g/kg of body mass per hour, the CHO is always combined with water and the subject is usually given doses every fifteen minutes until the end of the test (Coombes, & Hamilton, 2000). Giving athletes a single dose of sufficient CHO would be impractical, as the concentration level of CHO would quickly become far too high leading to GI distress and an increased insulin response, ultimately slowing the athlete down. The split dosage of CHO during exercise testing directly simulates how most endurance athletes ingest CHO during competition or training.

Caffeine Ingestion During Endurance Exercise

Numerous studies have shown caffeine to enhance prolonged submaximal exercise. As found in endurance events, both CHO and caffeine are thought to delay the onset of fatigue and increase exercise capacity. Studies have found that caffeine actually decreases time in time trial races with trained cyclists as well. When compared to just ingesting water or a water and CHO solution, a caffeine and CHO solution ingested during exercise has been found not only to decrease performance time in time trials, but also to increase the time to exhaustion in bike to exhaustion tests (Cox et al., 2002). A time trial consists of a subject cycling on a cycle ergometer for a given distance, the goal is to finish the course as fast as possible. In a bike to exhaustion test, subjects cycle on the cycle ergomter at a set VO_2 max until they feel they have to stop due to fatigue.

Time to exhaustion is significantly increased with the ingestion of caffeine whether the athlete habitually uses caffeine, has never used it, or uses very little of it. A study on habitual caffeine users (an average of over 700 mg/day) tested the hypothesis that caffeine-induced changes in exercise are less evident during periods of chronic caffeine ingestion. The research found that variable periods of short-term (up to four days) withdrawal from caffeine had no effect on caffeine-induced increases in endurance performance when compared to no withdrawal (Van Soeren & Graham, 1998). When subjects who were not caffeine users at all were given caffeine and tested for time to exhaustion, researchers found an increase in performance or time to exhaustion in all subjects (Denadai & Denadai, 1998).

With caffeine ingestion the level of epinephrine in blood is likely to increase during exercise. Epinephrine is associated with increasing heart rate, constricting blood vessels, dilating the air passageway, increasing blood lactate and stimulating glycolysis in muscle tissue. In essence, the presence of epinephrine in blood should be inhibitory to exercise performance because of the increasing heart rate, increased level of blood lactate, and stimulation of glycolysis in muscle, but in all studies these factors have proven not to inhibit performance (Yeo, Jentjens, Wallis & Jeukendrup, 2005).

In studies, the ingestion of caffeine has been found not only to increase the rate of CHO oxidation in glycolysis, but also to increase the rate of oxidation of free fatty acids (FFA) found in the blood. Research by McNaughton et al. (2008) found a significant improvement in performance in their subjects when they ingested caffeine and concluded that the improvement could possibly be based upon a greater reliance on fat metabolism, as indicated by increased FFA and a lower respiratory exchange ratio (RER). An RER of 0.70 indicates that fat is the predominant fuel source, an RER 0.85 suggests a mixture of both fat and CHO, and a value of 1.00 or above is indicative of CHO being the predominant fuel source. In the study, the subjects had an average RER of 0.85 in their trial with caffeine; in their trial without caffeine they had an average RER of 1.00. This finding suggests that one mode in which caffeine serves as an ergogenic aid is by increasing the body's utilization of FFA and decreasing the utilization of endogenous CHO stores, thereby, decreasing the need of exogenous CHO during exercise.

As briefly discussed in the introduction, Cox et al. (2002) observed endurance athletes ingesting defizzed Coke during latter stages of endurance exercise after earlier use of sports drinks (CHO and electrolyte). Interestingly Coke has an 11% CHO content while the sports drink had the normal 6% CHO content, and the caffeine concentration is significantly lower in Coke (~65 mg) than the caffeine doses associated with ergogenic benefits in laboratory research protocols (4–9 mg/kg body mass, ~280–630 mg). One of the aims in their study was to compare the effects of Coke ingestion late in exercise against the intake of larger or conventional caffeine doses. They found that the amounts of Coke typically consumed by athletes caused only a minor increase in plasma caffeine, or caffeine found in blood, but a performance enhancement similar to that attained by the larger caffeine doses was apparent. Their conclusion was that the ergogenic effect of coke was due to the small amounts of caffeine and an increase in CHO intake. This study suggests that all protocols of caffeine use are of equal and worthwhile benefit to exercise performance in endurance events.

Caffeine can be a powerful ergogenic aid for the performance in endurance events, but there is little evidence that supports that there is an ergogenic effect of caffeine on intermittent sprint performance. Although endurance athletes rely most on submaximal performance, there is typically a sprint to the finish of an event or stage which makes a study examining the effects of caffeine ingestion on sprint performance relevant. Caffeine was found to improve the total amount of sprint work performed by

8.5% and improve the mean peak power score by 7.0% when compared to a placebo trial (Schneiker, Bishop, Dawson & Hackett, 2006). With these findings, the final kick to the finish line can be enhanced with the ingestion of caffeine.

Caffeine, when combined with CHO during exercise, has been found to be a beneficial supplement. This is because not only is the body being refueled with exogenous CHO, but it's also receiving all the benefits that caffeine provides as discussed above. Cox et al. (2002) found that caffeine drastically increases exogenous oxidation during exercise likely due to increased intestinal absorption, but further research must be conducted to find the exact mechanism in which caffeine works in the body. It is generally believed that an increased contribution of exogenous CHO oxidation is beneficial because it reduces the reliance on endogenous stores. In a study performed on trained cyclists, exogenous CHO oxidation rates were highest in the trial with the CHO and caffeine solution (0.72 g/min) as compared to the trial with just a CHO solution (0.57 g/min). Also found in this study, there was no significant difference between the solutions in blood lactate going into minute forty-five, but once at forty-five minutes of exercise, blood lactate was significantly higher in the CHO and caffeine solution when compared to the CHO solution. Blood lactate or as it is better known, lactic acid, is the by-product of anaerobic (without oxygen) glycolysis and has major adverse effects on exercise performance (Williams, 2010). Yet, even with higher levels of blood lactate after minute forty-five, the cyclists with the CHO and caffeine solution outperformed their trial with the CHO-only solution (Yeo et al., 2005).

Caffeine Supplementation in Research

Caffeine has been found to enhance performance when 3–9 g/kg of body mass is ingested before and during exercise. However, a dose as little as 1.5 g/kg of body mass has also been found to enhance performance when ingested during the latter stages of prolonged exercise (Cox et al. 2002). Most studies administer caffeine as a single or bolus dose one-hour prior to exercise, while some administer a split dose, which has been found to delay or decrease caffeine concentration in urine. There is no difference in the ergogenic effects of caffeine when ingested as a split dose or as a bolus dose (Conway, Orr, & Stannard, 2002). The typical bolus dose of caffeine consists of 6 mg/kg of body mass taken one hour prior to exercise, while a split dose consists of ingesting various amounts of caffeine (1–5 mg/kg of body mass) prior to and at various times into exercise. Some studies used a 3 mg/kg of body mass one hour prior to and forty-five minutes into exercise protocol, while others used a smaller dosage of 1 mg/kg of body mass at a higher frequency of every twenty minutes into exercise. While all protocols induce similar ergogenic effects, peak caffeine concentration in blood occurs at 75–90 minutes after ingestion, therefore, doses of $\leq$ 3 mg/kg of body mass split into one hour intervals before and during exercise may be most beneficial (Cox et al., 2002; Yeo et al., 2005).

Protein Ingestion and Endurance Exercise

Clearly the predominant fuels for endurance exercise are carbohydrates and fats, but protein (PRO) serves an important role as well. Protein is both a structural and functional mechanism in the body that supports the growth and repair of damaged tissues and muscle hypertrophy (increase in the size of muscles), regulates enzyme synthesis, and is oxidized for energy. In the latter stages of intense endurance exercise PRO can be up to 15% of the body's fuel source, sufficient PRO intake is important for the performance of endurance athletes (Williams, 2010).

With acute endurance exercise, the proportion of CHO oxidation increases significantly, while the proportion of PRO oxidation decreases. Although the proportion of PRO oxidized decreases, it does not mean that the amount of PRO oxidized decreases. Because the total energy needs during endurance exercise may be ten times greater than at rest, there is an increase in absolute PRO oxidation (Tarnopolsky, 2004).

Under periods of low CHO intake or the stress of very intensive training, the daily amount of PRO oxidation could exceed that of a sedentary person or recreational athlete. Untrained athletes beginning endurance exercise may be deficient in PRO because their body is not used to the extra reliance on PRO for energy but with continued training their body adapts and returns to baseline. Insufficiency in PRO creates a negative nitrogen balance, while having sufficient PRO results in a neutral or positive nitrogen balance. Nitrogen balance is the method used to determine the protein requirements of humans; it involves quantifying the entire amount of PRO that is ingested and all of the nitrogen that is excreted. The measurement of nitrogen is used because the body excretes nitrogenous compounds rather than whole proteins; proteins are approximately 16% nitrogen (Tarnopolsky, 2004). A negative nitrogen balance usually results in a weight loss, strains and tears in muscle, and a slower recovery process from such injuries or other injuries; maintaining a positive or neutral nitrogen balance is vital for endurance athletes. However, ingesting too much PRO resulting in a positive nitrogen balance can provide an athlete with an unwanted weight-gain, athletes should be aware of this fact (Williams, 2010).

Studies have found that PRO intakes at or just below 1.0 g/kg of body mass were not sufficient to meet the needs of moderately to well-trained endurance athletes. A daily PRO intake of 1.2–1.6 g/kg of body mass is required for most endurance athletes to maintain a neutral nitrogen balance. Even in elite athletes, there is no need for PRO supplementation with a balanced diet that provides adequate energy and 10–15% of the diet comes from PRO. For example, a 4,000–5,000 kcal daily diet typical of an endurance athlete with PRO intake at 10%, the lower end of the spectrum, has an absolute PRO intake at 100–125 g/day exceeding the recommendations for PRO intake for endurance athletes (Tarnopolsky, 2004). A common misconception in athletes is that sufficient PRO cannot be obtained through diet alone, but obviously scientific research has found otherwise.

Although research suggests that PRO supplementation is not necessary to maintain endurance, there is evidence that PRO when combined with CHO can enhance endurance performance. In a study examining the effects of a CHO + PRO solution when compared to a solution of CHO-only, it was found that that the addition of PRO to a CHO supplement enhanced aerobic performance above that which occurred with the carbohydrate solution alone. Cyclists were given the supplements on separate occasions and cycled until exhaustion, when compared to the CHO solution, the CHO + PRO solution resulted in an average of seven extra minutes added to their time until exhaustion (Ivy, Res, Sprague, & Widzer, 2003). In a different study, researchers not only found that PRO, when combined in a CHO solution, resulted in significant improvements in cycling time to fatigue, but that it also resulted in reductions in post-exercise muscle damage when compared to a CHO-only solution (Saunders, Kane, & Todd, 2004). Additional research needs to be conducted in order to find out why this enhancement occurs.

Discussion

In doing research for the effects of Carbohydrate, Caffeine, and Protein on endurance performance, many interesting findings about ways to improve endurance capacity were found. Caffeine can improve endurance performance during prolonged exercise performed by increasing the amount of power the athlete can exhort and increasing the amount of time the athlete can maintain a particular intensity (Schneiker et al., 2006). More power means more revolutions per minute for a cyclist, greater stride length for a runner, and increased pull for a swimmer. Maintaining a higher intensity decreases the amount of time to complete the course of action, whether it’s a 1.5 km swim, 40 km bike, or 10 km run.

Although there is no factually stated best ergogenic aid for endurance activity, research suggests that a combination of CHO and caffeine may give the greatest enhancements to performance. Compared with glucose (CHO) alone, 3.0–6.0 mg/kg/hr caffeine combined with glucose increases the body’s exogenous carbohydrate oxidation, possibly as a result of increased reliance on fat oxidation (McNaughton et al. 2008). A greater reliance on fat oxidation, in this case, is great for endurance athletes because they are getting enhanced performance results while not using as much endogenous and exogenous CHO. If an athlete in an endurance event is able to utilize caffeine to rely more on their FFA than their exogenous CHO, they have a huge advantage over the other athletes. Not only will the athlete be able to carry less fuel on their bike or on themselves, but they will also be able to burn off the much unwanted excess FFA.

Carbohydrate intake during exercise is known to enhance performance because it helps refuel glycogen stores in order to keep the body oxidizing CHO. In separate studies researched, the addition of protein to a carbohydrate supplement enhanced aerobic performance above that which occurred with the carbohydrate solution alone. Consuming a CHO + PRO beverage can result in significant improvements on endurance performance which means a greater resistance to fatigue and help with the recovery of damaged muscles accrued from training or competition (Ivy et al., 2003; Saunders et al., 2004). Recovery is vital for endurance athletes, a pulled muscle, shin splints, or other muscle injuries can set an athlete back for several weeks, ultimately causing them to sit out a competition they had been training for.

Studies that examined CHO + Caffeine, and studies that examined the effects of CHO + Protein have been conducted, however, a study on the effects of all three ergogenic aids when combined was unable to be obtained. Findings in research suggest that a supplement containing CHO, caffeine, and PRO will produce the most beneficial ergogenic effects on endurance capacity. It is possible that when all three are ingested they counteract in a way that is harmful to performance, but perhaps they enhance performance at a level that has not yet been seen in a laboratory setting. Until research and data is collected it will remain a hypothesis that a solution of CHO, caffeine, and PRO is the best supplement for endurance exercise.

References

Bachle, L., Eckerson, J., Albertson, L, Ebersole K., Goodwin, J., & Petzel, D. (2001). The effect of fluid replacement on endurance performance. *Journal of Strength and Conditioning Research*, 15(2), 217–224.

Bell, D.G., & McLellan, T.M. (2003). Effect of repeated caffeine ingestion on repeated exhaustive exercise endurance. *Medicine and Science in Sports and Exercise*, 35(8), 1348–1354.

Conway, K.J., Orr, R., & Stannard, S.R. (2002). Effect of a divided caffeine dose on endurance cycling performance, postexercise urinary caffeine concentration, and plasma paraxanthine. *Journal of Applied Physiology*, 94, 1557–1562.

Coombes, J.S., & Hamilton, K.L. (2000). The effectiveness of commercially available sports drinks. *Sports Medicine,* 29(3), 181–209.

Cox, G.R., Desbrow, B., Montgomery, P.G., Anderson, M.E., Bruce, C.R., Macrides, T.A., Martin, D.T., Moquin, A., Roberts, A., Hawley, J.A., & Burke, L.M. (2002). Effect of different protocols of caffeine intake on metabolism and endurance performance. *Journal of Applied Physiology*, 93, 990–999.

Coyle, E.F., Coggan, A.R., Hemmert, M.K., & Ivy, J.L. (1986). Muscle glycogen utilization during prolonged exercise when fed carbohydrate. *Journal of Applied Physiology*, 63, 165–172.

Currell, K., Conway, S., & Jeukendrup, A.E. (2009). Carbohydrate ingestion improves performance of a new reliable test of soccer performance. *International Journal of Sport Nutrition and Exercise Metabolism*, 19, 34–46.

Denadai, B.S., & Denadai, M.L.D.R. (1998). Effects of caffeine on time to exhaustion in exercise performed below and above the anaerobic threshold. *Brazilian Journal of Medical and Biological Research*, 31, 581–585.

Graham, T.E., Helge, J.W., MacLean, D.A., Kiens, B., & Richter, E.A. (2000). Caffeine ingestion does not alter carbohydrate or fat metabolism in human skeletal muscle during exercise. *The Journal of Physiology*, 529, 837–847.

Graham, T.E., & Spriet, L.L. (1995). Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. *Journal of Applied Physiology*, 78(3), 867–874.

Ivy, J.L., Res, P.T., Sprague, R.C., & Widzer, M.O. (2003). Effects of a carbohydrate protein supplement on endurance performance during exercise of varying intensity. *International Journal of Sport Nutrition and Exercise Metabolism*, 13, 382–395.

Jacobson, T.L., Febbraio, M.A., Arkinstall, M.J., & Hawley, J.A. (2000). Effect of caffeine co-ingested with carbohydrate or fat on metabolism and performance in endurance-trained men. *Experimental Physiology*, 86, 137–144.

Lacerda, A.C.R., Alecrim, P., Damaceno, W.C., Gripp, F., Pinto, K.M.C., Silami-Garcia, E. (2009). Carbohydrate ingestion during exercise does not delay the onset of fatigue during submaximal cycle exercise. *The Journal of Strength and Conditioning Research*, 23(4), 1276–1281.

McNaughton, L.R., Lovell, R.J., Siegler, J.C., Midgley, A.W., Sandstrom, M., & Bentley, D.J. (2008). The effects of caffeine ingestion on time trial cycling performance. *The Journal of Sports Medicine and Physical Fitness*, 48, 320–325.

Patterson, S.D., & Gray, S.C. (2007) Carbohydrate-gel supplementation and endurance performance during intermittent high-intensity shuttle running. *International Journal of Sport Nutrition and Exercise Metabolism*, 17, 445–455.

Saunders, M.J., Kane, M.D., & Todd, M.K. (2004). Effects of carbohydrate-protein beverage on cycling endurance and muscle damage. *Medicine and Science in Sports and Exercise*, 36, 1233–1238.

Schneiker, K.T., Bishop, D., Dawson, B., Hackett, L.P. (2006). Effects of caffeine on prolonged intermittent-sprint ability in team-sport athletes. *Medicine & Science in Sports & Exercise,* 38, 578–585.

Tarnopolsky, M.D. (2004). Protein requirements for endurance athletes. *The International Journal of Applied and Basic Nutritional Sciences,* 20, 662–668.

Thomas, D.E., Brotherhood, J.R., Brand, J.C. (1991). Carbohydrate feeding before exercise: effect of glycemic index. *International Journal of Sports Medicine*, 12, 180–186.

Van Nieuwenhoven, M.A., Brouns, F., & Kovacs, E.M.R. (2005). The effect of two sports drinks and water on GI complaints and performance during an 18-km run. *Internation Journal of Sports Medicine*, 26(4), 281–285.

Van Soeren, M.H., & Graham, T.E. (1998). Effect of caffeine on metabolism, exercise endurance, and catecholamine responses after withdrawal. *Journal of Applied Physiology*, 85(4), 1493–1501.

Williams, M.H. (2010). *Nutrition for Health, Fitness and Sport* (9^{th} ed.). New York, NY: McGraw Hill.

Yeo, S.E., Jentjens, R.L.P.G., Wallis, G.A., & Jeukendrup, A.E. (2005). Caffeine increases exogenous carbohydrate during exercise. *Journal of Applied Physiology*, 99, 844–850.