Exogenous carbohydrate as an ergogenic aid: recent advances in dose, form and format

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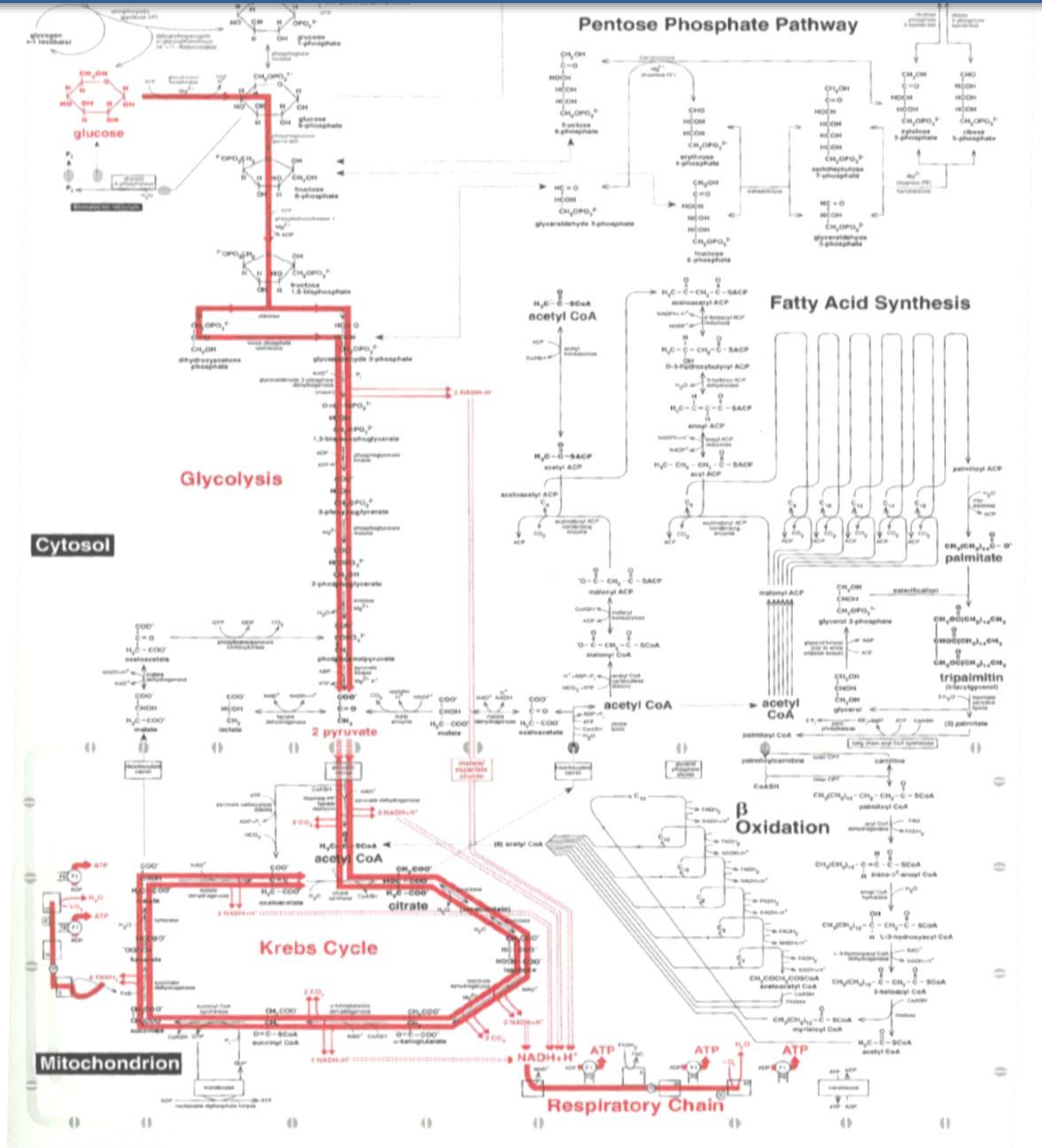
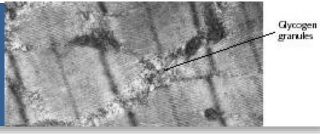
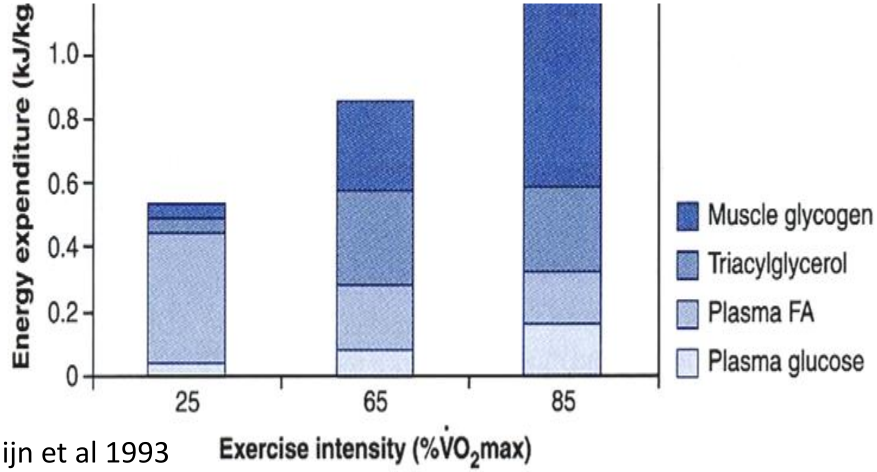
Performance Nutrition Heavily is Focused on Interventions Revolving Around the Maintenance of Muscle [ATP]



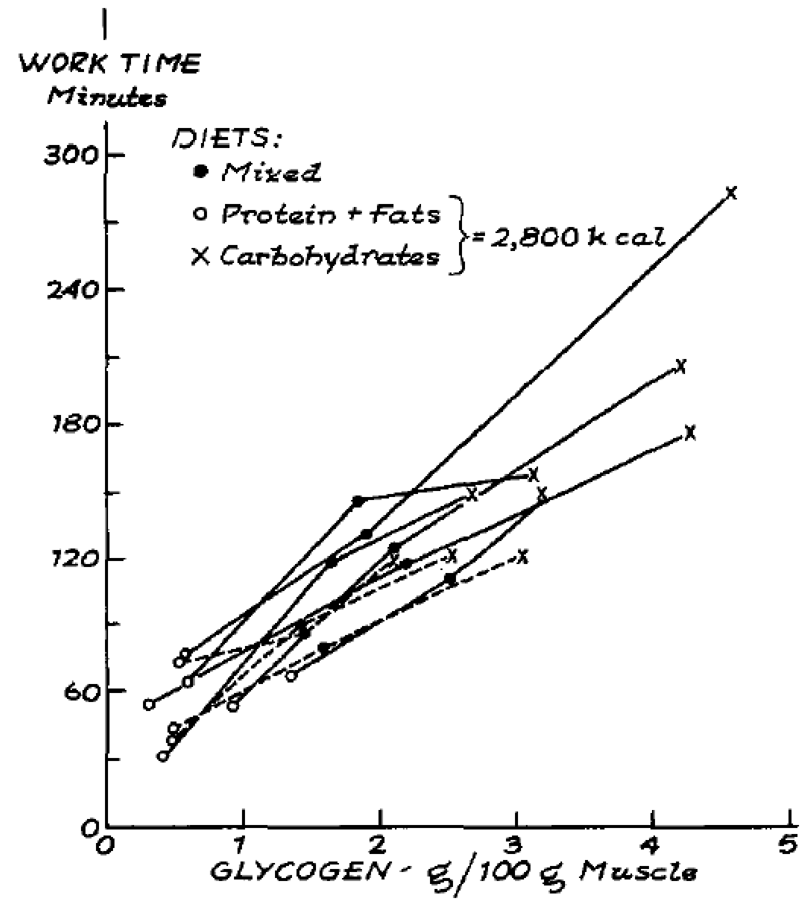
Glycogen - critical fuel for intense endurance





Romijn et al 1993

Dietary Carbohydrate ⇨ Pre-Exercise Muscle Glycogen ⇨ Endurance Capacity



Bergstrom J, et al. Acta Physiol Scand 1967;71(2):140-50.

Muscle Glycogen Use Rate Increases with Exercise Intensity

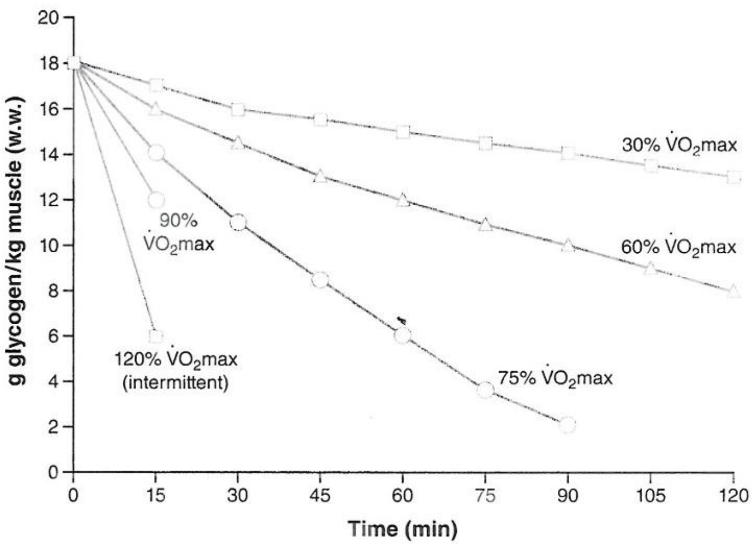


Figure 3.18 Effect of exercise intensity on rates of muscle glycogen utilization.

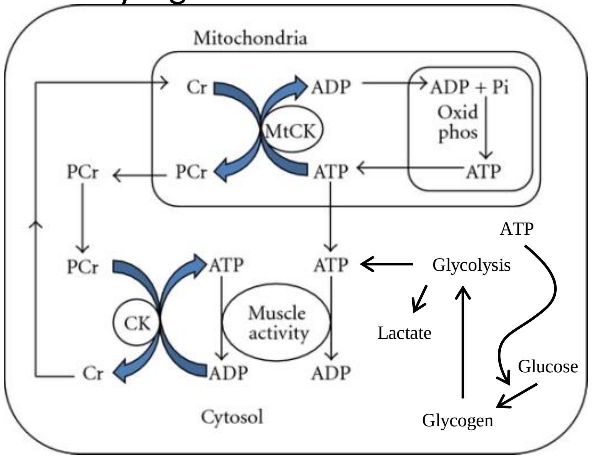
Saltin B, Karlsson J. In: Muscle metabolism…. NY: Plenum Press, 1971:289-99.

Glycogen is Essential for Muscle Contraction

Glycogen Shunt Theory (Shulman & Rothman, Proc Nat Acad Sci, 98(2): 457.

- ^{13}C and ^{31}P NMR measurements of muscle energetics
- Muscle contraction:
  - ~0-15 msec: PCR breakdown to buffer [ATP]
  - 20-100 msec: glycogenolysis->glycolysis provides ATP for contraction and to buffer [PCr]
  - Intercontraction: oxidative phosphorylation provides ATP for glycogenesis and buffer [PCr]

Glycogen shunt-PCr shuttle



Anaplerotic Addition to TCA Cycle Theory (e.g. Walton et al., J Physiol, 2003)

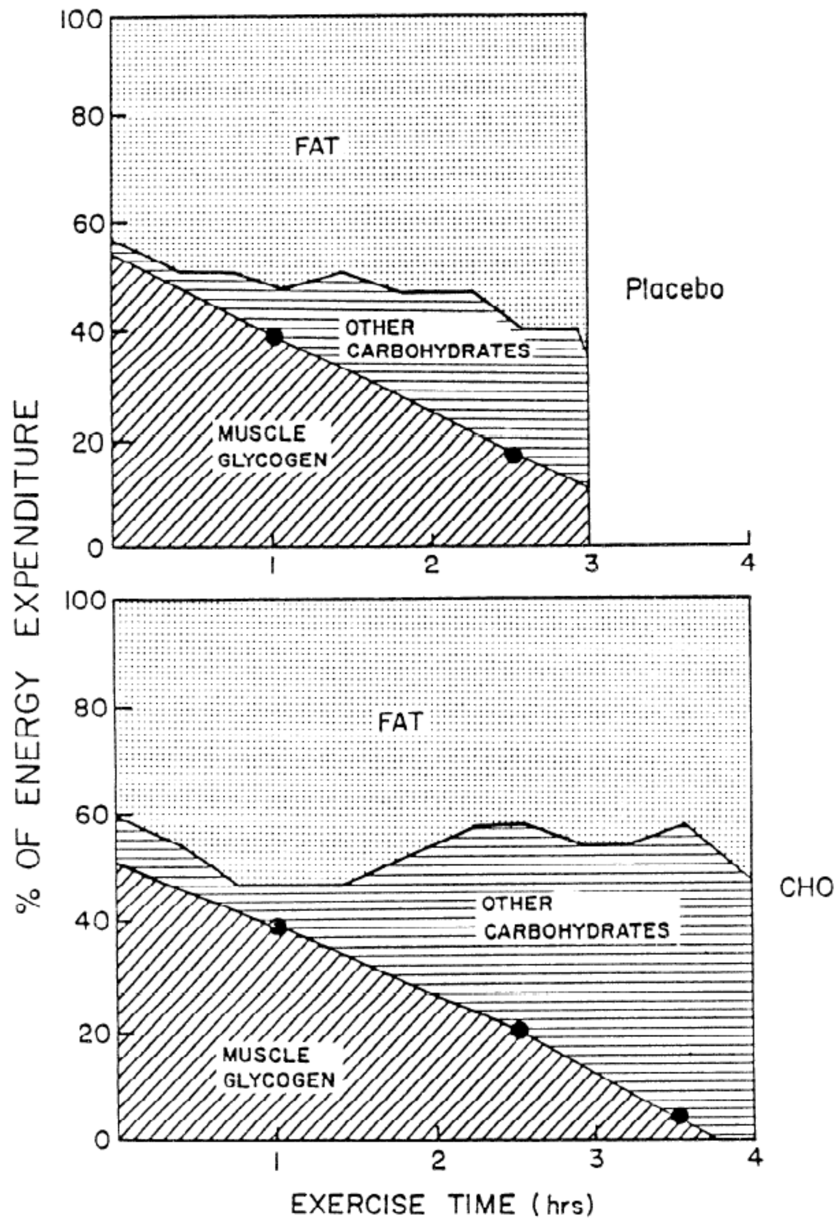
- Glycolysis substrate to maintain TCA [intermediate] and high rates of oxidative phosphorylation

Exogenous Carbohydrate Maintains Glycolytic Flux

Exercise to Exhaustion @ 70%$V0_2$max…

…with water only

…with glucose ingestion -> increase blood glucose contribution to offset glycogen and **maintain carbohydrate oxidation**



Ed Coyle, et al. J Appl Physiol 1986;61(1):165-72.

Effect Size of Exogenous Carbohydrate

RESEARCH REVIEW ARTICLE

Sports Med 2011; 41 (9): 773-792
0112-1642/11/0009-0773/$49.95/0

Effects of Acute Carbohydrate Supplementation on Endurance Performance

A Meta-Analysis

Tom J. Vandenbogaerde and *Will G. Hopkins*

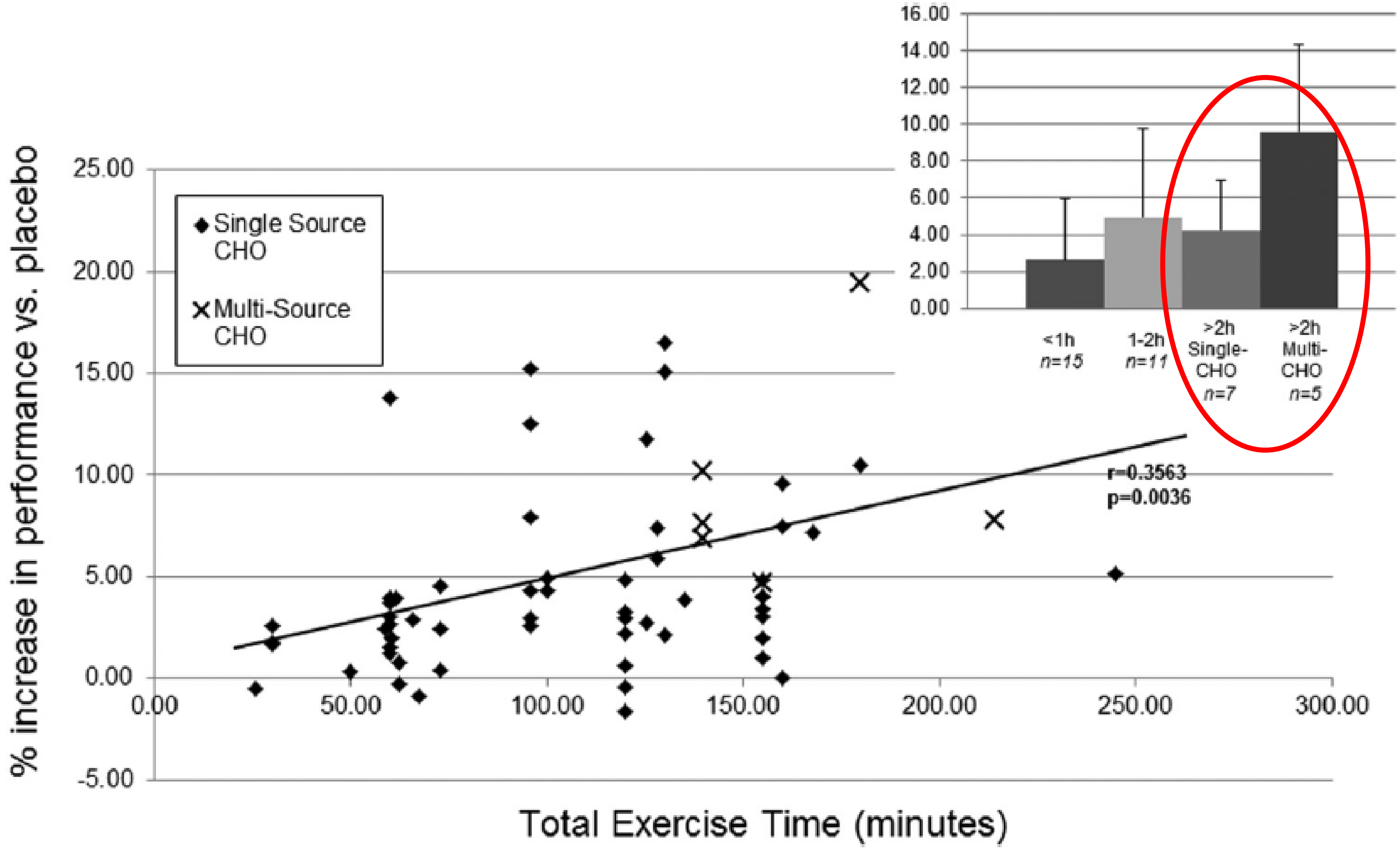
(n=122 contrasts)
"Carbohydrate during prolonged-intense exercise provides ~3-10% benefit over non-caloric placebo"

Effect Size Increased with Duration

Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations[1]

Trent Stellingwerff and Gregory R. Cox

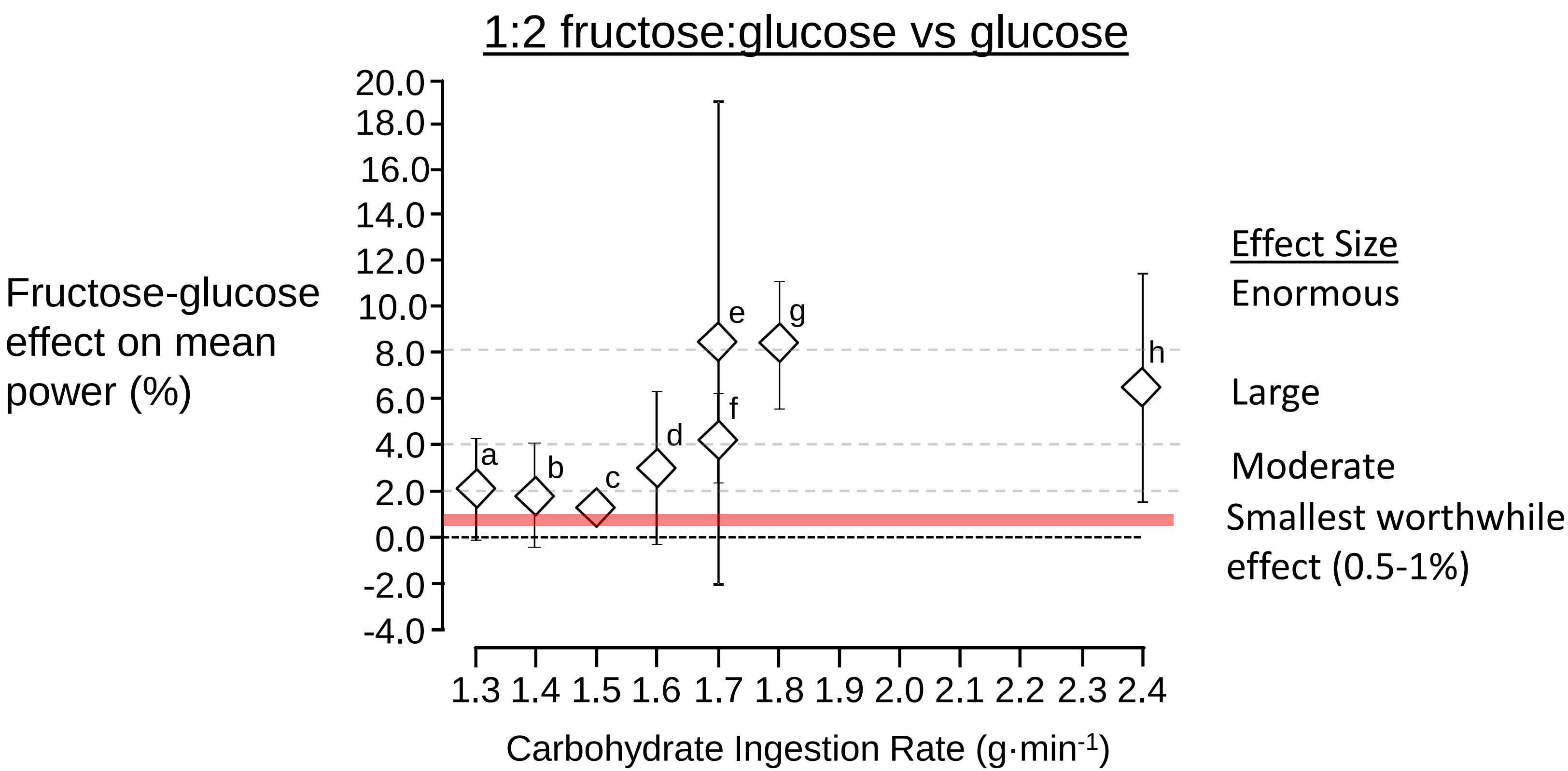
Appl. Physiol. Nutr. Metab. 39: 998–1011 (2014)



Fructose–Glucose Composite Carbohydrates and Endurance Performance: Critical Review and Future Perspectives

David S. Rowlands[1] · S. Houltham[1] · K. Musa-Veloso[2] · F. Brown[1] ·
L. Paulionis[2] · D. Bailey[3]

Sports Med 2015;45(11):1561-76.

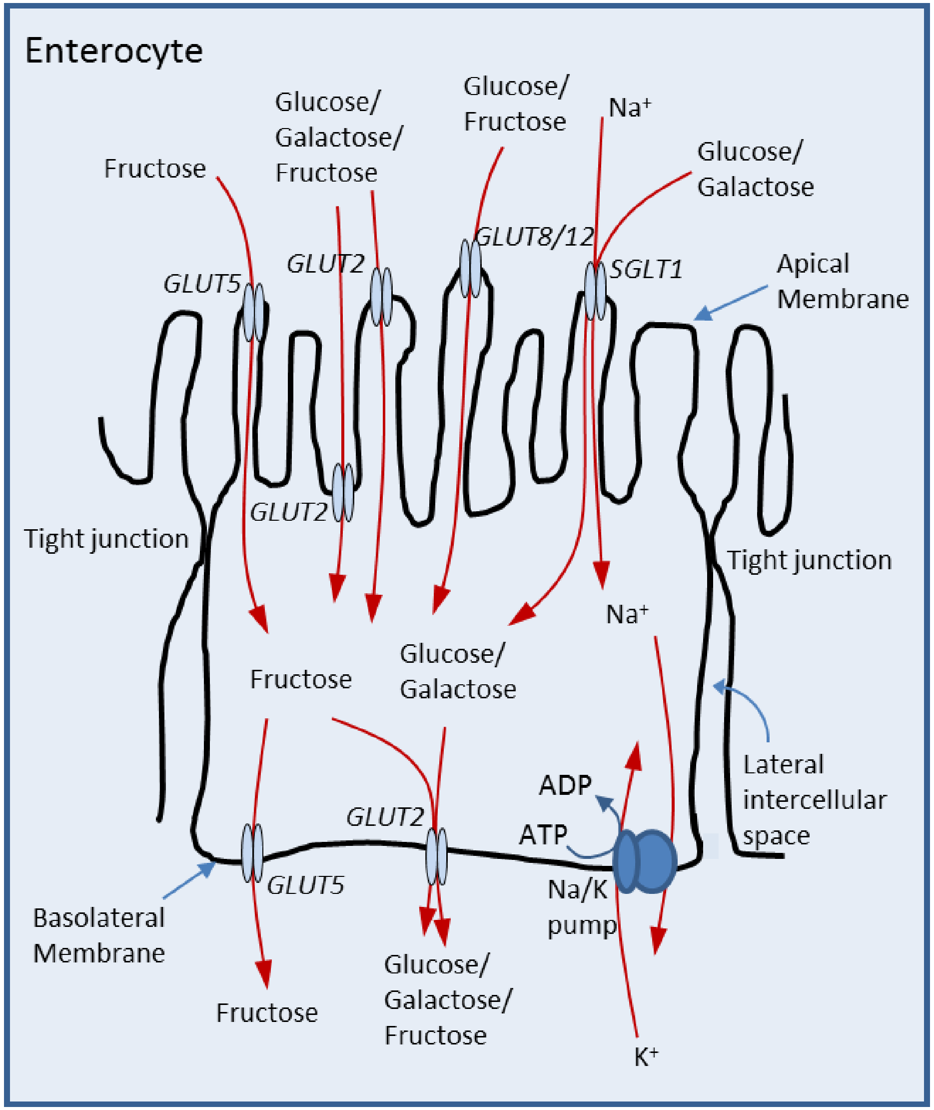


Multiple and Specific Monosaccharide Transporters Determine Multiple-Transportable Carbohydrate (MTC) Absorption Across the Gastrointestinal Enterocyte

Specific Transporters

Synergism

Glucose transport (SGLT1) stimulates expression and translocation of GLUT2 to apical membrane increasing non-specific monosaccharide transport capacity



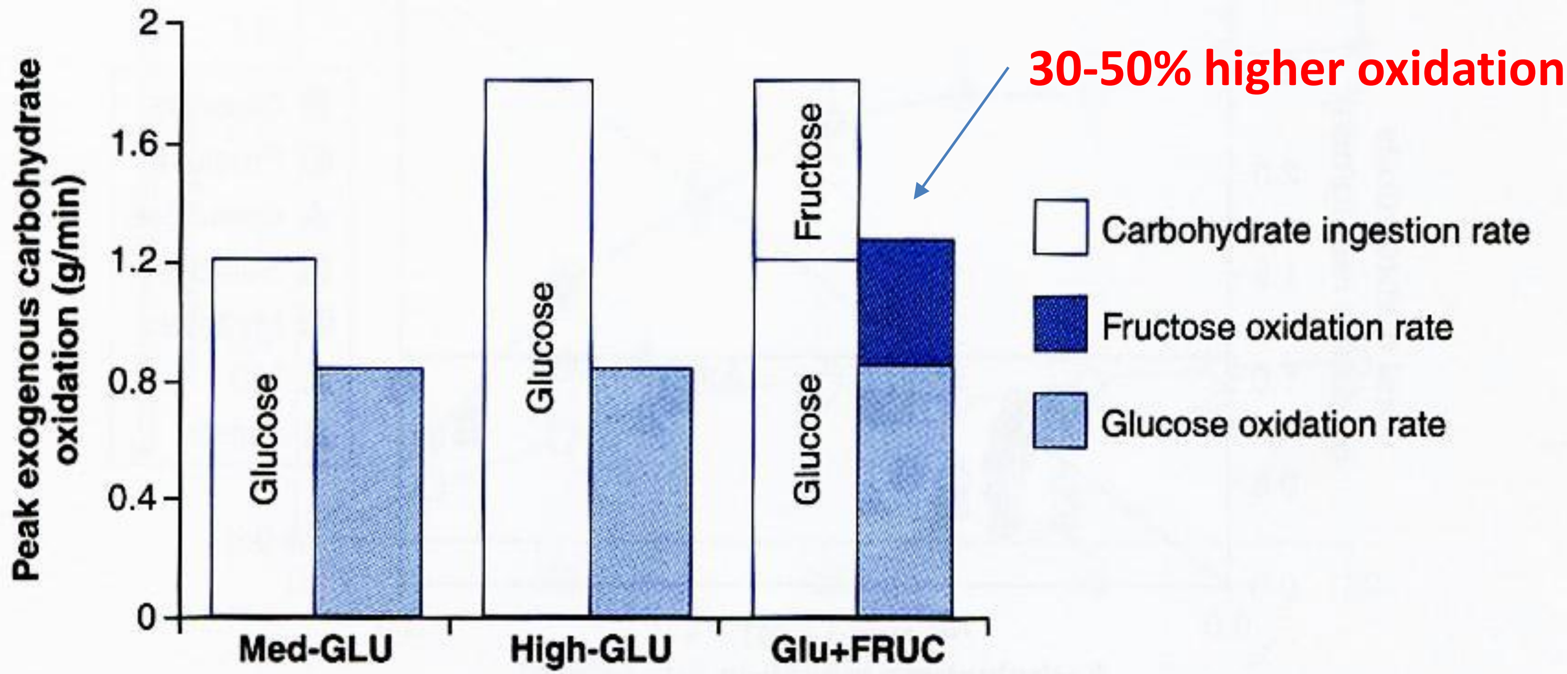
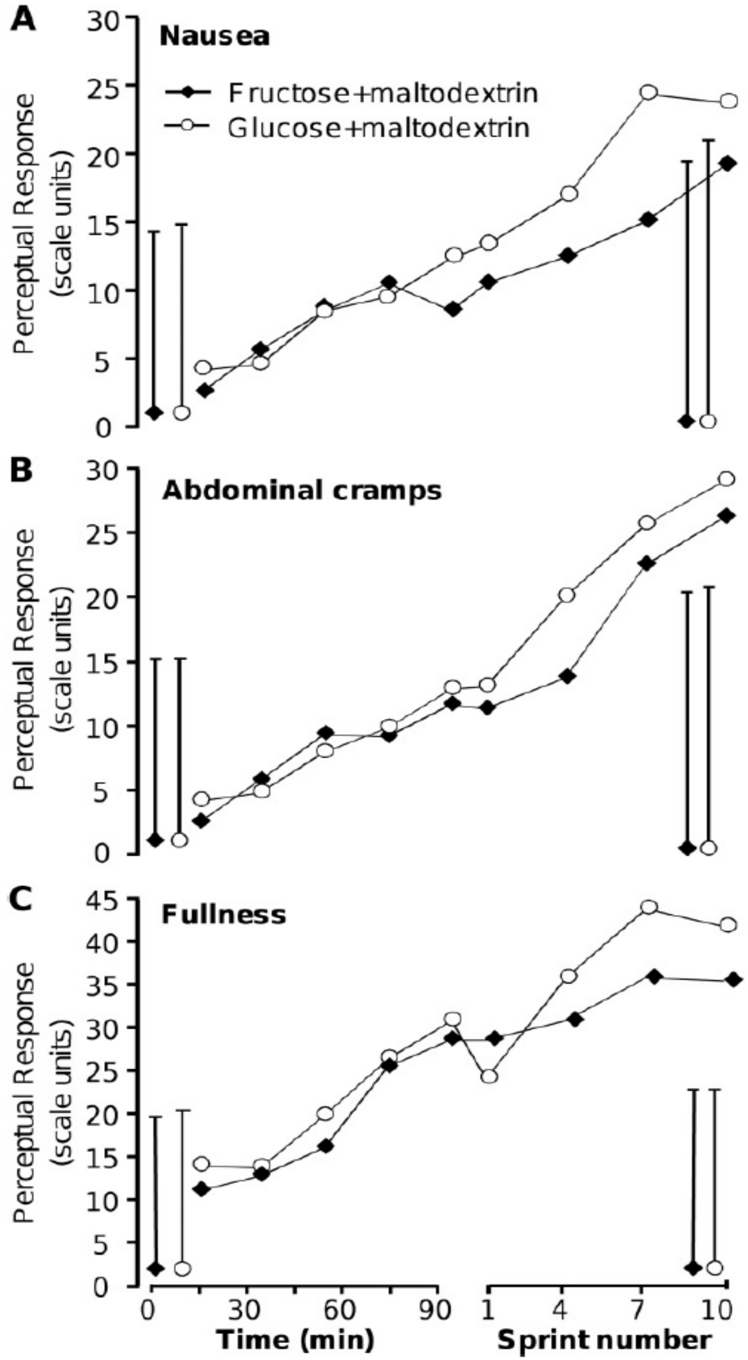


Figure 5.7 The oxidation rate of glucose plus fructose in a combined drink is higher than the oxidation rate of similar amounts of either glucose or fructose alone.

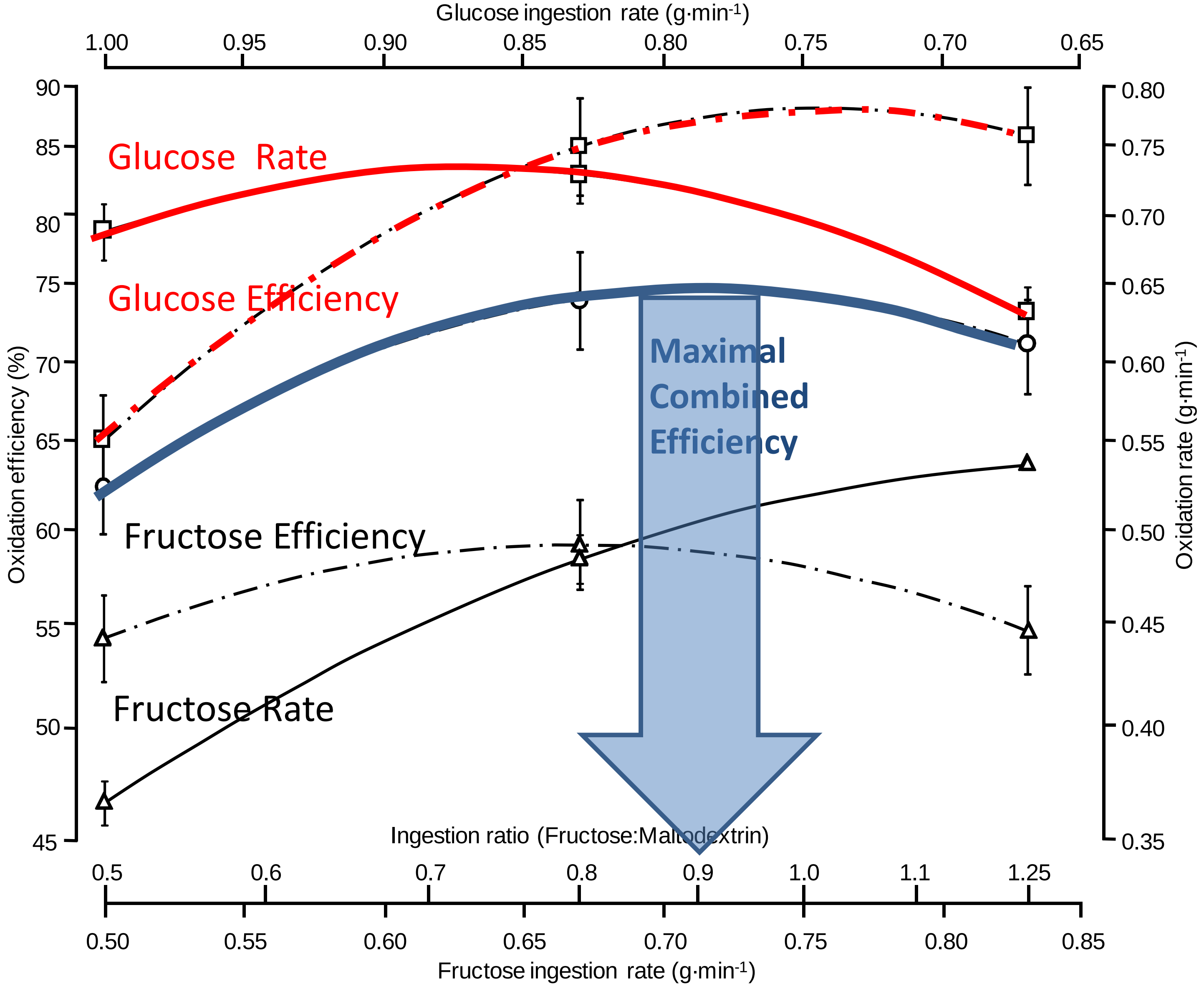
Reprinted, by permission, from A.E. Jeukendrup and R. Jentjens, 2000, "Oxidation of carbohydrate feedings during prolonged exercise: Current thoughts, guidelines, and directions for future research," *Sports Med* 29(6): 407-424.



Rowlands et al., 2012, APNM

Fructose:Maltodextrin Ratio - Optimal Oxidation Efficiency

Dual Tracers:
^{14}C-Fructose
^{13}C-Maltodextrin



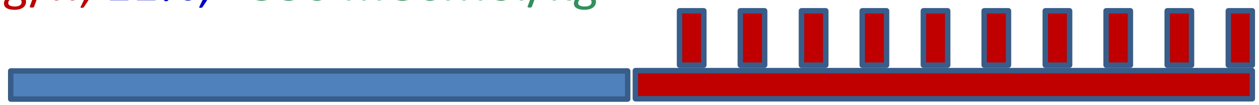
O'Brien et al., MSSE 2013

0.8:1.0 Fructose:Maltodextrin Ratio Enhances Intense Endurance Exercise Performance

O'Brien et al., MSSE, 2013

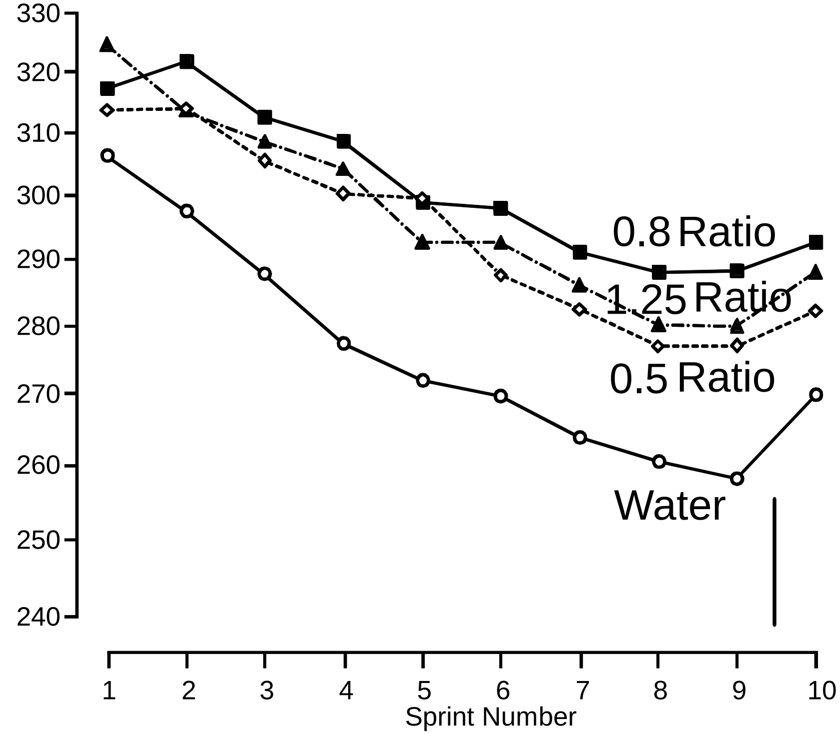
Drink: 90 g/h; 11%; ~330 mOsMol/kg

Protocol:

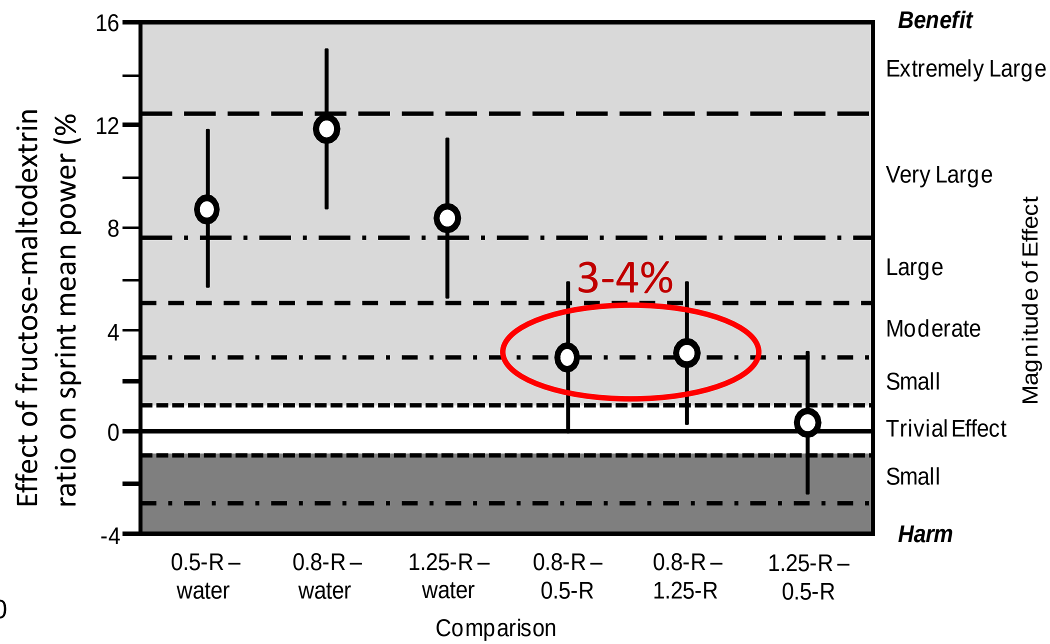


150 min 65% Vo_{2max} 10 x ~2 min sprints

Mean Sprint Power in Repeat-Sprint Test (W)

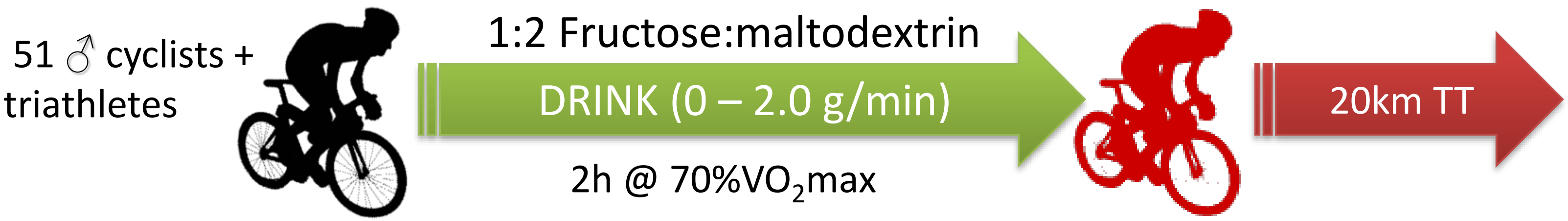


Fructose:Maltodextrin Effect on Mean Power

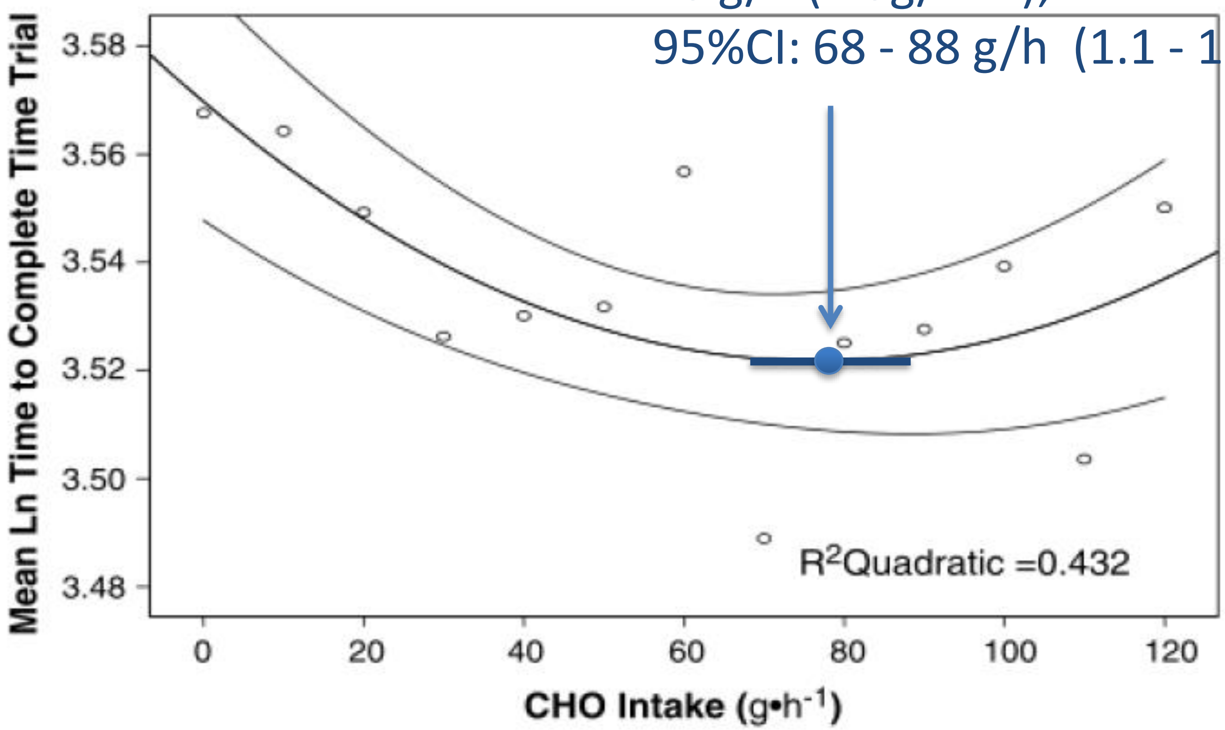


Optimal Exogenous Carbohydrate Dose?

JohnEric Smith et al., MSSE, 45(2):336, 2013



78 g/h (1.3g/min);
95%CI: 68 - 88 g/h (1.1 - 1.5 g/min)



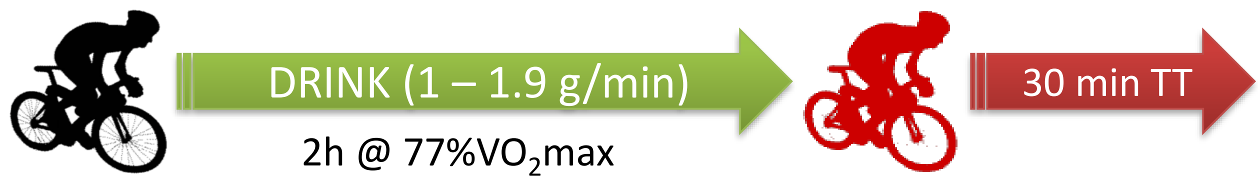
Carbohydrate dose influences liver and muscle glycogen oxidation and performance during prolonged exercise

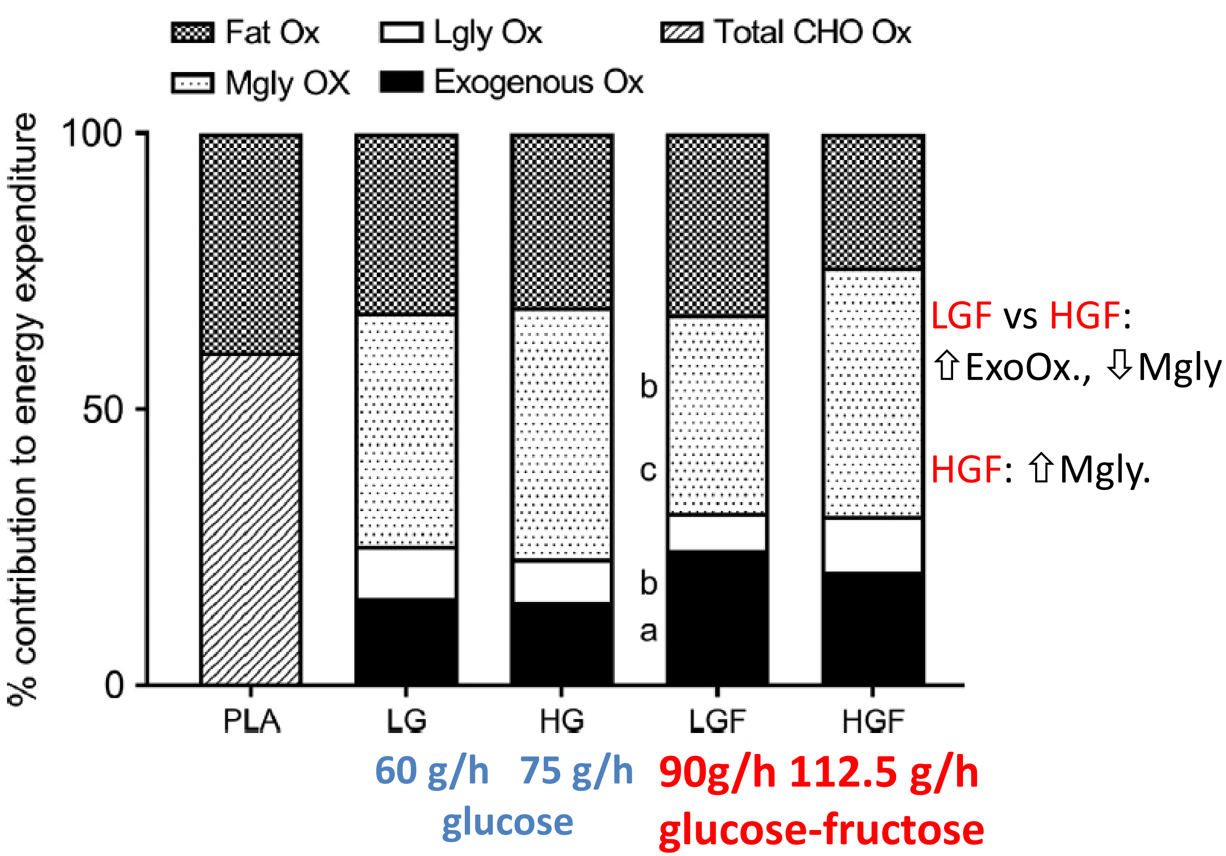
Andy J. King[1], John P. O'Hara[1], Douglas J. Morrison[2], Tom Preston[2] & Roderick F. G. J. King[1]

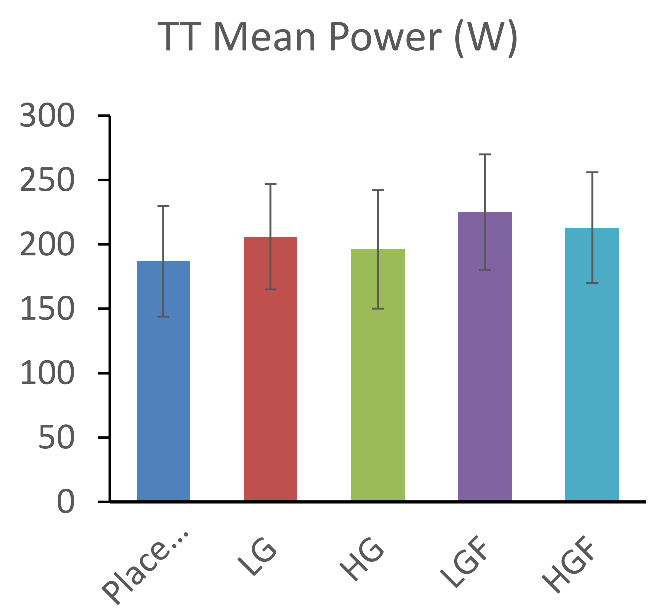
1 Research Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, United Kingdom
2 Scottish Universities Environmental Research Centre, East Kilbride, United Kingdom

Physiol Rep, 6 (1), 2018, e13555,

10 ♂ cyclists + triathletes in a crossover.



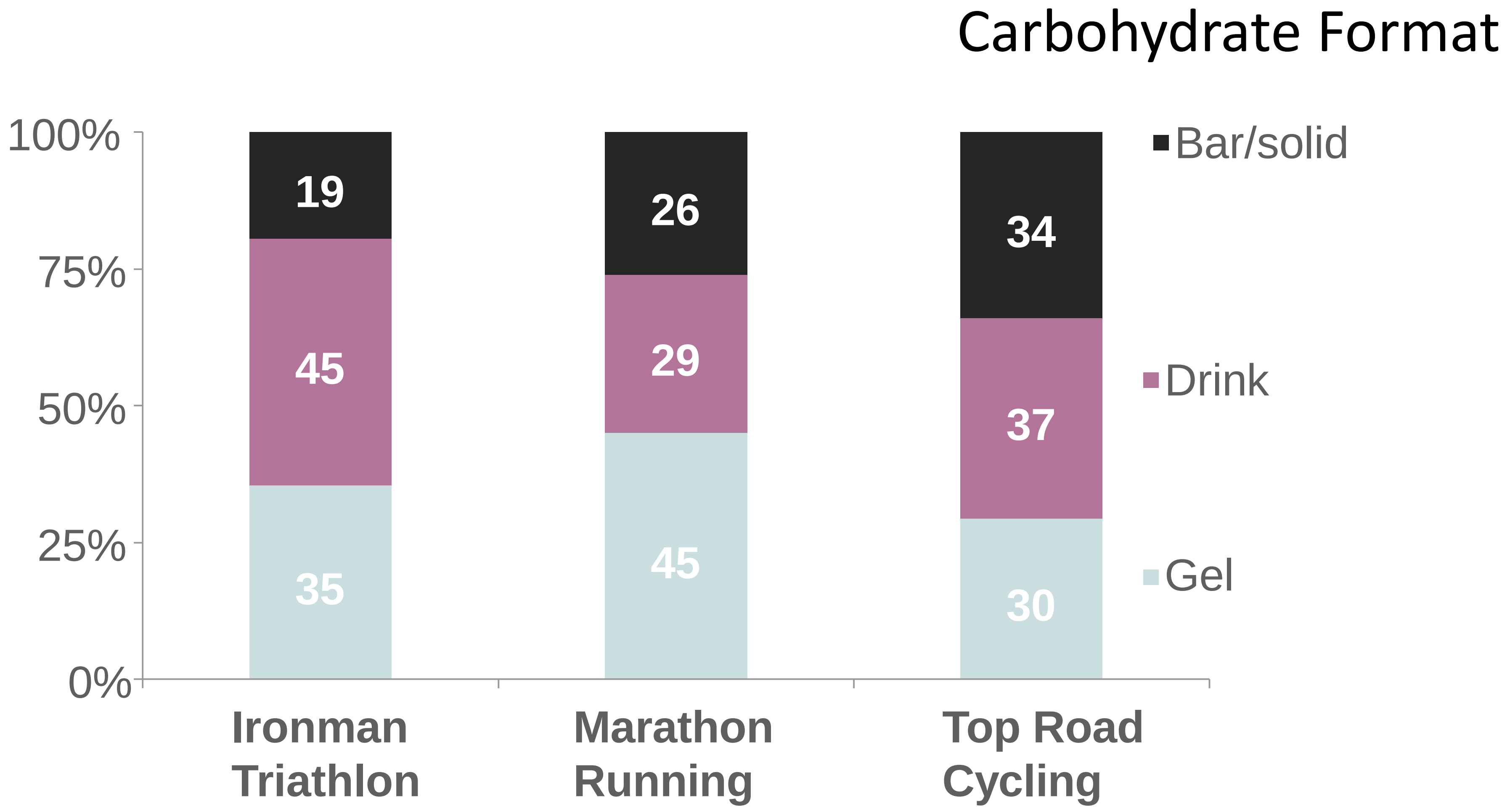




LGF vs HGF: 9.3% (-0.9–20.5)
LGF-HG: 15.2% (2.6–29.4)

Athletes Prefer a Mixed Carbohydrate Format

Beate Pfeiffer et al., MSSE, 44(2):344, 2012



Can Mixed Format Multiple-Transportable Carbohydrate Enhance Triathlon Race Performance?

In-competition Clinical Trial

Rowlands and Houltham, MSSE, 2017

N=74

Nov-13 | Dec-13 | Jan-14

- Recruitment
- Preliminary testing/ familiarisation
- CONTROL
- RACE 1 Taupo ½IM 14th Dec-13
- CONTROL
- RACE 2 Tauranga ½IM 4th Jan-14

21days

Standard training (5 days)	RACE					GI & RPE
Standard diet (24h)	Swim 1.9km (30-50mins)	T1	Bike 90km (180-210mins) *feed zone every 30km*	T2	Run 21.1km (90-150mins) *feed zone every 5km*	
Pre-race bolus 500 ml drink	1 gel (27g) during T1		CHO = 78g/h 1 bar (39g), 3 gels (81g), 4 drinks* (116g)		CHO = 78g/h 3 gels (81g), 2 drinks* (58g)	

Field Trial: Possible Small Worthwhile Effect of Multiple-Transportable Carbohydrate

FRU:GLU - GLU on triathlon race leg and finish time (~4h:30min:00)				
Time (fraction of min)	Estimate*	Lower 95%CL	Upper 95%CL	P
Finish Time**	−1.59*	−3.91	0.72	0.17
Individual Legs				
Swim	−0.21	−0.48	0.07	0.14
Bike	−0.64	−1.33	0.06	0.07
Run	−0.78	−2.94	1.39	0.48

*Threshold for small: 2.40 min.

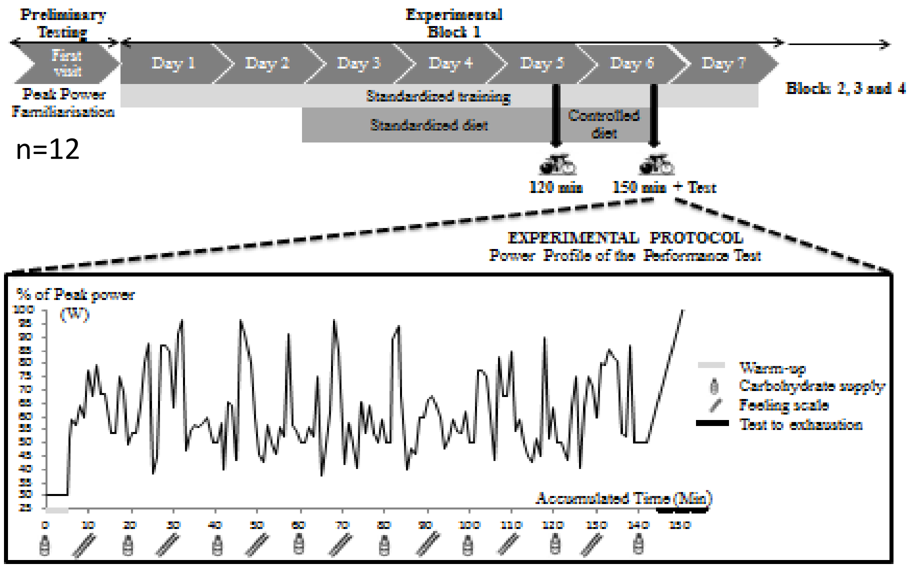
**Clinical MBI - adoption decision: 29.8% benefit/70.1% trivial/0.1% harm. Benefit:harm odds 566:1…

Take home: DO INTERVENTION STUDIES IN COMPETITION

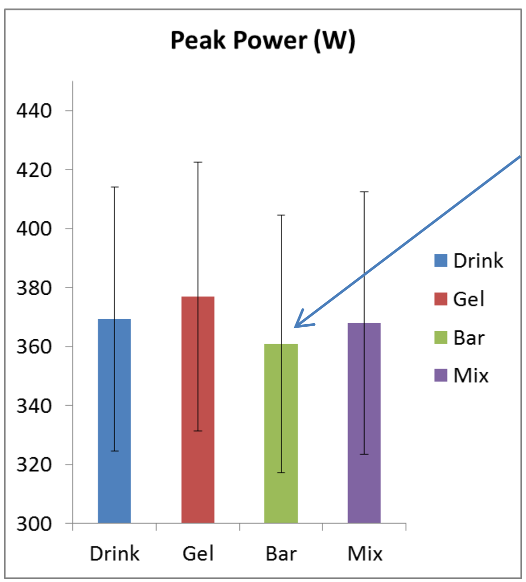
Take care with statistical inference

Bar Format Likely Harms Gut Comfort and Performance

Mathilde Guillochon, David Rowlands. IJSNEM, *2017*



n=12



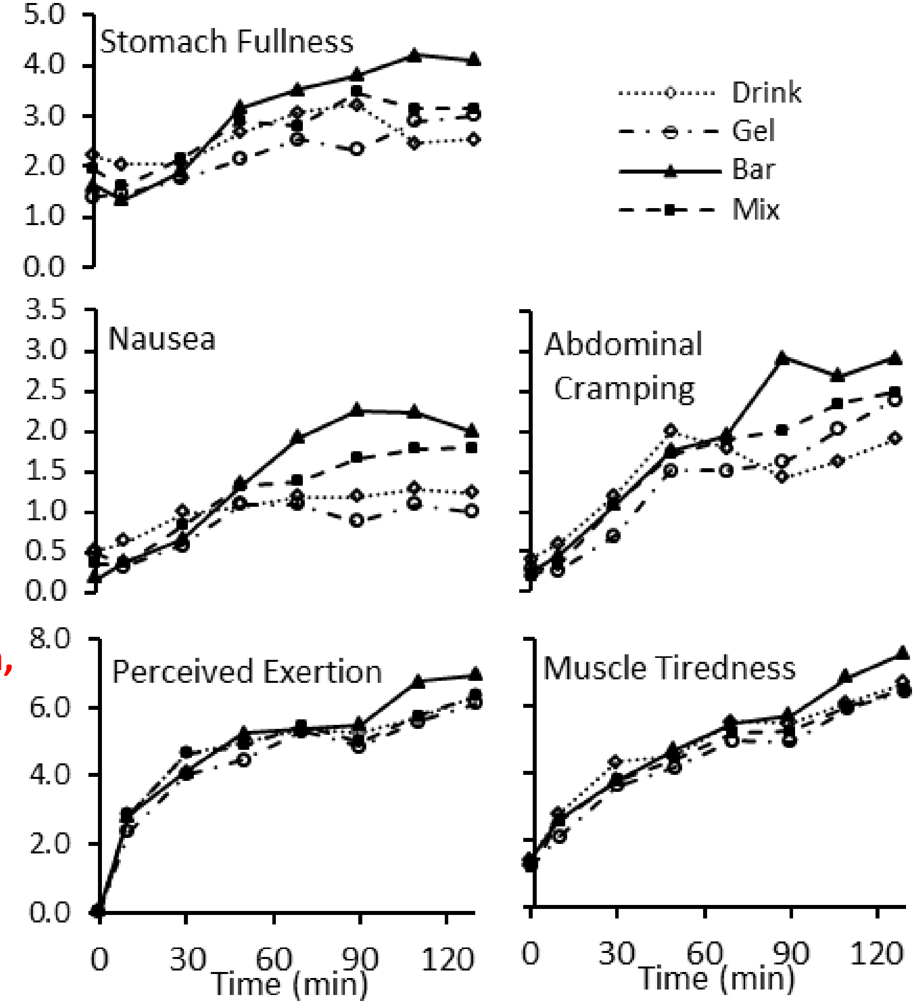
Peak Power:

Bar-Gel: -3.9%; ±4.3%

81%% likelihood **harm,**

0.8% **benefit**

Bars harm gut comfort (likelihood: 95-99.5%)



Bars: Lower Exogenous Carbohydrate Oxidation

Beate Pfeiffer, et al. MSSE 2010;42(11):2030.

bar<drink: ⇩22% (95%CI -56% to 12%)

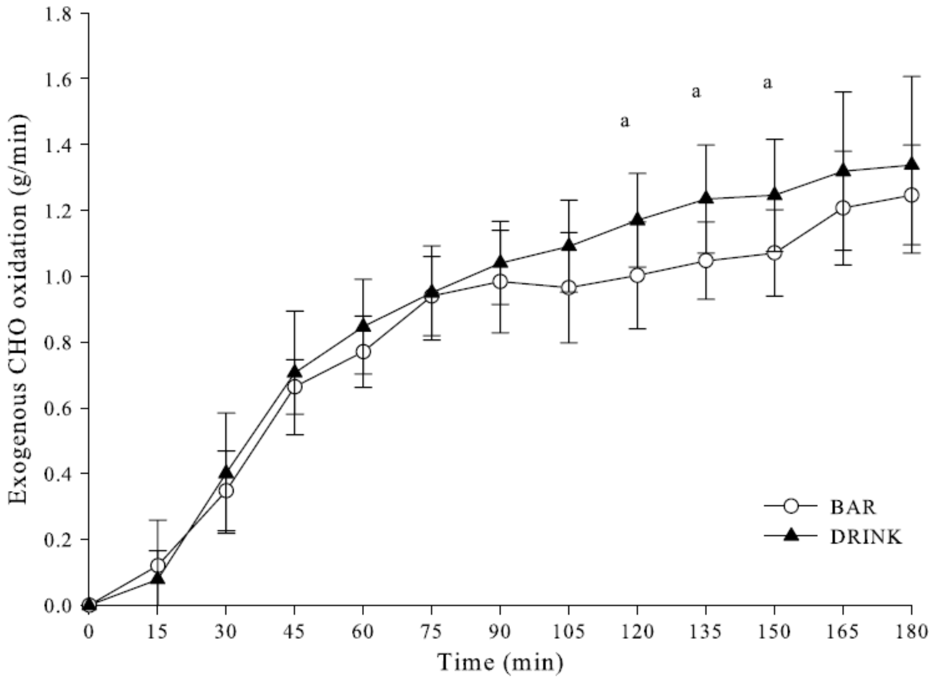


FIGURE 1—Exogenous CHO oxidation ($g \cdot min^{-1}$) during exercise with ingestion of BAR and DRINK. [a]Exogenous CHO oxidation in DRINK trial significantly greater than that in BAR trial ($P < 0.05$).

Stomach fullness bar>drink

⇨ digestion time

⇨ delayed absorption

Sport Nutrition to Assist Near sub-2h Marathon?

<u>Nike Sub2 Marathon</u>

- 2 years and $$millions
- Eluid Kipchoge - 2:00:25

(Berlin, 18 Sept 18. World Record: 2:01:39)

Speaking prior: Andrew Jones…, *"The variety of innovations we've put in place is worth a minimum of 90 sec and a maximum of 3 min."*

Training, drafting, car-race track, footwear, sport nutrition

Eluid Kipchoge

Novel Pectin/Alginate Gel Carbohydrate – Used in recent sub 2h Marathon attempts

Drink ingredients:
Maltodextrin-Fructose (2:1),
Pectin, Na Alginate, Na Chloride

⇩

Pectin+alginate forms gel in stomach pH encapsulating the carbs

⇩

⇩ Osmolality enabling ⇧ [CHO] and gastric emptying

Maurten
@MaurtenOfficial
Following

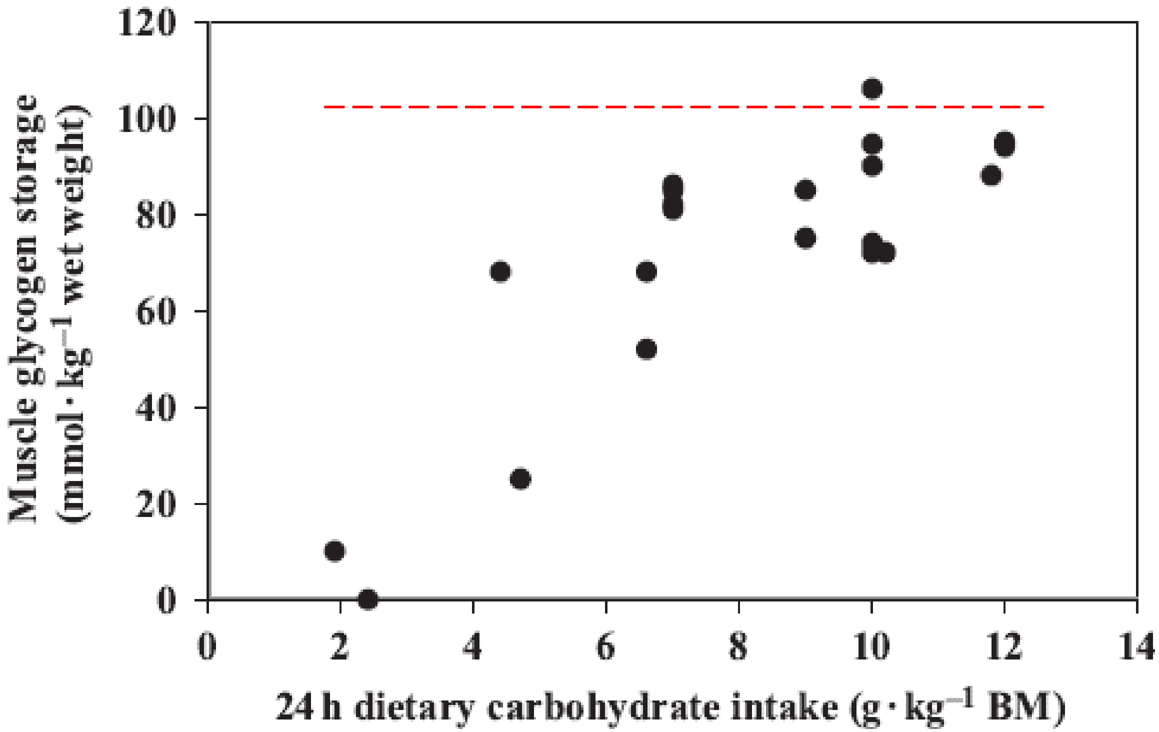
Replying to @TStellingwerff @jgault13 and 2 others

@EliudKipchoge used a combination of different Drink Mixes (based on hydrogel technology) and the the GEL 100 to reach the carbohydrates intake of approx. 100+ grams/hour.

1:26 PM - 19 Sep 2018

1. "...field trials on a number of elite athletes in Ethiopia in 2016" (Prof Andrew Bosch)
2. "Our Sub2 athletes use different compositions at each race. We started with 14% then 18% now at 30%. Well tolerated and mixes well" (Prof Yannis Pitsiladis, 2016-)
3. "gastric emptying, tracer data (Dec) (Pitsiladis); perf. test vs other carbs (Bosch) (2019).

Maximal Glycogen Restoration



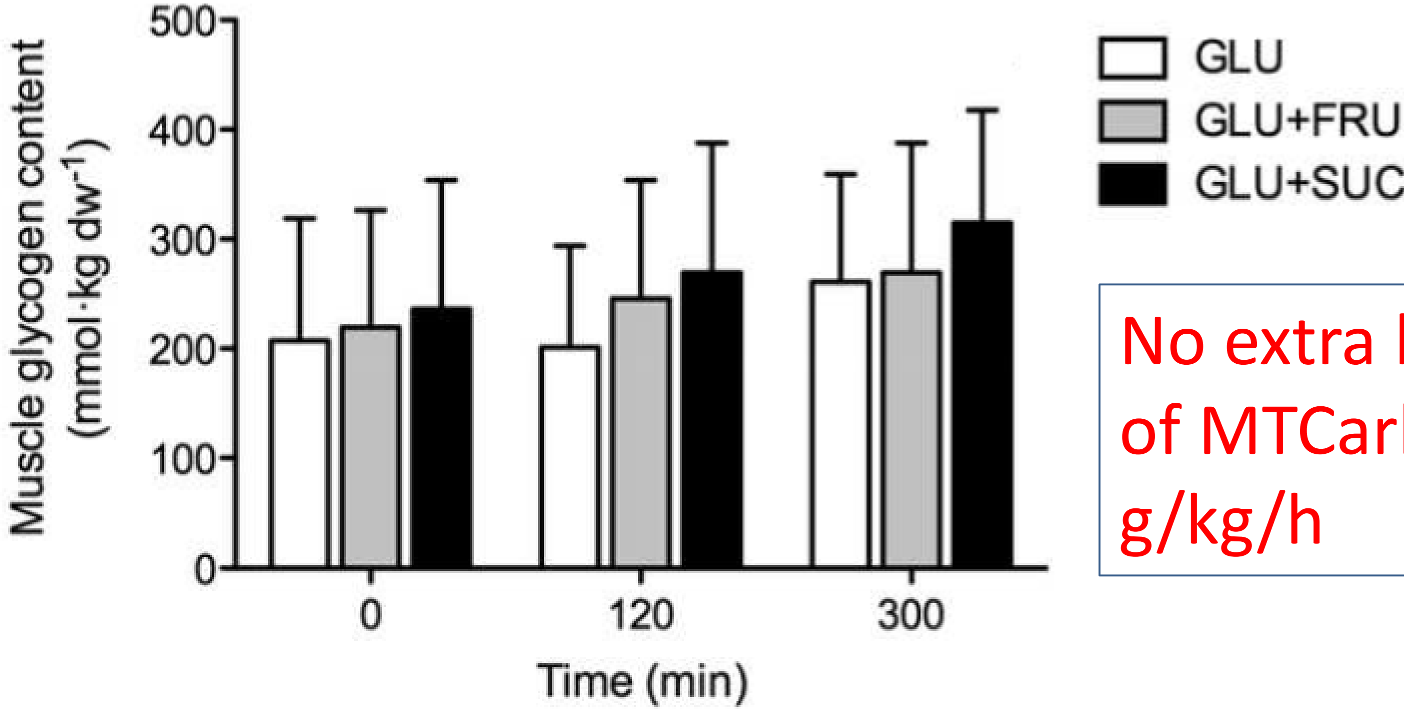
Burke L, Kiens B, Ivy J. J Sports Sci 2004;22:15-30.

- Maximal muscle glycogen storage: 100 mmol/kg ww (~600-700 g carbs).
- Maximal glycogen synthesis: <u>1.2 g carbohydrate/kg/h</u>
  - –Determined by: intestinal absorption rate ->systemic availability of carbohydrate, insulin sensitivity, glycogen synthase activity

Fructose co-ingestion does not accelerate post-exercise muscle glycogen repletion

Jorn Trommelen, Milou Beelen, Philippe J.M. Pinckaers, Joan M. Senden, Naomi M. Cermak, and Luc J.C. van Loon. MSSE, Nov 24, 2015.

Glycogen-depleting exercise ⇨ 5 h recovery period:
- 1.5 g·kg^{-1}·h^{-1} glucose,
- 1.2 g·kg^{-1}·h^{-1} glucose + 0.3 g·kg^{-1}·h^{-1} fructose (GLU+FRU),
- 0.9 g·kg^{-1}·h^{-1} glucose + 0.6 g·kg^{-1}·h^{-1} sucrose (GLU+SUC).



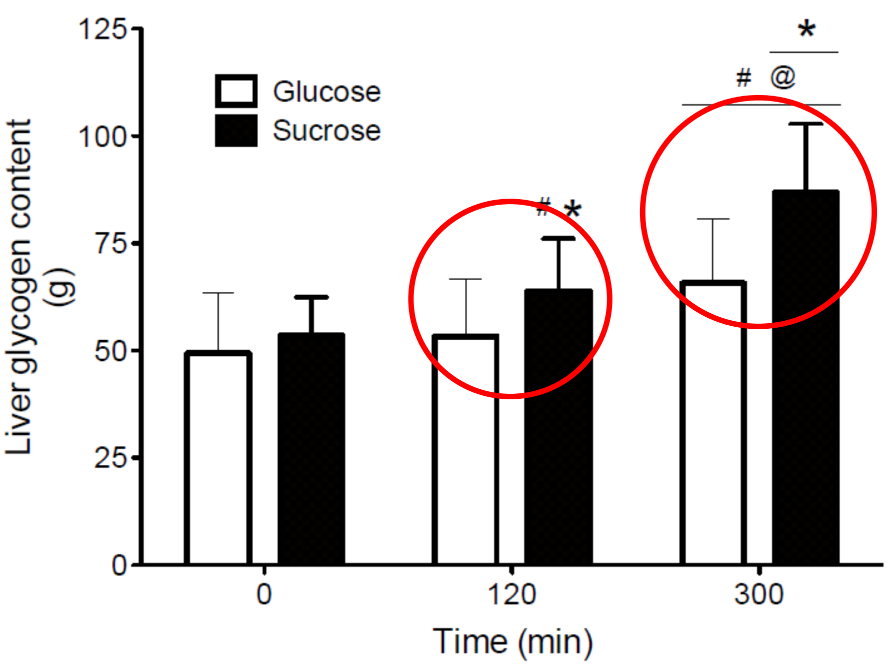
No extra benefit of MTCarbs >1.2 g/kg/h

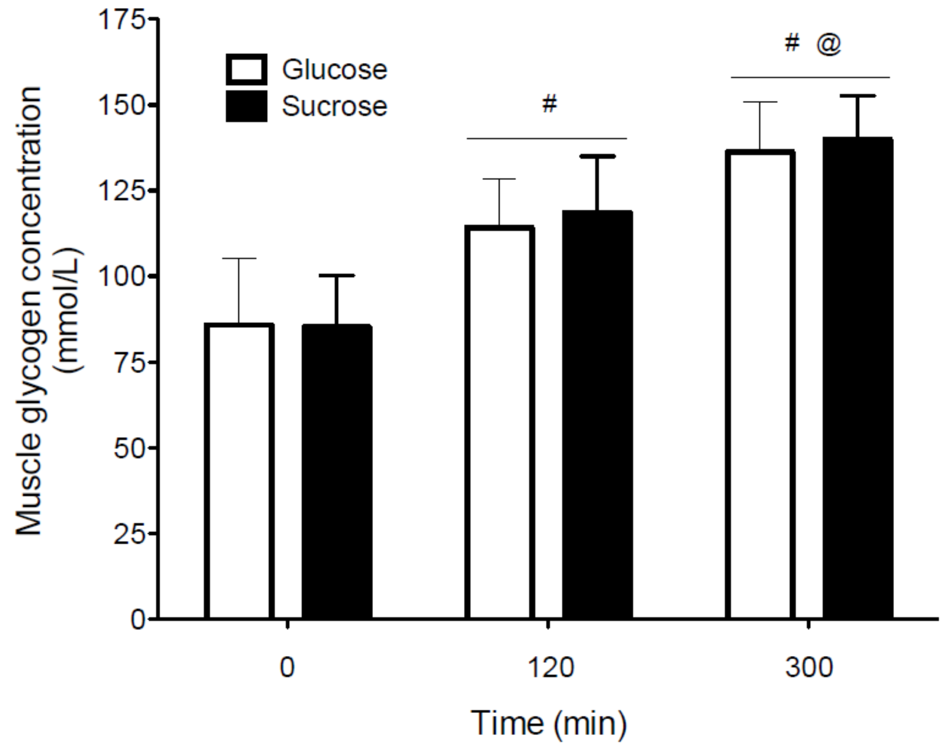
But… Sucrose Ingestion After Exhaustive Exercise Accelerates Liver, But Not Muscle Glycogen Repletion When Compared To Glucose Ingestion

Cas J. Fuchs, Javier T. Gonzalez, Milou Beelen, Naomi M. Cermak, Fiona E. Smith, Peter E. Thelwall, Roy Taylor, Michael I. Trenell, Emma J. Stevenson, Luc J.C. van Loon

JAP, 24 March 2016

- Sucrose vs Glucose ingestion (1.5 $g \cdot kg^{-1} \cdot h^{-1}$)
- Fructose on hepatic glycogen



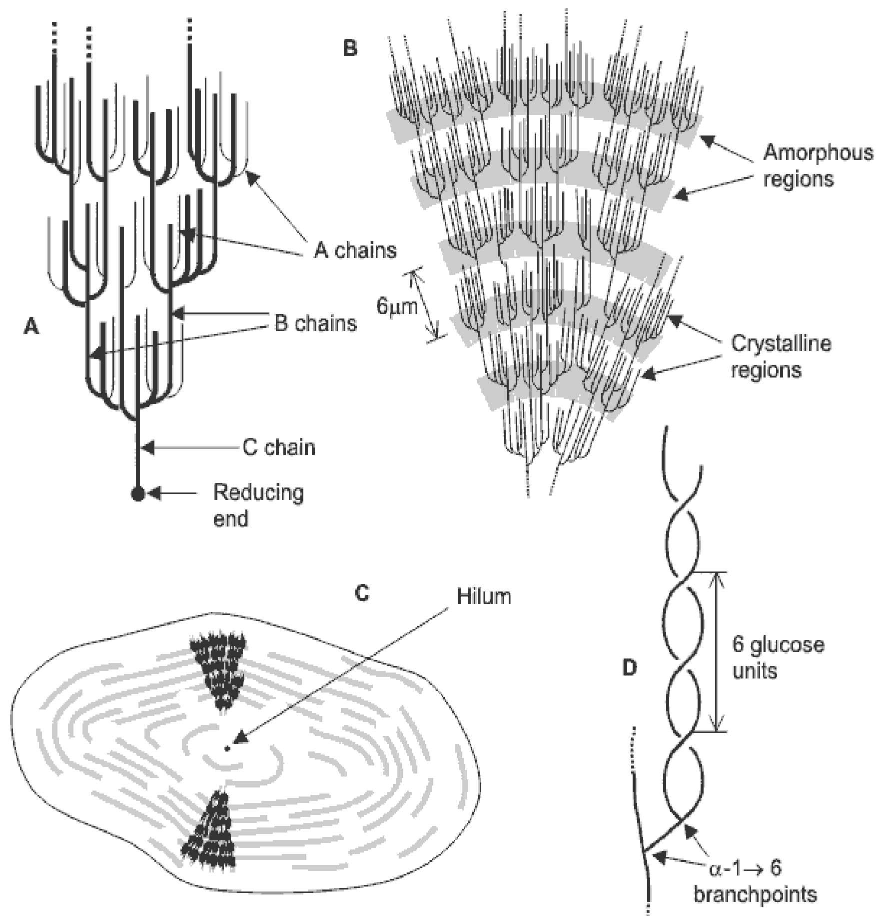


What practical utility of +25g liver glycogen when exogenous CHO available?

High-Molecular Weight Glucose Polymer

Waxy maize or potato starch:

- V. high Mr 500-700 kg·mol^{-1}, 3.1-4.6k glucose units·mol^{-1} (vs. typical maltodextrin 1-50)
- Branched amylopectin: multiple terminal ends for amylase action ⇨ **fast digestion**
- Very Hypotonic ⇨ **faster gastric emptying** (Leiper, et al. 2000)

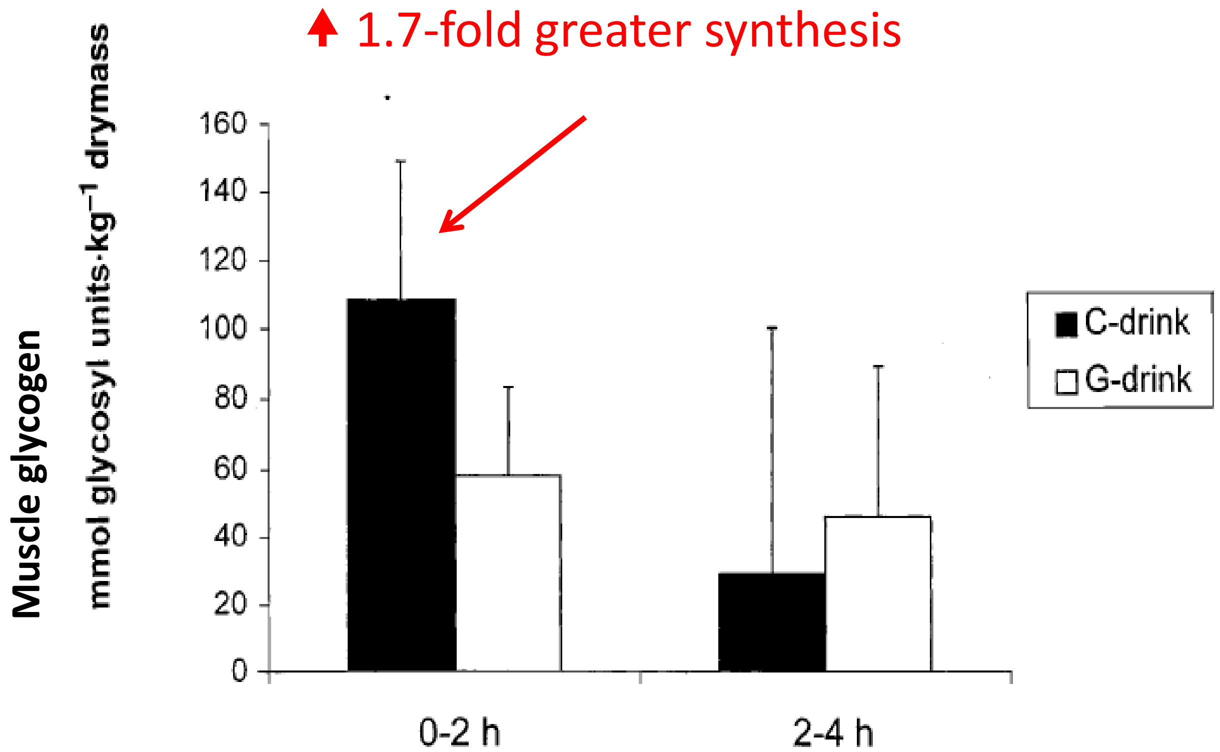


http://www.lsbu.ac.uk/water/hysta.html

Faster Glycogen Synthesis with HMW Polymer

K. Piehl Aulin, K. Soderlund, E. Hultman, 2000.

- Glycogen-depleting exercise ⇨
- ⇨ 300 g HMW polymer vs. 300 g glucose solution ingested first 90-min

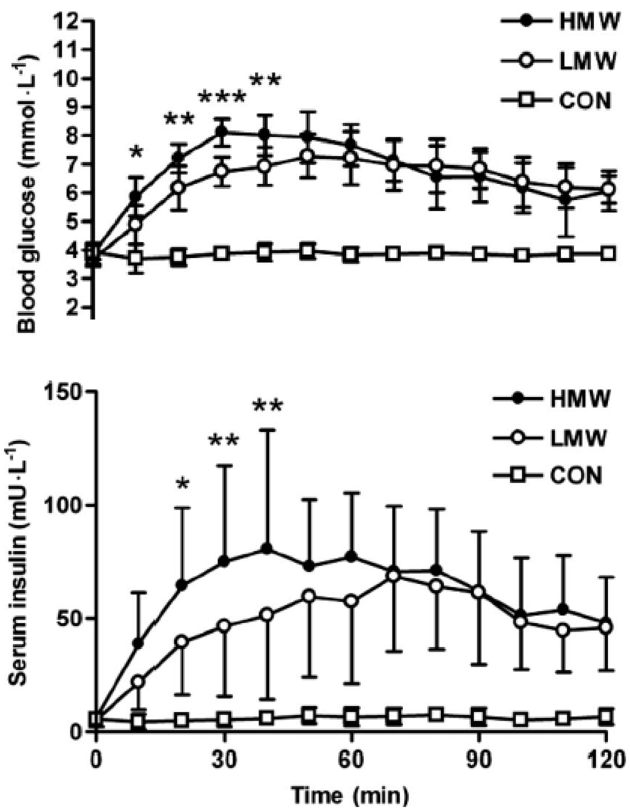


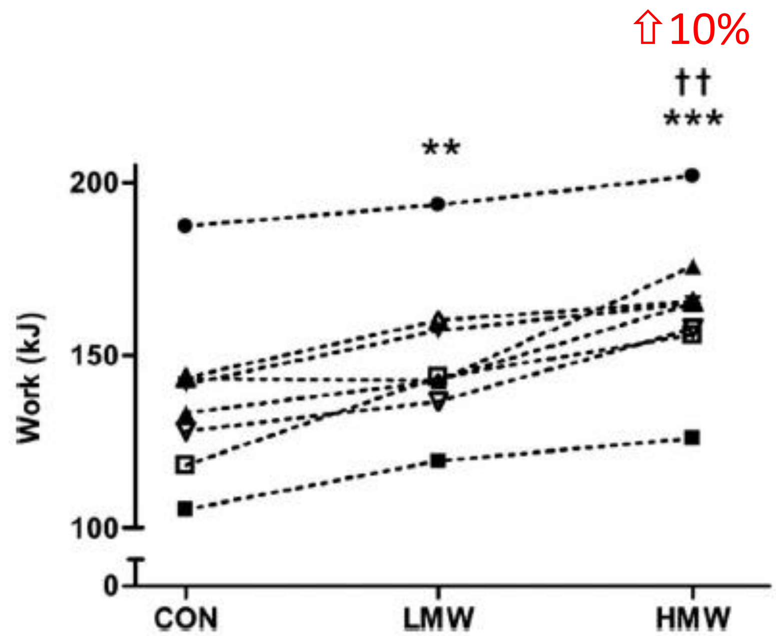
Aulin KP, Söderlund K, Hultman E (2000) Muscle glycogen resynthesis rate in humans after supplementation of drinks containing… . *Eur J Appl Physiol* 81(4): 0346.

Improved Subsequent Endurance Cycling Performance

F. Stephens, M. Roig, G. Armstrong, P. Greenhaff, 2008.

cycling to exhaustion ⇨ ingestion of 100 g HMW vs. 100 g LMW glucose polymer ⇨ 2-h rest ⇨ 15-min work test





Stephens, F. B., et al. 2008). Post-exercise ingestion of a unique, high molecular weight glucose polymer solution improves performance..... *J Sport Sci* 26(2): 149 - 154.

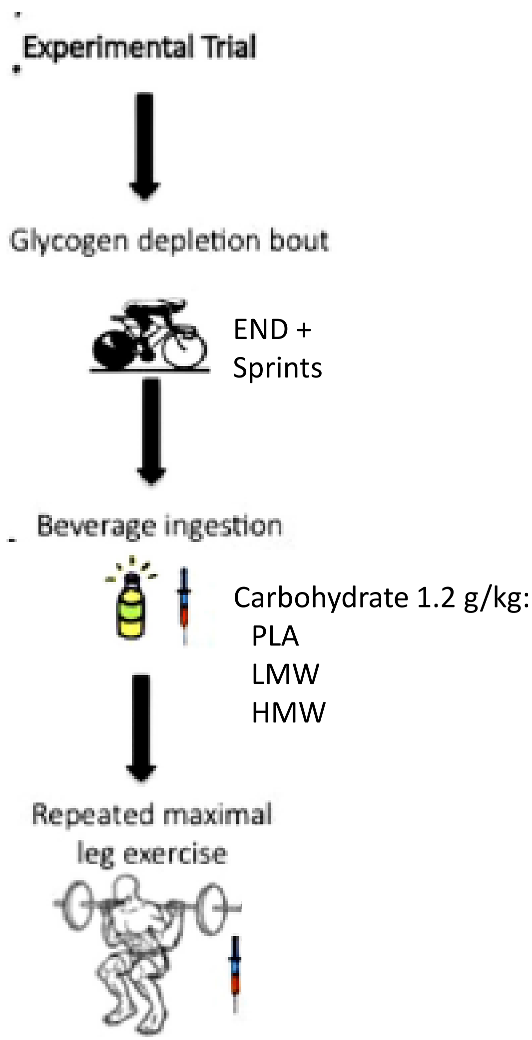
PLOS ONE 2016, 11(9): e0163009.

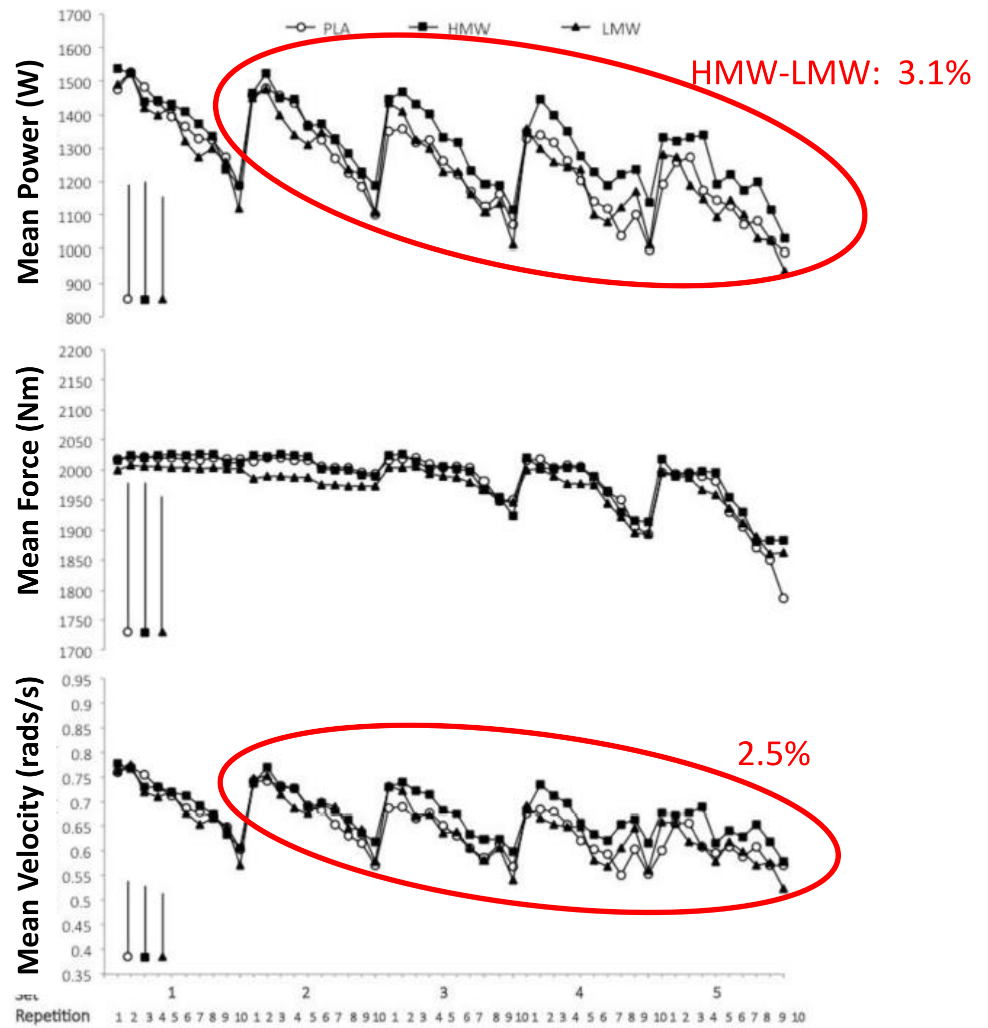
Ingestion of High Molecular Weight Carbohydrate Enhances Subsequent Repeated Maximal Power: A Randomized Controlled Trial

Jonathan M. Oliver[1]*, Anthony L. Almada[2], Leighsa E. Van Eck[1], Meena Shah[1], Joel B. Mitchell[1], Margaret T. Jones[3], Andrew R. Jagim[4], David S. Rowlands[5]

1 Department of Kinesiology, Texas Christian University, Fort Worth, Texas, United States of America,

Muscle kinetic and kinematics





Take Home

Optimising the Ergogenic Benefits of Supplemental Carbohydrate:

- ✓ Fructose:maltodextrin @ 0.8-1.0:1.0 ratio
- ✓ Drinks and gels favoured over bars (GI distress)
- ✓ Optimal average ingestion ~80 g/h (70-90 g/h) (better metabolic & GI)

Hydrogel ?

Glycogen Restoration:

- ✓ Ingest any carbs ~1.2 g/kg/h (>10 g/kg for full loading)
- ✓ Faster with High Molecular Weight polymers; but sucrose also works

Performance-Nutrition Research in General:

1. Quality boost needed: Low n; bias from design features; meaningful and translatable statistical inference
2. Intervention trials in real race conditions/ simulations
3. More on women; ultra endurance

Acknowledgements

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Xiaocai Shi

TCU

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Jonathan Oliver

Participants

Post-Grad Students

   

Megan Grace, Mathilde Guillochon, Wendy O’Brien, Marg Ros

End