Muscle glycogen recovery, exercise performance and the implications of environmental stress.

Brent Ruby, Ph.D., FACSM
The University of Montana

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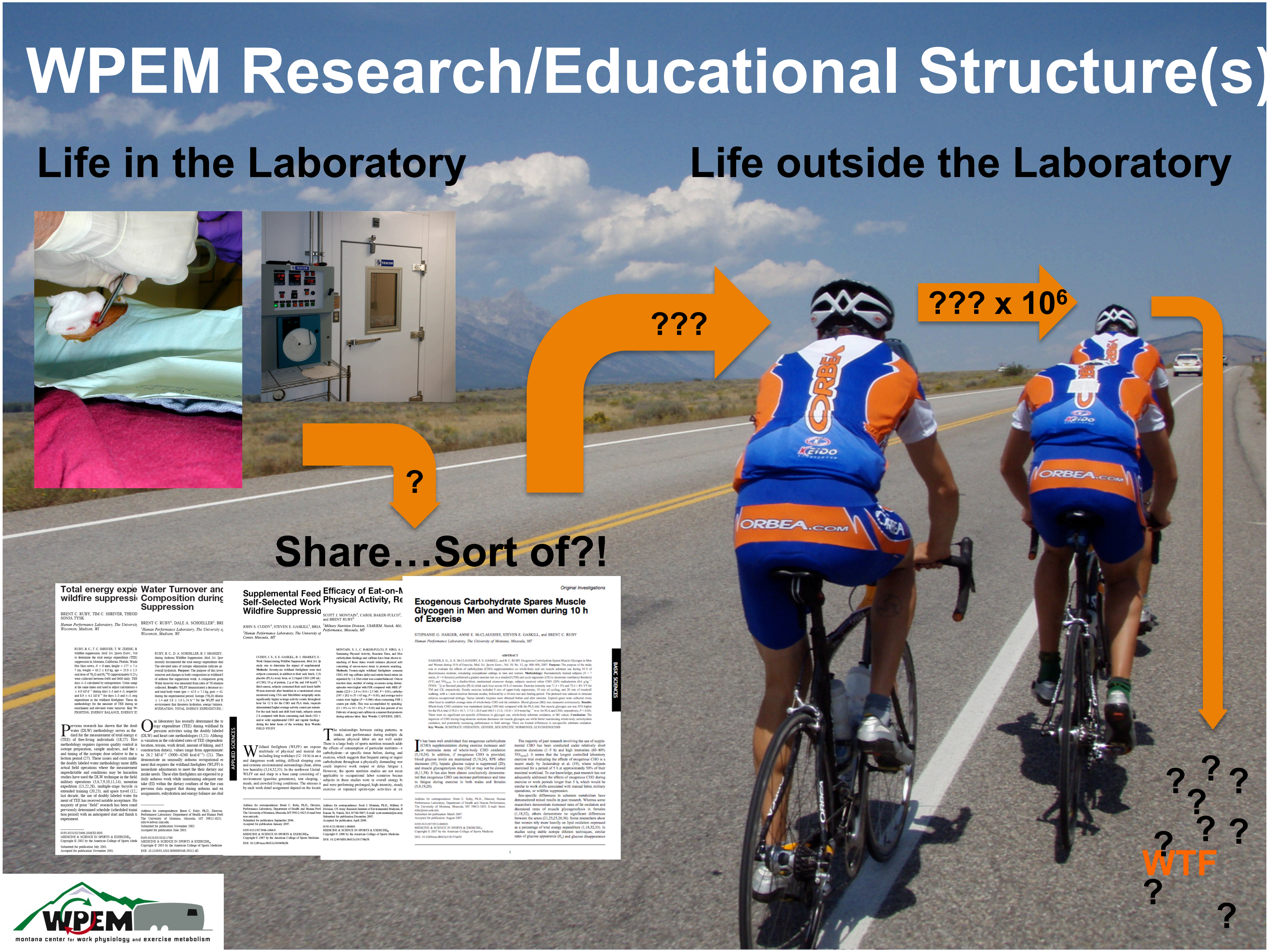
WPEM Research/Educational Structure(s)
Life in the Laboratory
Life outside the Laboratory
?
???
??? x 10^6
Share…Sort of?!
Exogenous Carbohydrate Spares Muscle Glycogen in Men and Women during 10 h of Exercise
WTF
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Laboratory ⟷ Field

- Energy Demands (DLW w/WLFF, WS100, Ironman, Iditarod, AFSOC)
- Hydration Demands (D2O w/WLFF, WS100, Ironman, Iditarod, AFSOC, Badwater)
- Reasons for Fatigue/Counter measures (Natick, WLFF)
- Instrumentation (physiological monitor systems lab and field)
- Mobility in the Field (data collection in varied environments)
- Environmental stress (heat, cold, hypoxia, recovery, gene response)

- Innovation/Creative application in a mission **oriented variable environment** to improve translation to the end user!

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JOURNAL OF APPLIED PHYSIOLOGY
Vol. 31, No. 6, December 1971. *Printed in U.S.A.*

Muscle glycogen utilization during prolonged exercise on successive days

DAVID L. COSTILL, RICHARD BOWERS, GEORGE BRANAM, AND KENNETH SPARKS
Human Performance Laboratory, Ball State University, Muncie, Indiana 47306

Recovery Happens!

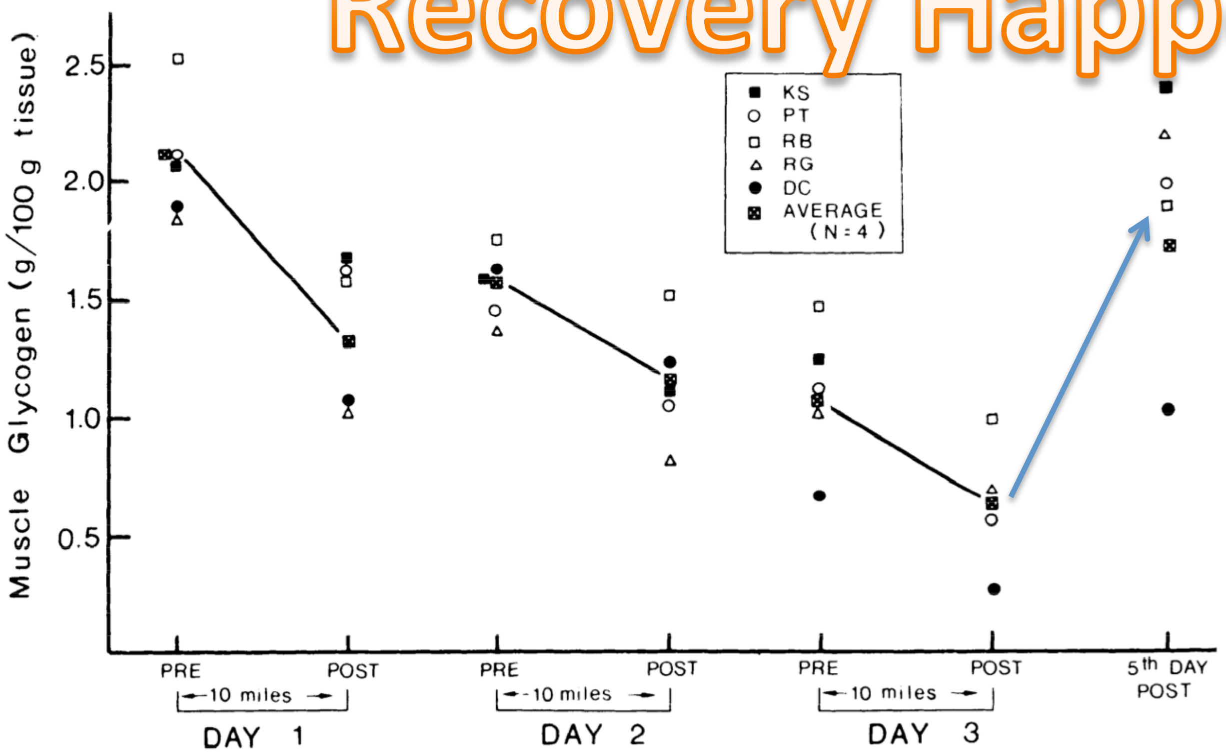

FIG. 2. Individual and mean muscle glycogen concentrations before and after each of 16.1-km runs. Muscle glycogen measured 5 days after 3rd run is referred to as "5th day post."

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April 15 , 1971

Muscle glycogen utilization during prolonged exercise on successive days

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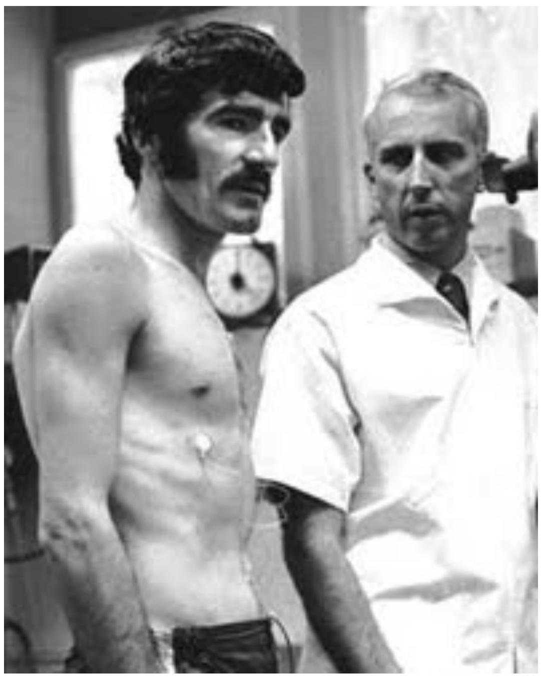
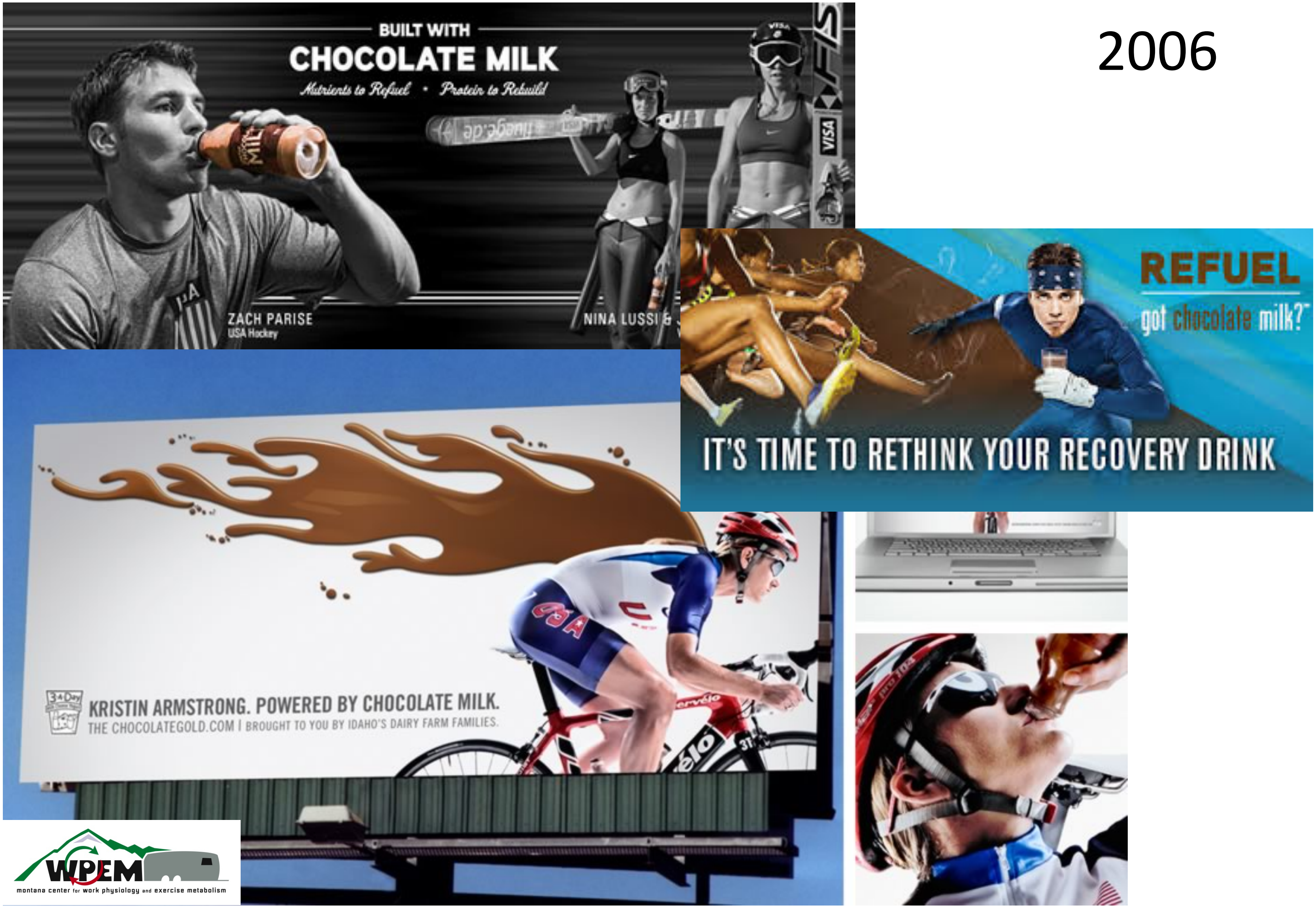
Human Performance Laboratory, Ball State University, Muncie, Indiana 47306



The fact that the diets of our subjects contained only moderate amounts (40–50%) of carbohydrate may explain why muscle glycogen replacement was incomplete for *subjects DC, RB,* and *PT* even after 5 days of rest. These observations hold unmistakable implications for men who must exercise exhaustively on successive days.

Recovery becomes…trendy?!

2006



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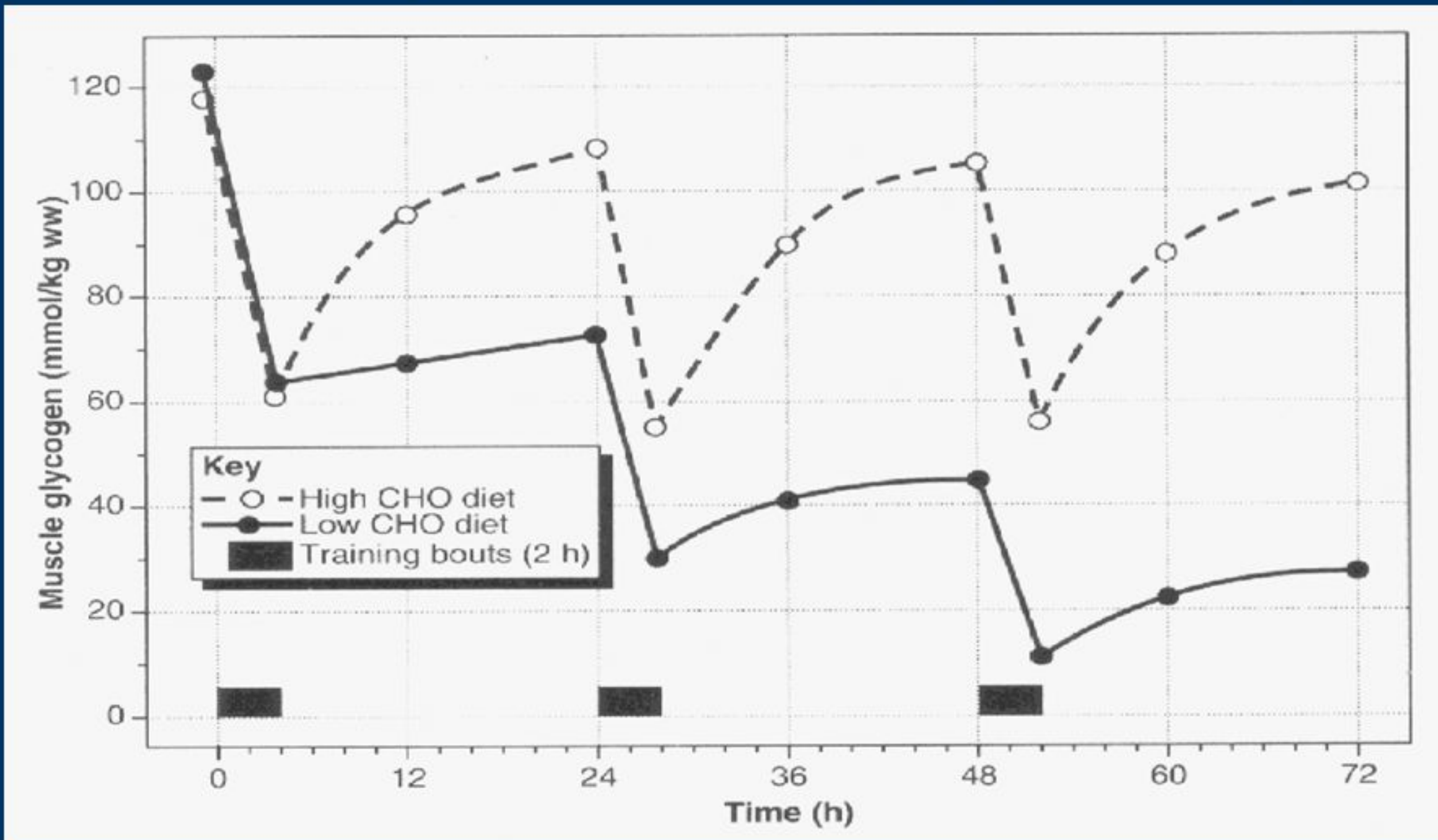
Stort karbohydratinntak gir best restitusjon ved daglig trening



(Costill & Miller, 1980)

Costill and Miller, Int J Sports Nutri 1:2-14, 1980

Carbohydrate-Protein Intake and Recovery from Endurance Exercise: Is Chocolate Milk the Answer?

Michael John Saunders, PhD, FACSM

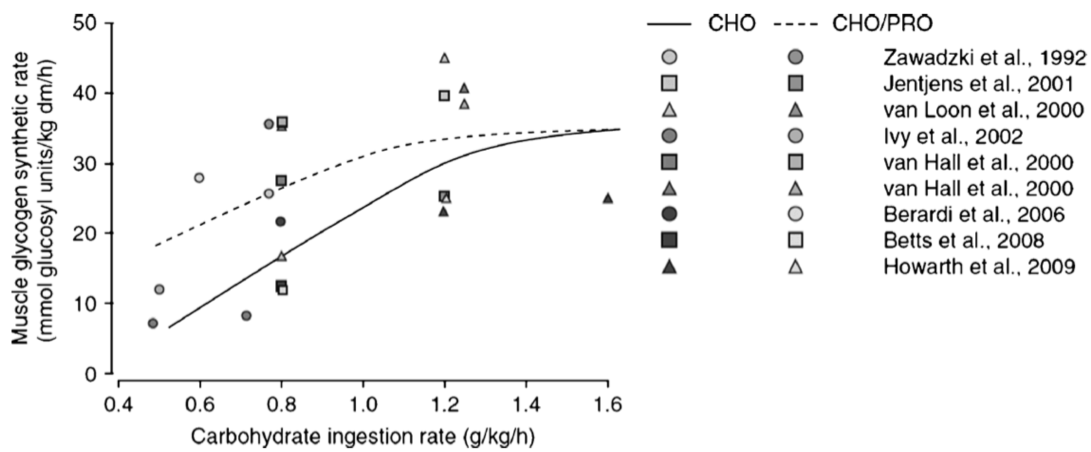


Figure 1: Influence of carbohydrate dose on glycogen resynthesis rate. (Reprinted from Betts JA, Williams C. Short-term recovery from prolonged exercise exploring the potential for protein ingestion to accentuate the benefits of carbohydrate supplements. *Sports Med*. 2000; 40:941–59. Copyright © 2010 Adis Journals. Used with permission.)

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J Appl Physiol 93: 1337–1344, 2002.
First published July 12, 2002; 10.1152/japplphysiol.00394.2002.

Early postexercise muscle glycogen recovery is enhanced with a carbohydrate-protein supplement

JOHN L. IVY,[1] HAROLD W. GOFORTH, JR.,[2] BRUCE M. DAMON,[3] THOMAS R. McCAULEY,[3] EDWARD C. PARSONS,[3] AND THOMAS B. PRICE[3]
[1]*Exercise Physiology and Metabolism Laboratory, Department of Kinesiology and Health Education, University of Texas at Austin, Austin, Texas 78712;* [2]*Department of Biology, Point Loma Nazarene University, San Diego, California; and* [3]*Department of Diagnostic Radiology, Yale University School of Medicine, New Haven, Connecticut 06510*

Received 3 May 2002; accepted in final form 2 July 2002

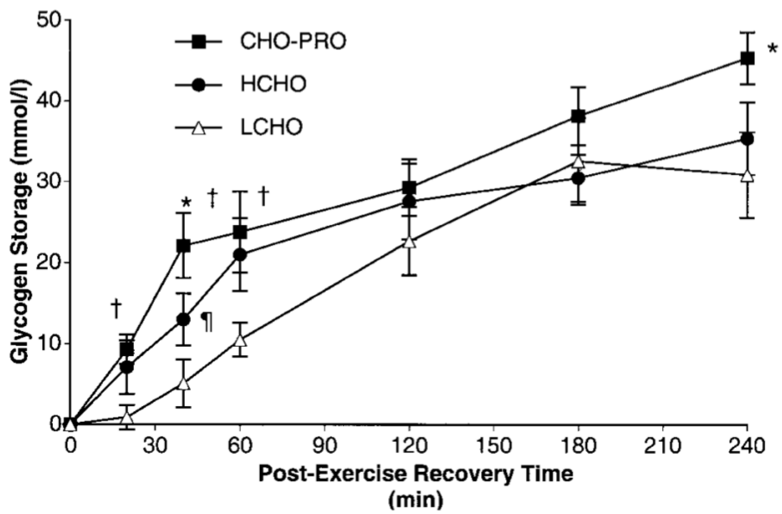

Fig. 1. Patterns of muscle glycogen storage during recovery as determined by nuclear magnetic resonance spectroscopy for the carbohydrate-protein (CHO-Pro; ■), isocarbohydrate (LCHO; △), and isocaloric carbohydrate (HCHO; ●) supplements. Supplements were provided immediately after and 2 h after exercise. *CHO-Pro significantly different from LCHO and HCHO ($P < 0.05$). †CHO-Pro significantly different from LCHO ($P < 0.05$). ¶HCHO significantly different from LCHO ($P < 0.05$).

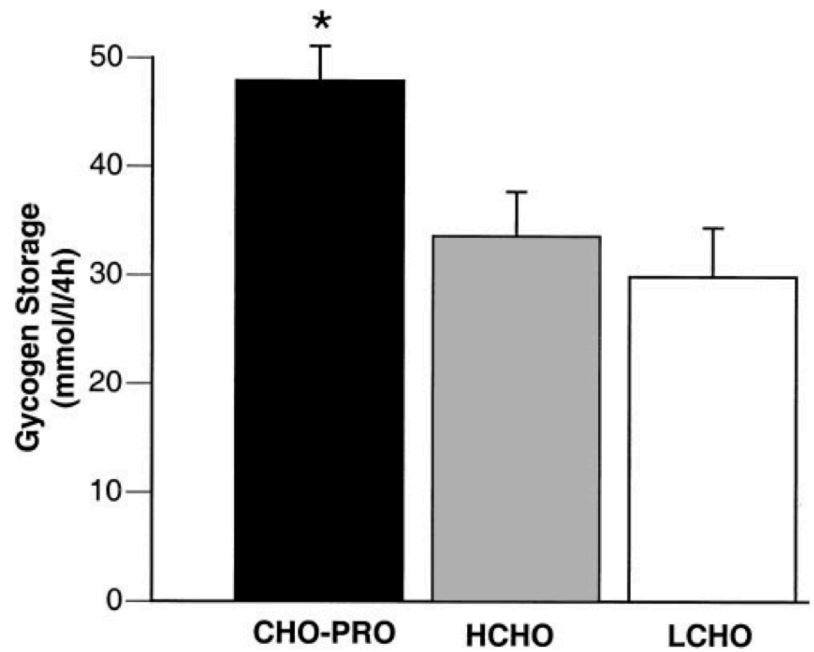

Fig. 2. Total muscle glycogen storage in the vastus lateralis during 4 h of recovery from intense cycling. Treatments were with CHO-Pro, LCHO, and HCHO supplements provided immediately after and 2 h after exercise. *Significantly different from HCHO and LCHO ($P < 0.05$).

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J Appl Physiol 105: 7–13, 2008.
First published May 8, 2008; doi:10.1152/japplphysiol.01121.2007.

High rates of muscle glycogen resynthesis after exhaustive exercise when carbohydrate is coingested with caffeine

David J. Pedersen, Sarah J. Lessard, Vernon G. Coffey, Emmanuel G. Churchley, Andrew M. Wootton, They Ng, Matthew J. Watt, and John A. Hawley
School of Medical Sciences, RMIT University, Bundoora, Victoria, Australia

Submitted 18 October 2007; accepted in final form 30 April 2008

8 mg/kg BW

75 kg rider…600 mg!

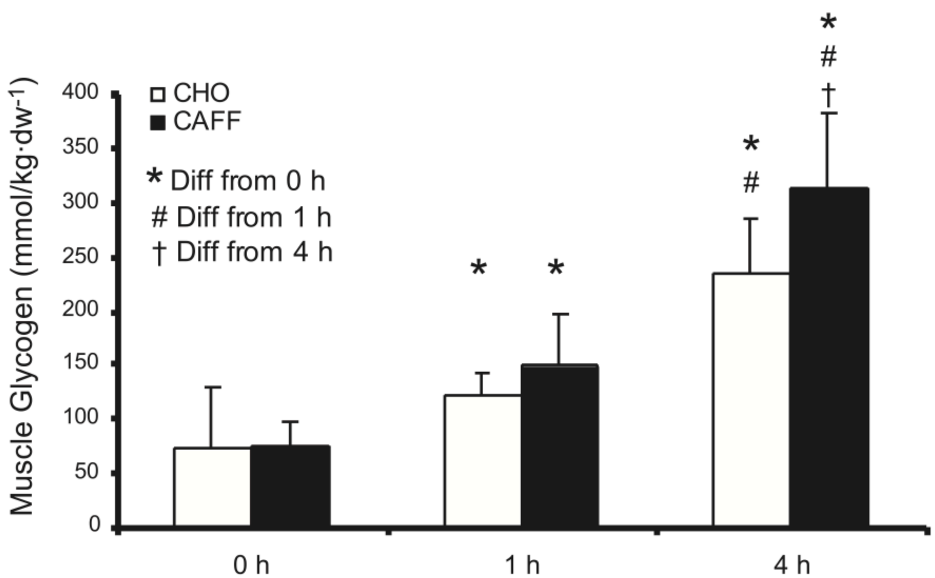

Fig. 1. Skeletal muscle glycogen content immediately after exercise (0 h) and after 1 h and 4 h of recovery following cycling to volitional fatigue [~70% peak O_2 uptake ($\dot{V}O_{2peak}$)]. During recovery subjects consumed 1 g carbohydrate/kg body mass (BM) (CHO) or 1 g carbohydrate/kg BM + 8 mg caffeine/kg BM (Caff). *Significant difference vs. 0 h; #significant difference vs. 1 h; †significant difference, CHO vs. Caff 4 h ($P < 0.05$). All values are

Consider the near 6 hour half life and how this may compromise sleep quality!

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Amino Acids (2005) 28: 71–76
DOI 10.1007/s00726-004-0143-z

Amino Acids
Printed in Austria

The addition of fenugreek extract (*Trigonella foenum-graecum*) to glucose feeding increases muscle glycogen resynthesis after exercise

B. C. Ruby, S. E. Gaskill, D. Slivka, and **S. G. Harger**

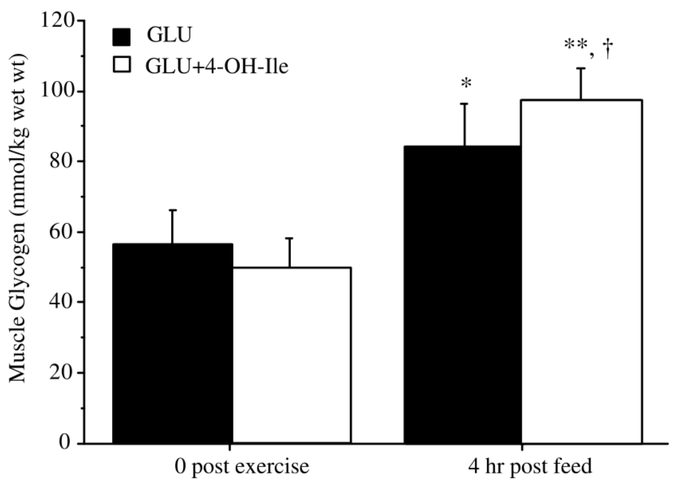
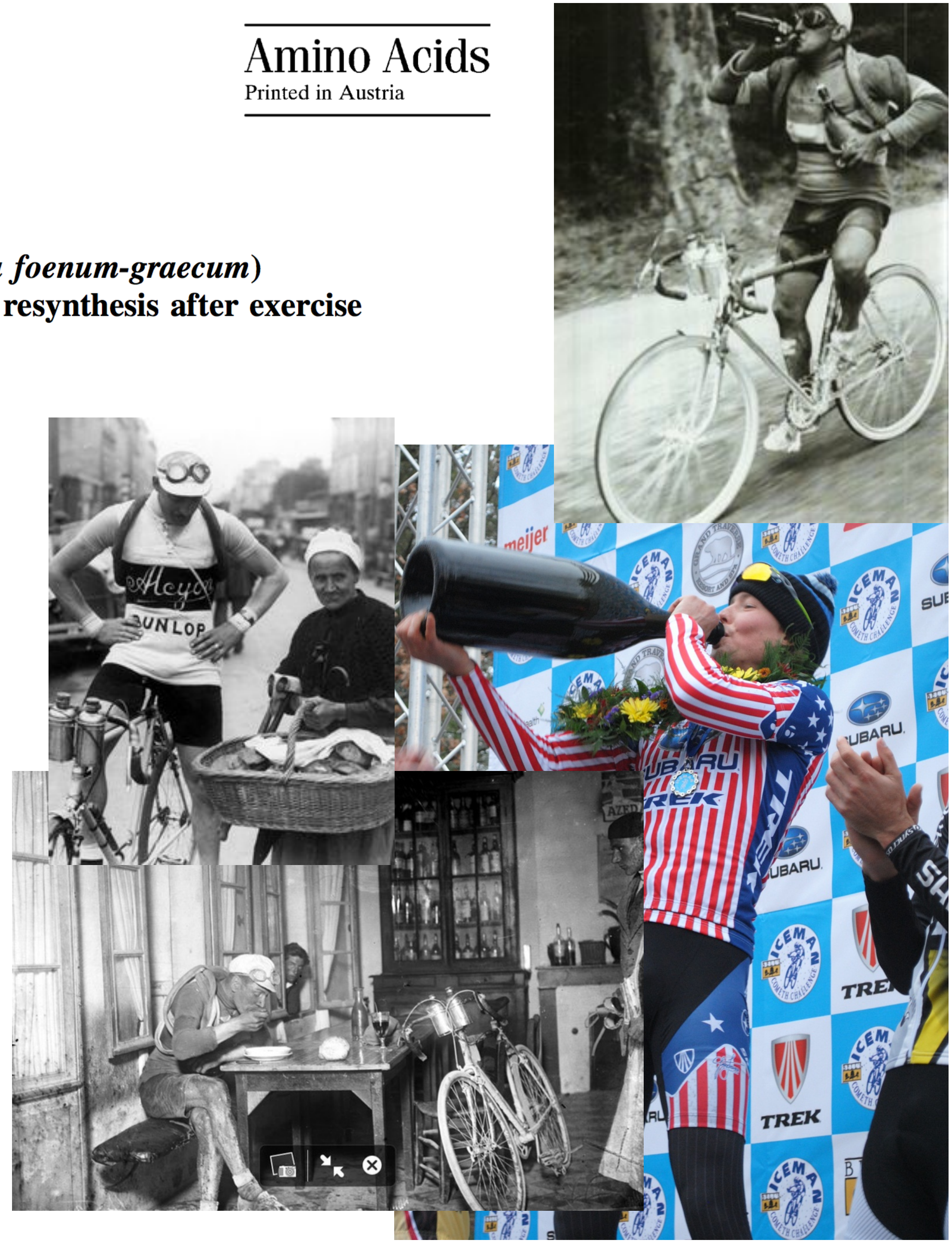


Fig. 3. Changes in muscle glycogen (vastus lateralis) in response to the oral glucose and experimental feedings (GLU vs. GLU + 4-OH-Ile). Feedings occurred immediately after post exercise biopsy (0 post exercise) and again at 120 minutes (4 hr post feed). * – significant increase from 0 post exercise (GLU), $p < 0.05$, ** – significant increase from 0 post exercise (GLU + 4-OH-Ile), $p < 0.05$, † – 4 hr post feed (GLU + 4-OH-Ile) vs. 4 hr post feed (GLU), $p < 0.05$



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Impacts of Ambient Environmental and Peripheral Muscle Temperature on Rates of Muscle Recovery.

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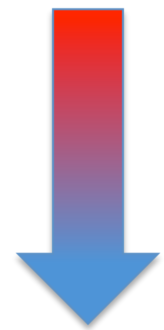
Environmental Temperature and Glycogen Resynthesis

Int. J Sports Med. 31(8): 561-566, 2010

Authors M. Naperalsky[2], B. Ruby[1,2], D. Slivka[1]

Affiliations [1] University of Montana, Montana Center For Work Physiology and Exercise Metabolism, Missoula, United States
[2] University of Montana, Health and Human Performance, Missoula, United States



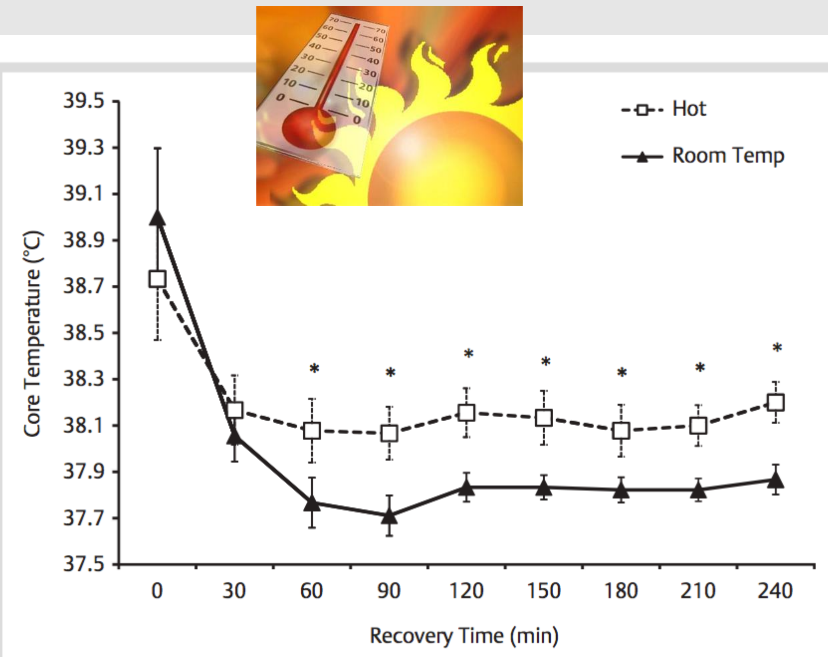


Fig. 1 Mean core temperature in the Heat and at Room Temperature. * $p<0.05$ from room temperature.

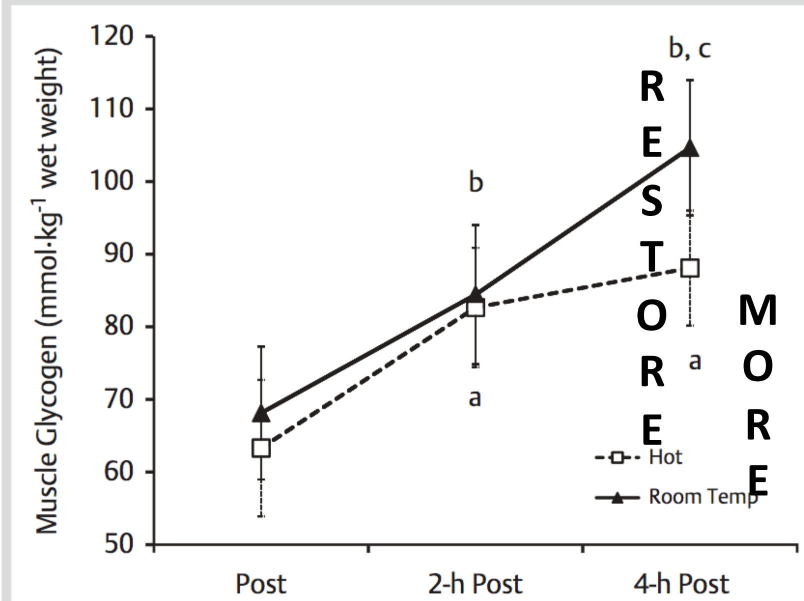


Fig. 2 Muscle glycogen during recovery (time × trial interaction), at Post, 2 h and 4 h post exercise. **a** $p<0.05$ from Post (Hot); **b** $p<0.05$ from Post (Room Temp); **c** $p<0.05$ from 2-h Post (Room Temp).

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Cryobiology

journal homepage: www.elsevier.com/locate/ycryo

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Cryobiology 66 (2013) 250–255

Effects of post-exercise recovery in a cold environment on muscle glycogen, PGC-1α, and downstream transcription factors

Dustin Slivka [a,*], Matthew Heesch [a], Charles Dumke [b], John Cuddy [b], Walter Hailes [b], Brent Ruby [b]

[a] University of Nebraska at Omaha, School of Health Physical Education and Recreation, Omaha, NE, United States
[b] University of Montana, Montana Center for Work Physiology and Exercise Metabolism, Missoula, MT, United States

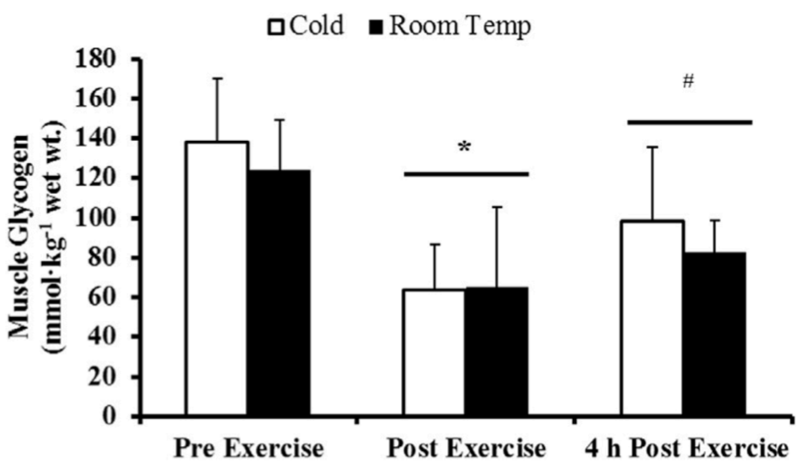

Fig. 2. Muscle glycogen pre, post, and 4 h post exercise. *$p < 0.05$ from pre exercise, #$p < 0.05$ from post exercise. Data are mean ± SD.

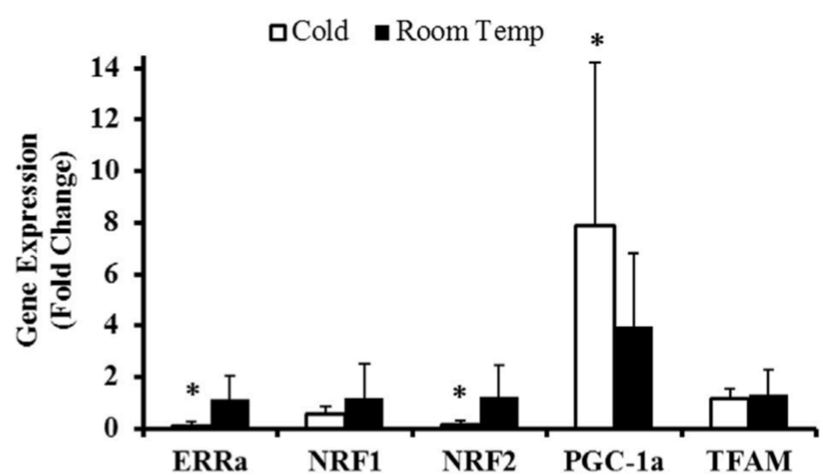

Fig. 3. Gene expression relative to beta actin. *$p < 0.05$ from room temp. Data are mean ± SD.

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J SPORTS MED PHYS FITNESS 2012;52:158-64

Effect of local cold application on glycogen recovery

T. J. TUCKER [1], D. R. SLIVKA [2], J. S. CUDDY [1], W. S. HAILES [1], B. C. RUBY [1]

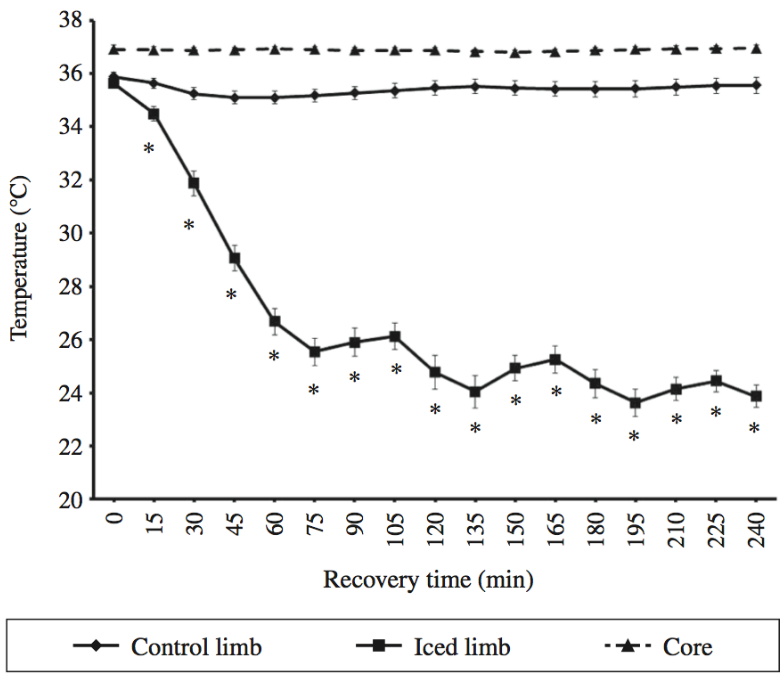

Figure 1.—Intramuscular and core temperature during recovery. *P<0.05 from control limb.

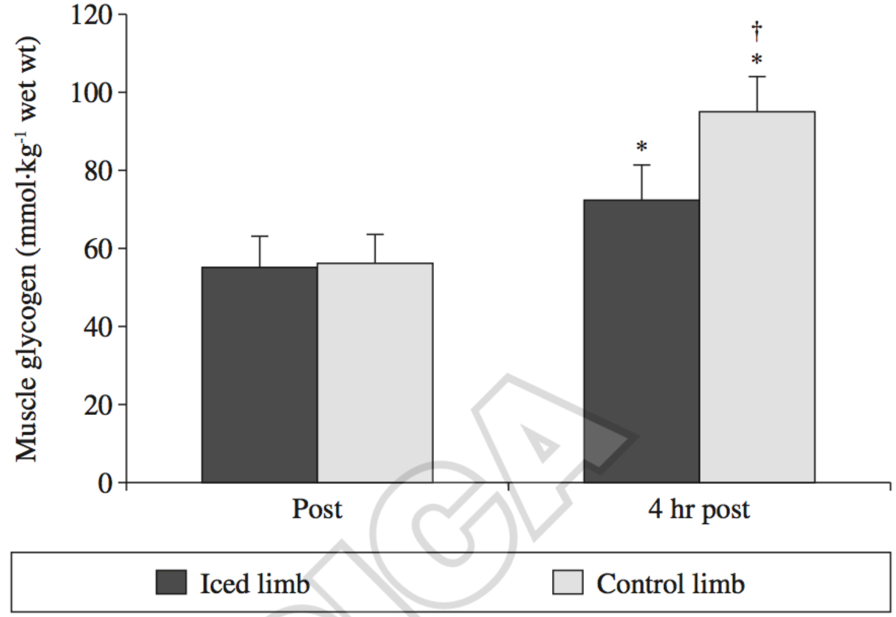

Figure 2.—Muscle glycogen during recovery (time x trial interaction). *P<0.05 from post ride muscle glycogen. †P<0.05 from ice (at 4 hr post).

Postexercise Cold-Water Immersion Does Not Attenuate Muscle Glycogen Resynthesis

WARREN GREGSON[1], ROBERT ALLAN[1], SUSAN HOLDEN[1], PADRAIC PHIBBS[1], DOMINIC DORAN[1], IAIN CAMPBELL[1,2], SARAH WALDRON[1,2], CHANG HWA JOO[1], and JAMES P. MORTON[1]

[1]Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UNITED KINGDOM; and [2]Department of Anaesthesia, Wythenshawe Hospital, Manchester, UNITED KINGDOM

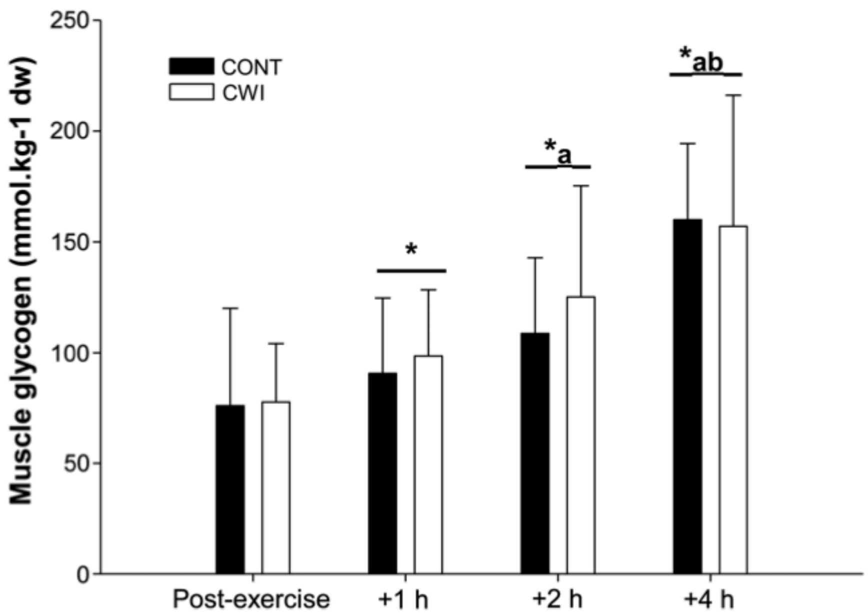

FIGURE 3—Skeletal muscle glycogen content immediately after exercise and during 4 h of recovery in CONT and CWI ($n = 9$, mean ± SD). A main effect for time was observed ($P < 0.01$). *Significant difference from postexercise ($P < 0.05$). (a) Significant difference versus 1 h ($P < 0.05$). (b) Significant difference versus 2 h ($P < 0.05$).

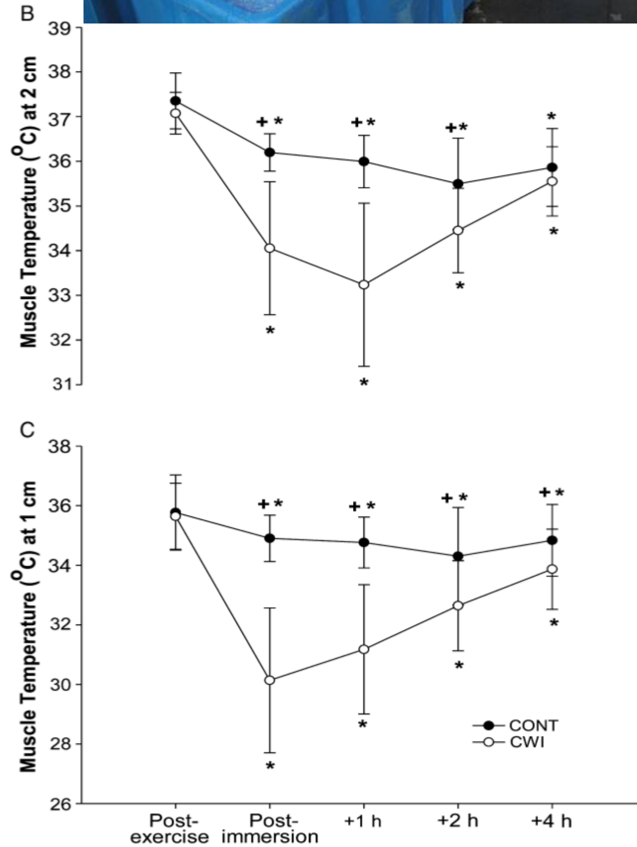

FIGURE 2—Muscle temperature immediately after exercise and during 4 h of recovery in CONT and CWI at temperature probe depths of 3 cm (A), 2 cm (B), and 1 cm (C) ($n = 9$, mean ± SD). Main effects for condition ($P < 0.01$) and time ($P < 0.01$) were found along with a significant interaction between condition, time, and probe depth ($P < 0.01$). *Significant difference from postexercise ($P < 0.05$). $^{+}$Significant difference between conditions ($P < 0.05$).

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Local heat application enhances glycogenesis

Dustin Slivka, Tyler Tucker, John Cuddy, Walter Hailes, and Brent Ruby

Appl Physiol Nutri Metab. 37(2): 247-51, 2012

Fig. 1. Core temperature, heated limb intramuscular temperature, and control limb intramuscular temperature throughout recovery. *, $p < 0.05$ from heated limb. Data are means ± SD.

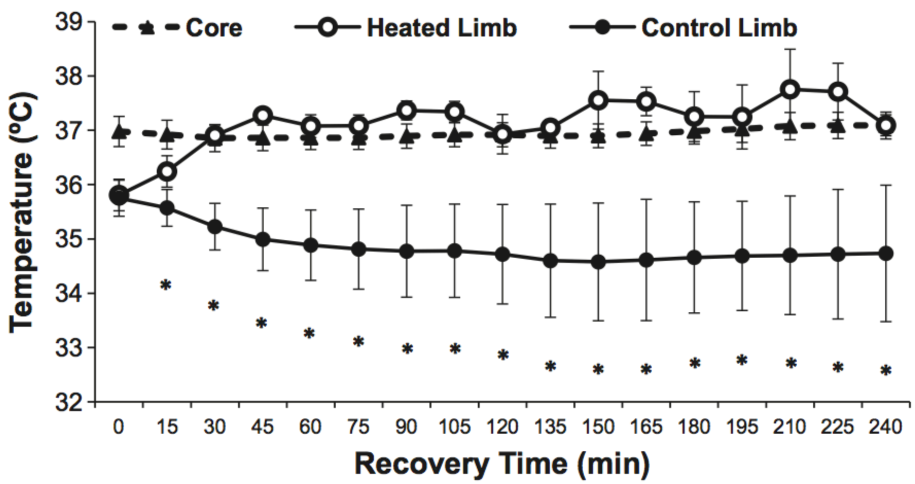
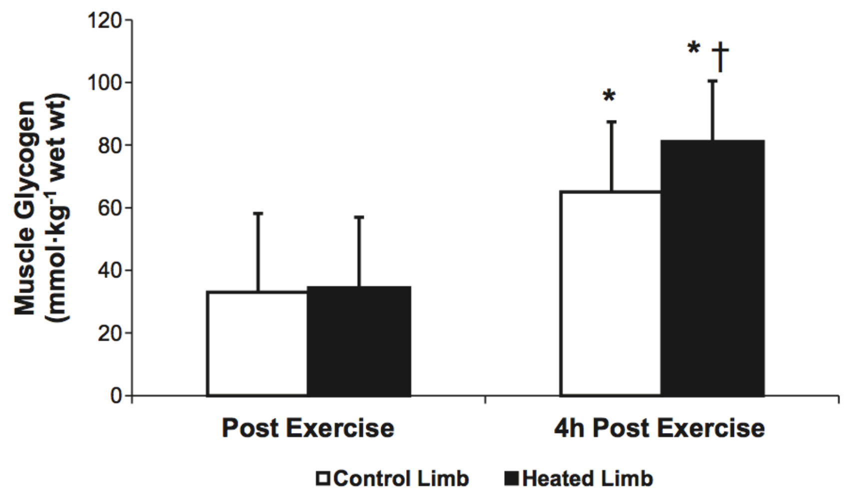


Fig. 2. Muscle glycogen immediately postexercise and at 4 h post-exercise in the heated limb and the control limb. *, $p < 0.05$ from postexercise; †, $p < 0.05$ from the control limb. Data are means ± SD.



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Glycogen Synthesis after Road Cycling in the Fed State

Reinert A et al. Glycogen Synthesis after Road … Int J Sports Med 2009; 30: 545–549

Authors **A. Reinert, D. Slivka, J. Cuddy, B. Ruby**

Affiliations Montana Center for Work Physiology and Exercise Metabolism, The University of Montana, Missoula, United States

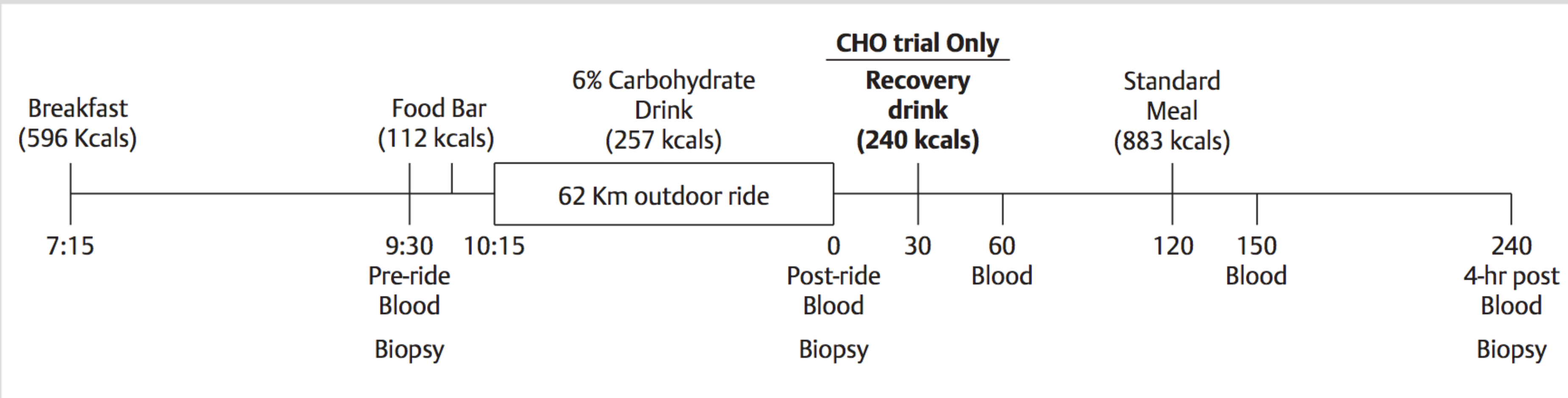

Fig. 1 Experimental events and schedule.

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Reinert A et al. Glycogen Synthesis after Road… Int J Sports Med 2009; 30: 545–549

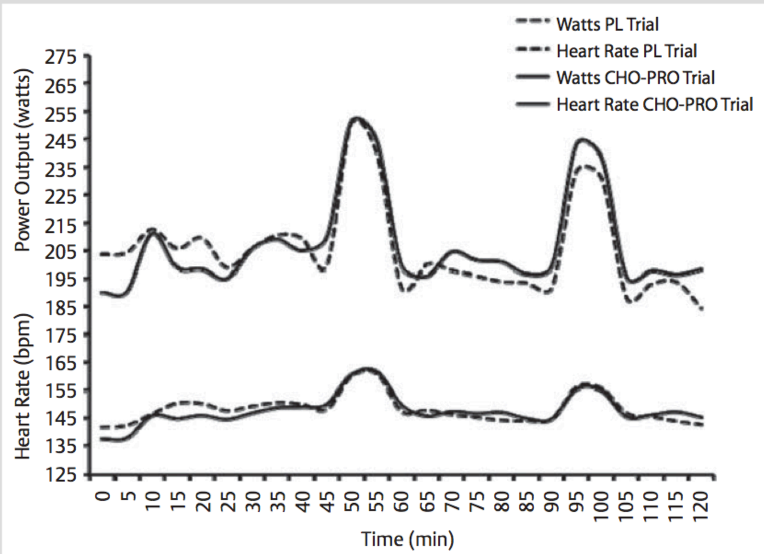

Fig. 2 Mean heart

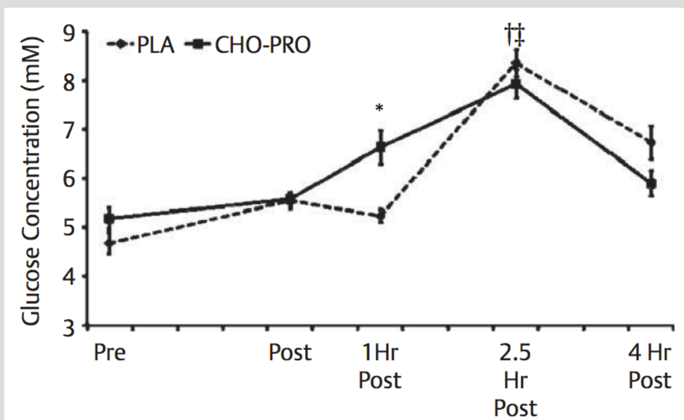

Fig. 3 Serum glucose concentrations (mM) during the exercise and recovery periods. *,p<0.05, CHO-PRO vs. PL. †,p<0.05 vs. post (PLA); ‡,p<0.05 vs. post (CHO-PRO).

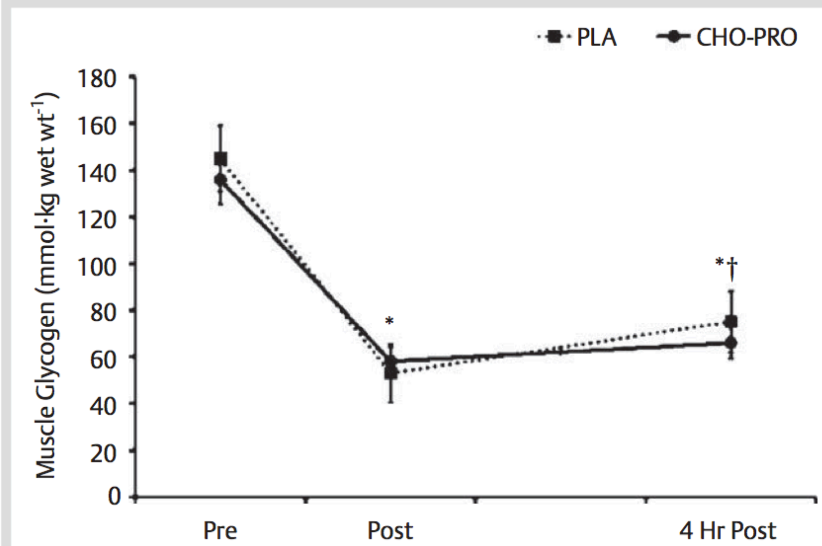

Fig. 5 Muscle glycogen concentrations (mmol · kg^{-1} wet wt) for pre, post and 4 h post-exercise. *,p<0.05 vs. pre (main effect of time); †,p<0.05 vs. post (main effect of time).

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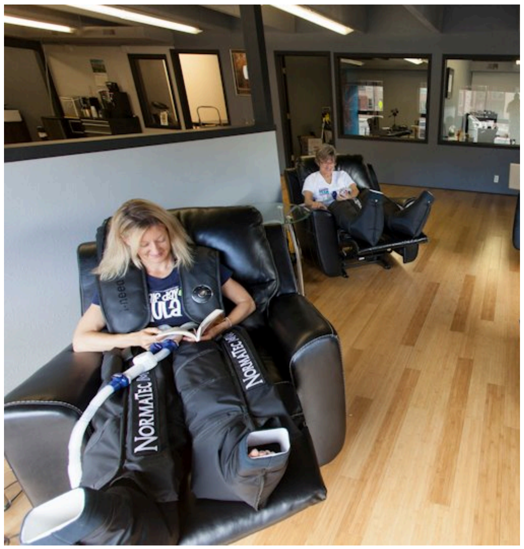
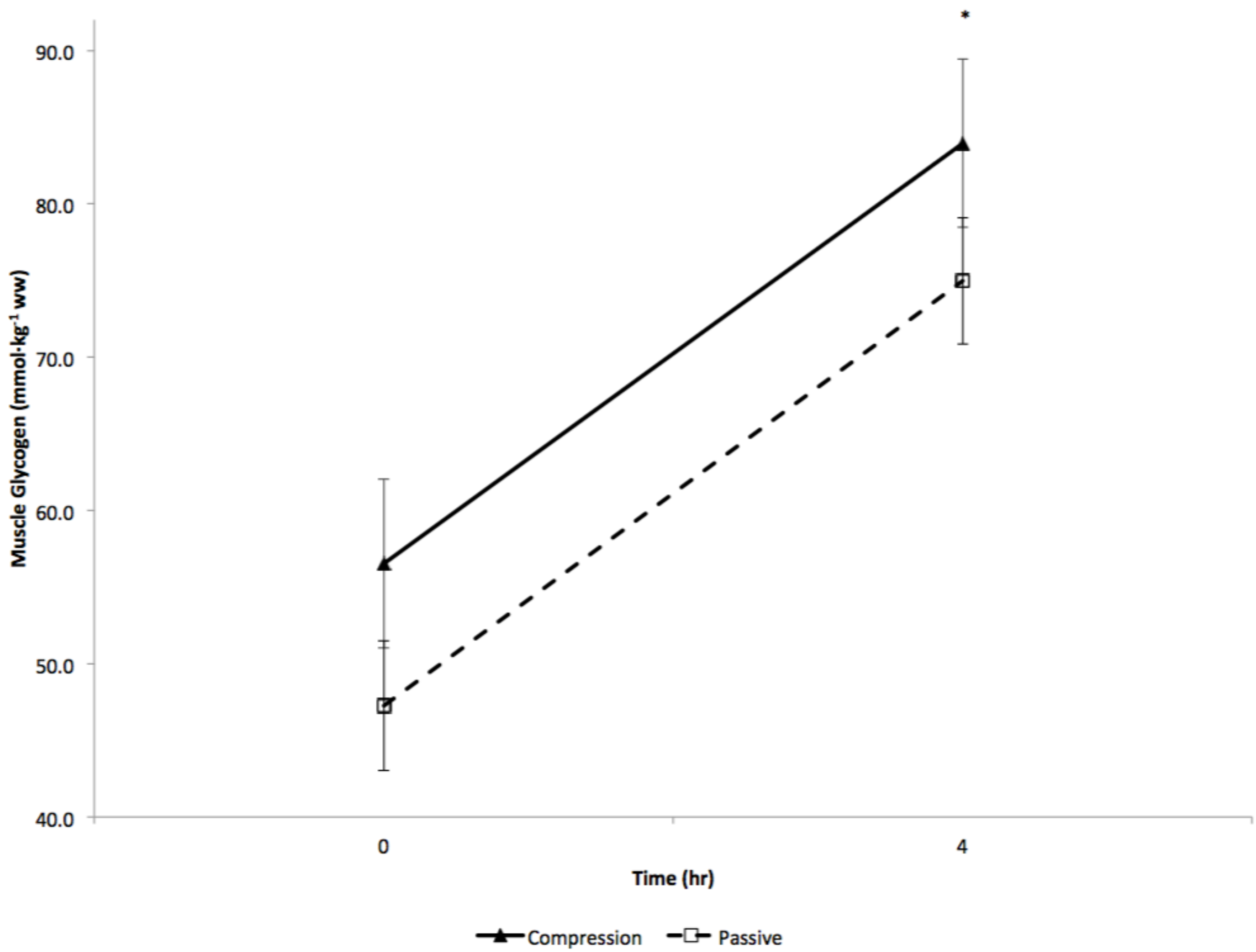
EFFECT OF LOWER LIMB COMPRESSION (NORMATEC) ON GLYCOGEN RESYNTHESIS

Nathan A. Keck[2], John S. Cuddy[1], Walter S. Hailes[1], Charles L. Dumke[2], and Brent C. Ruby[1]

In Press – Journal of Strength and Conditioning Research, 2014





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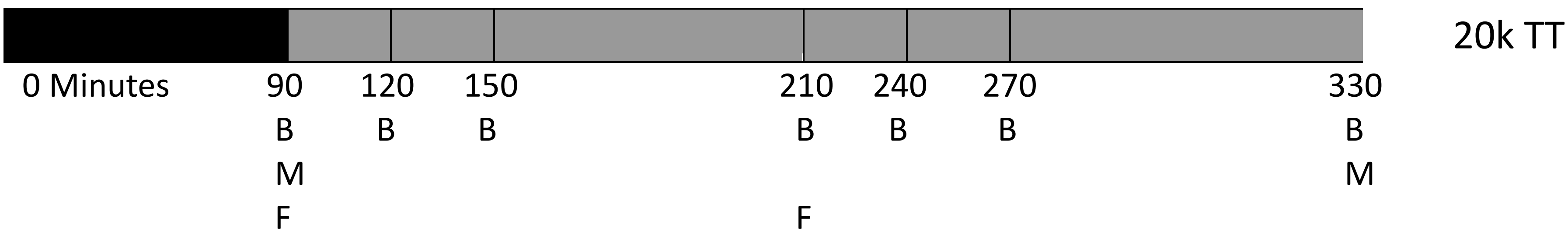
FAST FOOD RESULTS IN SIMILAR POST-EXERCISE GLYCOGEN RECOVERY AND EXERCISE PERFORMANCE COMPARED TO SPORT SUPPLEMENTS.

Article in preparation for submission…International Journal of Sports and Exercise Metabolism

Timeline



= Depletion Ride   = Recovery   = 20k Time Trial

B= Blood Draw   M= Muscle Biopsy   F= Feeding

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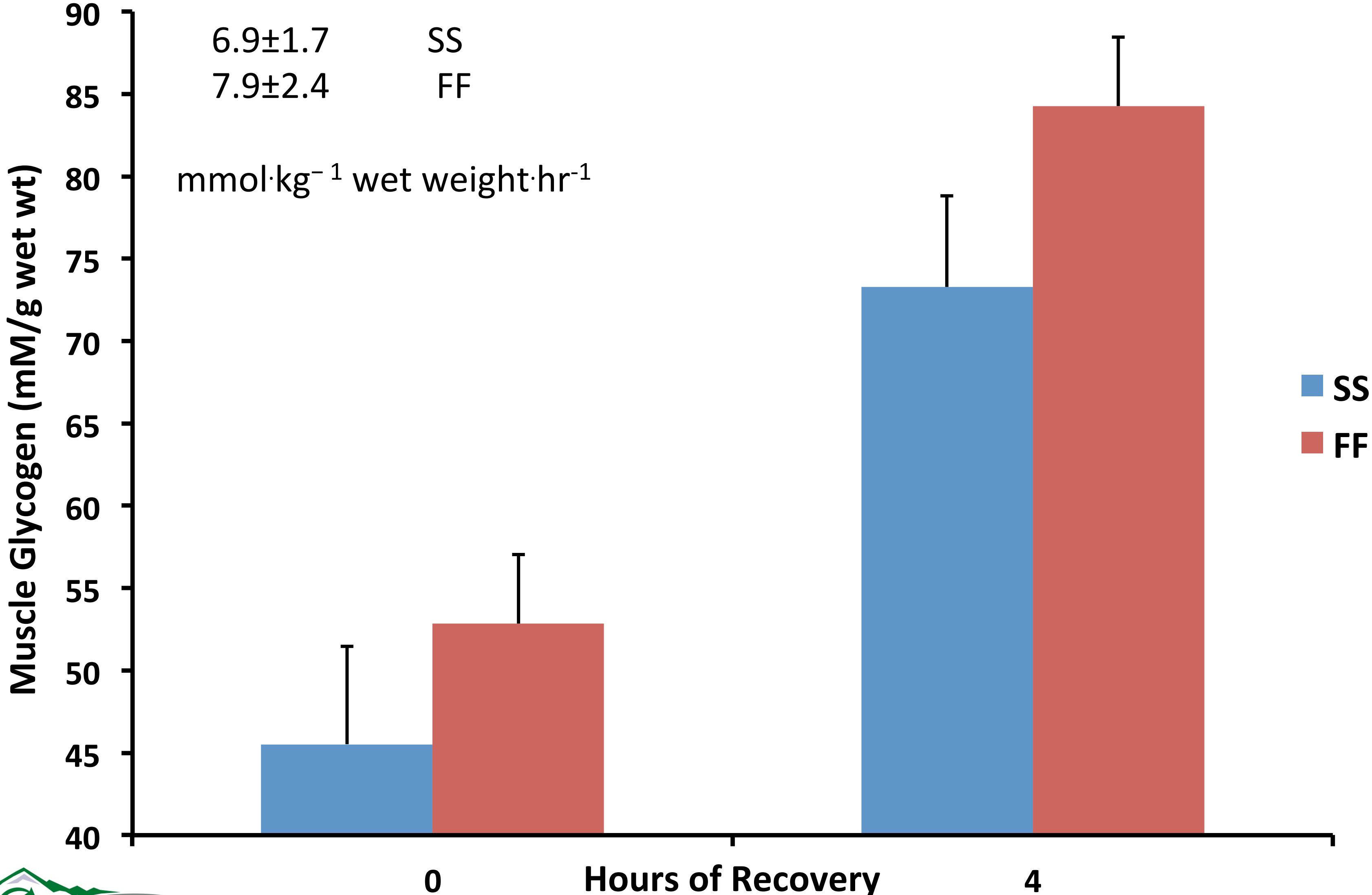
6.9±1.7 SS
7.9±2.4 FF
mmol·kg⁻¹ wet weight·hr⁻¹
Muscle Glycogen (mM/g wet wt)
90
85
80
75
70
65
60
55
50
45
40
0
Hours of Recovery
4
SS
FF

Fueling your choices

DESPUÉS DE *mi*

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Conclusions/Take Home!

- Food = recovery!
- Environmental conditions can influence recovery of glycogen
- No magic bullet!
- Diversity of options – some cheap, some $$, some trendy…

And some…maybe only available – In Boulder

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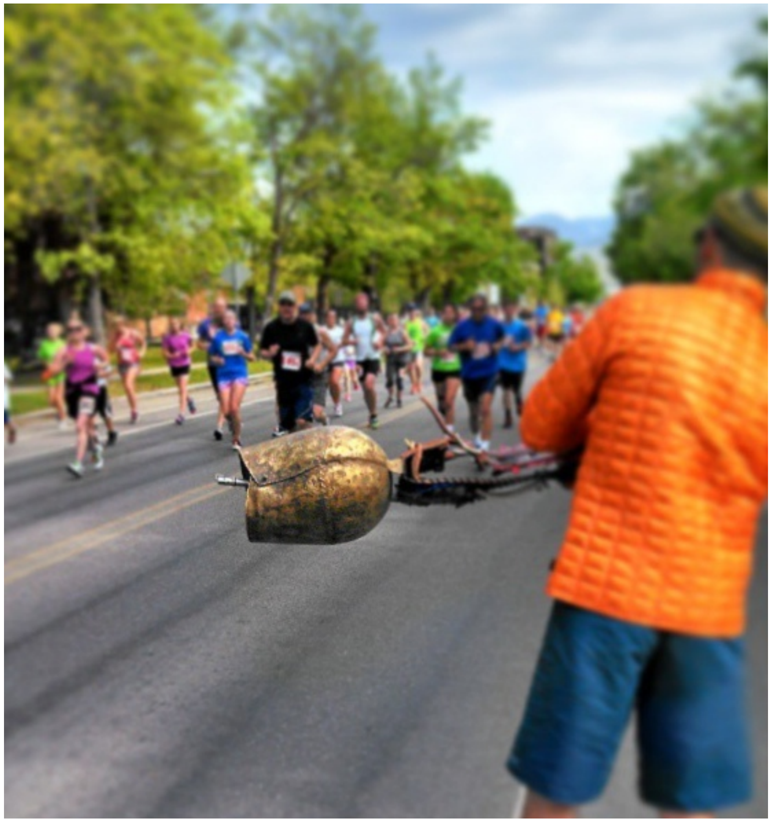
Questions:



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