Institution: UNIVERSITY OF BIRMINGHAM

Unit of Assessment: C26 Sport & Exercise Sciences, Leisure & Tourism

Title of case study: Maximising carbohydrate delivery to fuel enhanced athletic performance

1. Summary of the impact

This case study relates to the optimisation of endurance performance in athletes through the use of newly developed carbohydrate-based sports foods and beverages. It describes a systematic program of scientific research that resulted in major advances in our understanding of how to optimise athletic performance through nutrition. This research substantially influenced the sports nutrition guidance for athletes given by the very highest global authoritative source (i.e., International Olympic Committee Consensus Statement on Sports Nutrition [IOC]). Furthermore, the research has stimulated development of innovative food and beverage products in the sports nutrition manufacturing industry allowing the benefits of the research to reach consumers and athletes on a truly global scale.

2. Underpinning research

It is widely accepted that consuming carbohydrate-based sports foods or beverages during exercise can provide an additional energy source for the body and working muscles and enable athletes to sustain or improve their exercise performance. Such products typically provide glucose-only based carbohydrate forms (e.g., glucose, maltodextrin) which can effectively deliver carbohydrate to the body for utilisation as energy when ingested at moderate quantities (e.g., on average 0.5 – 1.0 grams of glucose ingested during each minute of exercise [0.5-1.0 g/min]). However, there is a limitation in the body's ability to fully utilise the energy from consuming glucose-only based carbohydrate forms when they are ingested at higher rates during exercise; i.e. the utilisation for energy (known as 'exogenous carbohydrate oxidation') is limited to a maximum of ~1 g/min despite ingestion at rates well in excess of this (e.g., >1.5 g/min).

A systematic programme of scientific research conducted by researchers in the School of Sport and Exercise Sciences at the University of Birmingham between 2000-2010 and published between 2004 and 2011 generated the following research insights that underpin the impact described in this case study:

a. The utilisation of ingested carbohydrate during exercise can be increased by up to 65% by consuming 'multiple-transportable carbohydrates'

It was demonstrated that the limitation to the oxidation of glucose-only carbohydrates at 1.0 g/min could be overcome by co-ingesting a fructose containing carbohydrate source (e.g., fructose, sucrose) with glucose (see outputs R1 and R2 below). In fact, in one study co-ingestion of very large quantities of glucose + fructose (2.4 g/min in a 1:1 ratio) during exercise resulted in 65% greater exogenous carbohydrate oxidation rates than ingestion of glucose only with peak oxidation rates of 1.75 g/min reached, far in excess of the previously accepted 1.0 g/min limit to exogenous carbohydrate oxidation (R3). The results were confirmed in a comprehensive collection of further studies (summarized in R4) and have been extended to many food forms (drinks, sports bars, energy gels). Glucose is absorbed in the intestine through a sodium-dependent glucose transporter protein called SGLT1, which may become saturated at high rates of glucose ingestion. Fructose is another carbohydrate type but its absorption is not affected by SGLT1 saturation, because fructose is absorbed by a different intestinal transporter (GLUT5). Thus, the results of high exogenous carbohydrate oxidation with glucose and fructose ingestion were attributed to the stimulation of multiple transport mechanisms for absorption in the intestine (hence the term 'multiple transportable carbohydrates') facilitating greater total carbohydrate delivery to the bloodstream for oxidation during exercise.

b. Fluid delivery during exercise is also enhanced with the ingestion of 'multiple-transportable carbohydrates'

In addition to enhancing exogenous carbohydrate oxidation during exercise, the ingestion of

drinks containing multiple transportable carbohydrates was shown to be more beneficial for the emptying of fluid from the stomach and delivery of fluid to the bloodstream than glucose-only carbohydrate drinks (R5). This indicates these multiple carbohydrate-containing beverages have advantages in terms of energy provision and hydration during prolonged exercise and should therefore offer superior outcomes for exercise performance.

c. The ingestion of 'multiple-transportable carbohydrates' can improve prolonged endurance performance by 8% over glucose-only based carbohydrate forms

The superiority of multiple transportable carbohydrates for endurance performance was shown in a study demonstrating that consuming glucose + fructose drinks during prolonged exercise improved exercise performance by ~8% over consuming glucose only drinks. This was in addition to the 11% benefit glucose only provided over water, so the total benefit of glucose + fructose over water was 19% (R6). This study provided evidence that by overcoming the limitations to ingested carbohydrate delivery during exercise it is possible to provide additional performance benefits to athletes.

Key Researchers:

- Professor Asker Jeukendrup: was the Principal Investigator in this research program. He was in full-time employment at the University of Birmingham from 1998-2011 which included the entire period during which the research supporting the case study was carried out.
- Dr Roy Jentjens: completed his PhD and Postdoctoral Training at the University of Birmingham between 1998-2004. During this period he made key contributions to the research supporting the case study through directly leadership of specific projects and, latterly, through support of further PhD students working in the same research program under the guidance of Professor Jeukendrup.
- PhD students: Dr Gareth Wallis (2003-2006, now Lecturer), Dr Luke Moseley (2000-2003), Dr Kevin Currell (2004-2007). As part of their PhD studies, these three PhD students made critical contributions to the research program supporting the case study.

3. References to the research

Research Outputs:

R1) Jentjens RL, Moseley L, Waring RH, Harding LK & Jeukendrup AE. High rates of exogenous carbohydrate oxidation from a mixture of glucose and fructose ingested during prolonged exercise. Journal of Applied Physiology, 96(4):1277-84, 2004. **[DOI:10.1249/MSS.0b013e318182a9c7]**

R2) Wallis GA, Rowlands DS, Shaw C, Jentjens RL & Jeukendrup AE. Oxidation of combined ingestion of maltodextrins and fructose during exercise. Medicine and Science in Sports and Exercise, 37(3):426-32, 2005. **[DOI:10.1249/01.mss.0000155399.23358.82]**

R3) Jentens RL & Jeukendrup AE. High rates of exogenous carbohydrate oxidation from a mixture of glucose and fructose ingested during prolonged exercise. British Journal of Nutrition, 93(4):485-92, 2005. **[DOI:10.1249/MSS.0b013e318182a9c7]**

R4) Jeukendrup AE. Carbohydrate and exercise performance: the role of multiple transportable carbohydrates. Current Opinion in Clinical Nutrition and Metabolic Care, 13:452-457, 2010. **[DOI: 10.1097/MCO.0b013e328339de9f]**

R5) Jeukendrup AE & Moseley L. Multiple transportable carbohydrates enhance gastric emptying and fluid delivery. Scandinavian Journal of Medicine and Science in Sports, 20:11-121, 2010. **[DOI: 10.1111/j.1600-0838.2008.00862.x]**

R6) Currell K & Jeukendrup AE. Superior endurance performance with ingestion of multiple transportable carbohydrates. Medicine and Science in Sports and Exercise, 40(2):275-281, 2008. **[DOI: 10.1249/mss.0b013e31815adf19]**

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4. Details of the impact

The research insights that support this impact case study have been extensively disseminated to scientific audiences through traditional means since 2004 (e.g., international conferences and peer-reviewed academic publications). This is the primary mechanism by which the research informed the two major impacts as described below:

a) Impact on expert sport nutrition recommendations for athletes

Until the publication of the research insights described herein, consensus agreement was that in order to optimise performance, endurance athletes should consume carbohydrate during exercise at rates between 30-60 g per hour (i.e., 0.5 – 1.0 g/min). Such a recommendation was provided by multiple authoritative sources, including the American College of Sport Medicine Position Stand on Nutrition and Athletic Performance (2009) and the International Olympic Committee Consensus on Nutrition for Sport (2004). It was based on evidence that the utilisation of ingested carbohydrates during exercise was limited to ~ 1 g/min, and therefore consuming extra carbohydrate of a single transportable source would not provide further metabolic advantages. However, the accumulating number and consistency of new research insights highlighted above contributed to a fundamental change in sport nutrition guidelines recommended for athletes performing in endurance sports and this has received endorsement at the very highest level by being incorporated into the most recent (2010, published in 2011) International Olympic Committee Consensus on Nutrition for Sport. [see corroborating sources 1-3] Specifically, International Olympic Committee Consensus on Nutrition for Sport concludes (with reference to endurance exercise): 'As the duration of the event increases, so does the amount of carbohydrate needed to optimise performance. To achieve the relatively high rates of intake (up to 90 g/h) needed to optimise performance in events lasting more than about 3 hours, athletes should practise consuming carbohydrate during training to develop an individual strategy, and should make use of sports foods and drinks containing carbohydrate combinations that will maximise absorption from the gut and minimise gastrointestinal disturbances.'

b) Impact on the global sport nutrition food and beverage manufacturing industry

Starting in 2007 and continuing to this day (currently 2012) the research described in Section 2 has directly underpinned new product innovation in the lucrative sport nutrition food and beverage manufacturing industry. This research has impacted industry at all levels from national-level small or medium enterprises (SMEs) through to the global fast moving consumer goods (FMCG) industry. For example, the UK-based companies Torq [4] and For Goodness Shakes! [5] both utilise the science of multiple transportable carbohydrates in their product design and heavily use the underpinning research in their marketing and materials. In the case of FMCG, in 2007 Nestlé SA launched an entire range of products (the C2MAX product range, which includes sports bars, gels and beverages deigned for endurance athletes) which is marketed globally under their sports nutrition brand PowerBar®. [6] The term C2MAX is derived directly from the research undertaken at the University of Birmingham and refers to the presence of two types of carbohydrate (i.e., C2, glucose and fructose) to maximise (MAX) energy delivery to the body during exercise. Therefore, the research supporting this impact case study has been of direct benefit to industry and the economy via its influence on innovation and new product development within the food and beverage sector. In addition, the involvement of industry and in particular the marketing of new products has facilitated the dissemination of the research to non-academic audiences. [6] Finally, the manufacture of products utilising the research insights generated at the University of Birmingham enables both recreational and serious athletes globally to optimise their endurance performance through access to the very best research-driven nutrition products.

5. Sources to corroborate the impact

a) Impact on expert sport nutrition recommendations for athletes

References 1-3 provide documentary evidence of the adoption of the research insights discussed in Section 2 into sports nutrition guidelines for athletes by the very highest authoritative source, the International Olympic Committee consensus statement on sports nutrition.

[1] IOC consensus statement on sports nutrition 2010. Journal of Sports Sciences, 29 Suppl 1:S3-4, 2011.

[2] Burke LM, Hawley JA, Wong SH & Jeukendrup AE. Carbohydrates for training and competition.

Journal of Sports Sciences, 29 Suppl 1:S17-27, 2011.
[3] Jeukendrup AE. Nutrition for endurance sports: Marathon, triathlon and road cycling. Journal of Sports Sciences, 29 Suppl 1:S91-99, 2011.

b) Impact on the global sport nutrition food and beverage manufacturing industry

Sources 4-6 provide evidence of product innovation in the food and beverage industry based on the research insights discussed in Section 2 and also of the extensive use of the research insights in marketing and communication materials.

[4] http://www.torqfitness.co.uk/nutrition/torq-gel (Manufacturer: Torq [UK])
[5] http://www.nectarfuel.com/world-class-energy.html (Manufacturer: For Goodness Shakes! [UK])
[6] http://www.powerbar.com/c2max/default.aspx (click youtube video for a consumer facing explanation of the research insights) (Manufacturer: Nestle SA [Global]).