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Nutritional Strategies to Improve Post-Exercise Recovery and Subsequent Exercise Performance: A Narrative Review

Short title: Nutritional strategies to prepare for the next training/competition session

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Supplementary Material 1. Summary of studies exploring the effects of carbohydrate on muscle glycogen resynthesis after exhaustive exercise.

Study	Subject	VO_2max (ml.kg^{-1}.min^{-1})	Exercise Test	Treatment	Time of sampling	Result
Blom et al. [19]	27 physically active males	NR	Series of 20 min cycling at 75% VO_2max on bicycle ergometer and 10 min rest until exhaustion	**LG**: 0.35 g.kg^{-1} glucose in a solution with 30% concentration **MG**: 0.70 g.kg^{-1} glucose in a solution with 30% concentration **HG**: 1.40 g.kg^{-1} glucose in a solution with 30% concentration **MF**: 0.70 g.kg^{-1} fructose in a solution with 30% concentration **MS**: 0.70 g.kg^{-1} sucrose in a solution with 30% concentration	6 h after exercise	**Muscle glycogen resynthesis**: HG = MG = MS > LG = MF **BGC after 1 h**: HG > MG = LG = MF = MS **Insulin concentration after 1 h**: HG > MG = LG = MF = MS
Burke et al. [27]	5 well-trained cyclists	NR	2 h cycling at ~75% of VO_2max followed by 4 × 30 sec all-out sprints with 2 min recovery	**HGI:** 4 meals of 2.5 g.kg^{-1} CHO with high glycemic index (GI=118) during 24 h **LGI:** 4 meals of 2.5 g.kg^{-1} CHO with high glycemic index (GI=50) during 24 h	24 h after exercise	**Muscle glycogen resynthesis:** HGI > LGI
Van Den Bergh et al. [20]	7 healthy active males	NR	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**FRU:** 80 g.h^{-1} fructose with 8% concentration **GLU:** 80 g.h^{-1} glucose with 8% concentration	8 h after exercise	**Muscle glycogen resynthesis:** GLU < FRU
Burke et al. [194]	8 well-trained male triathletes	NR	2 h cycling at ~75% of VO_2max followed by 4 × 30 sec all-out sprints with 2 min recovery	**Gorging diet:** 4 large meals consist 2.5 g.kg^{-1} of CHO during 24 h **Nibbling diet:** total of 10 g.kg^{-1} of CHO during 24 h in 16 meals	24 h after exercise	**Muscle glycogen resynthesis:** Gorging diet = Nibbling diet

Ivy et al. [13]	12 healthy active males	NR	70 min cycling at ~68% of VO_2max followed by 6 × 2 min intervals at 88% VO_2max with 2 min recovery	**P-EX:** 2 g.kg^{-1} of glucose immediately after exercise **2P-EX**: 2 g.kg^{-1} of glucose 2 h after exercise	2 and 4 h after exercise	**Muscle glycogen resynthesis:** P-EX > 2P-EX
Wallis et al. [21]	6 healthy endurance-trained males	67.0 (±3.0)	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**GLU+FRU:** 0.8 g.kg^{-1}.h^{-1} of glucose and 0.4 g.kg^{-1}.h^{-1} of fructose solution with 18% concentration **GLU:** 1.2 g.kg^{-1}.h^{-1} of glucose solution with 18% concentration	1 and 4 h after exercise	**Muscle glycogen resynthesis:** GLU > GLU+FRU **Muscle glycogen synthesis rates:** GLU = GLU+FRU **BGC:** GLU = GLU+FRU **Insulin:** GLU = GLU+FRU **[BLa$^-$]:** GLU < GLU+FRU
Decombaz et al. [28]	10 well-trained male cyclists	NR	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**MAL+FRU:** 69 g.h^{-1} maltodextrin and fructose with 2:1 ratio and 15% concentration **MAL+GAL**: 69 g.h^{-1} maltodextrin and galactose with 2:1 ratio and 15% concentration **MAL+GLU**: 69 g.h^{-1} maltodextrin and glucose with 2:1 ratio and 15% concentration	6.5 h after exercise	**Liver glycogen resynthesis:** MAL+FRU = MAL+GAL > MAL+GLU
Trommelen et al. [22]	14 well-trained male cyclists	NR	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**GLU+FRU**: 0.6 g.kg^{-1}.h^{-1} glucose + 0.6 g.kg^{-1}.h^{-1} maltodextrin + 0.3 g.kg^{-1}.h^{-1} fructose **GLU+SUC**: 0.6 g.kg^{-1}.h^{-1} glucose + 0.6 g.kg^{-1}.h^{-1} maltodextrin + 0.3 g.kg^{-1}.h^{-1} sucrose **GLU**: 0.9 g.kg^{-1}.h^{-1} glucose + 0.6 g.kg^{-1}.h^{-1} maltodextrin	5 h after exercise	**BGC**: GLU+FRU = GLU+SUC = GLU **Insulin**: GLU+FRU = GLU+SUC > GLU **[BLa$^-$]**: GLU+FRU = GLU+SUC > GLU **Muscle glycogen resynthesis**: GLU+FRU = GLU+SUC = GLU **GI score**: GLU+FRU = GLU+SUC < GLU
Fuchs et al. [25]	15 well-trained male cyclists	61.5 (±5.2)	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**SUC**: 1.5 g.kg^{-1}.h^{-1} sucrose solution with ~20% concentration **GLU**: 1.5 g.kg^{-1}.h^{-1} glucose (0.9 g.kg^{-1}.h^{-1} dextrose monohydrate and 0.6 g.kg^{-1}.h^{-1} maltodextrin) solution with ~20% concentration	5 h	**Liver glycogen resynthesis**: SUC = GLU **Muscle glycogen resynthesis**: SUC = GLU **BGC** **at 65, 75 and 90 min**: SUC < GLU **Insulin** **at 45, 75 and 90 min**: SUC < GLU **NEFA**: SUC = GLU

Podlogar et al. [195]	9 healthy endurance-trained participants (male = 7, female = 2)	51.1 (±8.7)	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	**GLU+GAL**: 0.8 g.kg^{-1}.h^{-1} glucose and 0.4 g.kg^{-1}.h^{-1} galactose **GLU**: 1.2 g.kg^{-1}.h^{-1} glucose **GAL**: 1.2 g.kg^{-1}.h^{-1} galactose	4 h	**Muscle glycogen resynthesis**: GLU > GLU+GAL = GAL **BGC**: GLU+GAL = GAL > GLU **Insulin**: GLU+GAL = GLU > GAL = ↔ **[BLa^{-}]**: GLU+GAL = GLU > GAL **Phosphorylation of**: • **Akt ^{pThr308}**: GLU+GAL = GLU > GAL • **Akt^{pSer473}**: GLU+GAL = GLU = GAL • **GS^{pSer641}**: GLU+GAL = GLU = GAL • **GSK^{PSer21}**: GLU+GAL = GLU = GAL

Abbreviations: Akt^{pThr308}: Phosphorylated Akt at threonine 308; Akt^{pSer473}: Phosphorylated Akt at serine 473; BGC: Blood glucose concentration; [BLa-]: Blood lactate concentration; CHO: Carbohydrate; FRU: Fructose; GLA: Galactose; GLU: Glucose; GSK^{PSer21}: Phosphorylated Glycogen synthase kinase-3 at serine 21; HGI: High glycemic index; LG: Large glucose solution; LGI: Low glycemic index; MAL: Maltodextrin; MF: Medium fructose solution; MG: Medium glucose solution; MS: Medium sucrose solution; NEFA: Non-esterified fatty acid concentrations; NR: Not reported; P-EX: Post exercise; SUC: Sucrose; 2P-EX: Two hours post exercise.

Supplementary Material 2. Summary of studies exploring the effects of carbohydrate on subsequent exercise performance after exhaustive exercise.

Study	Subject	VO_2max (ml.min^{-1}.kg^{-1})	Pre-conditioning	Recovery Period	Treatment	Subsequent Exercise	Main findings
Casey et al. [23]	10 healthy males	NR	TTE test on bicycle ergometer at 70% of VO_2max	4 h	**GLU:** 1 g.kg^{-1} glucose solution with 18.5% concentration **SUC:** 1 g.kg^{-1} sucrose solution with 18.5% concentration **PLA:** non-caloric flavored water	Cycling TTE test at 70% of VO_2max	**TTE:** GLU = SUC = PLA **Liver glycogen resynthesis:** GLU = SUC > PLA **Muscle glycogen resynthesis:** GLU = SUC = PLA **CHO oxidation**: GLU = SUC > PLA **BGC**: GLU = SUC > PLA **Epinephrine**: GLU = SUC = PLA **Norepinephrine**: GLU = SUC = PLA [BLa-]: GLU = SUC = PLA **Ammonia concentration**: GLU = SUC = PLA **RER**: GLU = SUC > PLA
Erith et al. [40]	7 male semi-professional soccer players	58.0 (±1.0)	LIST	22 h	**HGI-diet:** 8 g.kg^{-1}.d^{-1} CHO with GI = 70 **LGI-diet:** 8 g.kg^{-1}.d^{-1} CHO with GI = 35	LIST	**TTE_{LIST}**: HGI-diet > LGI-diet **Sprint performance**: HGI-diet = LGI-diet **Distance covered**: HGI-diet = LGI-diet
Wong et al. [39]	7 male trained endurance runners	62.1 (±2.2)	TTE test on level treadmill at workload corresponding to 70% VO_2max	4 h	**HGI**: 1.5 g.kg^{-1} of CHO with GI = 77 **LGI**: 1.5 g.kg^{-1} of CHO with GI = 37	TTE test on level treadmill at workload corresponding to 70% VO_2max	**TTE**: HGI > LGI **[BLa^-]**: HGI = LGI **HR**: HGI = LGI **RPE**: HGI = LGI **RER**: HGI = LGI **CHO oxidation**: HGI = LGI **Fat oxidation**: HGI = LGI
Brown et al. [196]	7 male amateur cyclists	NR	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until	3 h	**LGI**: a low glycemic index meal with (672kcal ,140g CHO ,13 g fat ,27 g PRO, GI=40)	5-km cycling TT on cycle ergometer	**TT**: HGI = LGI **Insulin**: HGI > LGI **RER**: HGI > LGI **CHO oxidation**: HGI > LGI **Fat oxidation**: HGI < LGI

			volitional exhaustion		**HGI**: a high glycemic index meal with (774 kcal, 140 g CHO,12 g fat, 31 g PRO, GI=72)		
Alghannam et al. [197]	10 recreationally endurance trained individuals (male = 9, female = 1)	61.00 (±1.0)	TTE test on treadmill at workload corresponding to 70% of VO_2max	4 h	**H-CHO:** 1.2 $g.kg^{-1}.h^{-1}$ CHO solution with 12% concentration **L-CHO:** 0.3 $g.kg^{-1}.h^{-1}$ CHO solution with 3% concentration	TTE test on treadmill at workload corresponding to 70% of VO_2max	**TTE:** H-CHO > L-CHO **Muscle glycogen resynthesis:** H-CHO > L-CHO **Insulin:** H-CHO > L-CHO **[BLa^-]:** H-CHO = L-CHO **CHO oxidation:** H-CHO > L-CHO **Fat oxidation:** H-CHO < L-CHO
Maunder et al. [33]	8 trained male endurance runners and triathletes	NR	TTE test on treadmill at workload corresponding to 70% of VO_2max	4 h	**GLU+MAL:** 300 ml solution with 18 g glucose and 27 g maltodextrin **FRU+MAL:** 300-ml solution with 18 g fructose and 27 g maltodextrin	TTE test on treadmill at workload corresponding to 70% of VO_2max	**TTE:** FRU+MAL < GLU-MAL **CHO oxidation:** FRU+MAL < GLU-MAL **BGC:** FRU+MAL = GLU-MAL **[BLa^-]:** FRU+MAL < GLU-MAL
Podlogar et al. [198]	11 endurance-trained participants (Male = 8, Female = 3)	56.9 (±4.8)	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	4 h	**GLU+MAL:** 1.2 $g.kg^{-1}.h^{-1}$ of 1:1.5 dextrose: maltodextrin ratio **FRU+MAL:** 1.2 $g.kg^{-1}.h^{-1}$ of 1:1.5 fructose: maltodextrin ratio	60 min steady state cycling at 50% Wmax, followed by TT to total amount work of 2,400 J	**TT:** GLU+MD = FRU+MD **CHO oxidation:** GLU+MD < FRU+MD
McCarthy et al. [199]	10 recreationally-active males	47.0 (±5.4)	5 × 4-min intervals at ~80% VO_2peak separated by 2-min at ~40% VO_2peak and	2 h	**CHO:** 1.2 $g.kg^{-1}.h^{-1}$ of CHO (sucrose, dextrose, maltodextrin, modified corn starch)	5 × 4-min intervals at ~80% VO_2peak separated by 2-min at ~40% VO_2peak	**TTE:** CHO > PLA

			ended with an TTE test at ~90% VO_2peak		**PLA:** low-calorie drink	and ended with an TTE test at ~90% VO_2peak	
Gray et al. [34]	8 trained male cyclists (male = 5, female = 3)	Short recovery time experiment: 66.9 (±6.1) Overnight recovery experiment: 62.9 (±9.8)	A decreasing intermittent glycogen-depleting exercise protocol on cycle ergometer until volitional exhaustion	Short recovery time experiment: 4 h Overnight recovery experiment: 15 h	**GLU+FRU:** 0.6 $g.kg^{-1}.h^{-1}$ glucose + 0.6 $g.kg^{-1}.h^{-1}$ fructose solution with 20% concentration **GLU:** 1.5 $g.kg^{-1}.h^{-1}$ glucose solution with 20% concentration	Short recovery time experiment: TTE test at 70% Wmax Overnight recovery experiment: TTE test at 65% Wmax	**Short recovery time experiment:** • **TTE:** GLU+FRU > GLU • **CHO oxidation during rest:** GLU+FRU > GLU • **CHO oxidation during TTE:** GLU+FRU = GLU • **GI score:** GLU+FRU = GLU • **$[BLa^-]$:** GLU+FRU = GLU • **BGC:** GLU+FRU = GLU **Overnight recovery experiment:** • **TTE:** GLU+FRU > GLU • **$[BLa^-]$:** GLU+FRU = GLU • **BGC:** GLU+FRU = GLU • **CHO oxidation:** GLU+FRU = GLU Fat oxidation: GLU+FRU = GLU
Hengist et al. [36]	12 male Rugby Union players	NR	8 SSG with high intensity	3 h	**GLU+FRU:** 0.4 $g.kg^{-1}.h^{-1}$ fructose, 0.4 $g.kg^{-1}.h^{-1}$ glucose solution with 20% concentration + 0.3 $g.kg^{-1}.h^{-1}$ PRO	8 SSG with high intensity	**Mean speed during sessions:** GLU+FRU = GLU **GI score:** GLU+FRU = GLU

					GLU: 0.8 g.kg^{-1}.h^{-1} glucose solution with 20% concentration + 0.3 g.kg^{-1}.h^{-1} PRO		
Naderi et al. [37]	11 junior male professional taekwondo athletes	NR	5 times simulated taekwondo effort test (STET) with 45-min rest, STET included 3 rounds that lasting 200 sec with 1-min rest between rounds.		**Immediately after each STET:** **C45:** 45 g of 2:1 glucose: fructose solution (60 g.h^{-1}) with 7.5% Concentration **C22.5:** 22.5 g of 2:1 glucose: fructose solution (30 g.h^{-1}) with 3.5% Concentration **PLA:** beverage contained 2.2 g No caloric sweetener powder		**Total kicks:** C45 = C22.5 = PLA **Total successful kicks:** C45 = C22.5 = PLA **Successful kick %:** C45 = C22.5 = PLA **RPE:** C45 = C22.5 = PLA **BGC:** C45 = C22.5 > PLA
Podlogar et al. [200]	8 trained male cyclists	62.2 (±5.4)	2 × 2-min at RCP, followed by 4 × 8-min at 104% RCP with 4 min of active recovery (i.e., easy cycling). After the successful completion participants cycled for 60 min at workload corresponding to 90% of VT1.	> 12 h	**2 h before second exercise:** **GLU+RICE:** 2 g.kg^{-1} glucose and rice, in 1:2 ratio **FRU+RICE:** 2 g.kg^{-1} fructose and rice, in 1:2 ratio	TTE test at VT1	**TTE:** FRU+RICE > GLU+RICE **BGC:** FRU+RICE = GLU+RICE **[BLa$^-$]:** FRU+RICE = GLU+RICE **CHO oxidation:** FRU+RICE > GLU+RICE

Abbreviations: BGC: Blood glucose concentration; CHO: Carbohydrate; GI: Glycemic index; GI score: Gastrointestinal discomfort scores; LIST: Loughborough Intermittent Shuttle Test; NR: Not reported; PRO: Protein; RCP: Respiratory compensation point; RPE: Rate of perceived exertion; SSG: Small sided games; TT: Time trial; STET: Simulated Taekwondo effort test; C45: Solution containing 45 g of carbohydrate; C22.5: Solution containing 22.5 g of carbohydrate; PLA: Placebo; VO_2peak: Peak oxygen uptake; H-CHO: High carbohydrate solution; L-CHO: Low carbohydrate solution; MAL: Maltodextrin; VO_2max: Maximal oxygen uptake; HR: Heart rate; VT1: First ventilatory threshold; Wmax: Peak power achieved during incremental cycling test; [BLa-]: Blood lactate concentration during or after exercise; TTE: Time to exhaustion; TTE_{LIST}: Time to exhaustion in Loughborough Intermittent Shuttle Test; FRU: Fructose; GLA: Galactose; GLU: Glucose; HGI: High glycemic index; LGI: Low glycemic index; NR: Not reported; RER: Respiratory exchange ratio; SUC: Sucrose.

Supplementary Material 3. Summary of studies exploring the effects of carbohydrate and protein co-ingestion on subsequent exercise performance after exhaustive exercise.

Study	Subject	VO_2max ($ml.kg^{-1}.min^{-1}$)	Pre-conditioning	Recovery Period	Treatment	Subsequent Exercise	Result
Rustad et al. [56]	8 endurance-trained males	NR	**Warm up:** 3 × 4 min cycling at 50, 55 and 60% of VO_2max. **Interval Main exercise:** 20-min intervals at workload corresponding to ~72% of VO_2max with 5-min rest between intervals. After voluntary exhaustion, subjects were given 5-min of rest before completing a maximal number of 1 min intervals at 90% of VO_2max with 1 min rest between intervals.	18 h	**CHO:** 0.6 $g.kg^{-1}.h^{-1}$ maltodextrin + 0.6 $g.kg^{-1}.h^{-1}$ glucose solution with 17% concentration **CHO+PRO:** 0.4 $g.kg^{-1}.h^{-1}$ maltodextrin + 0.4 $g.kg^{-1}.h^{-1}$ glucose solution with 7% concentration + 0.4 $g.kg^{-1}.h^{-1}$ of PRO whey **PLA:** non-caloric flavored water	**Warm up:** 3 × 4 min at 50, 55 and 60% of VO_2max. **Test:** TTE test at 72% of VO_2max	**TTE:** CHO+PRO > CHO > PLA **RPE:** CHO+PRO = CHO = PLA **RER:** CHO+PRO = CHO > PLA **CHO oxidation:** CHO+PRO > CHO > PLA **BGC_{15min}:** CHO+PRO = CHO > PLA **[BLa^-]:** CHO+PRO = CHO = PLA **Insulin:** CHO+PRO = CHO = PLA **FFA:** CHO+PRO = PLA < CHO **Muscle damage biomarkers:** • **CK** ↔ • **LDH** ↔ • **Myoglobin** ↔ **Nitrogen balance:** CHO+PRO > CHO > PLA **Valine concentration:** CHO+PRO > CHO
Dahl et al. [57]	9 endurance trained males	58.1 (±1.7)	TTE test on bicycle ergometer at 70% of VO_2peak	1.5 h	**CHO:** 0.6 $g.kg^{-1}.h^{-1}$ maltodextrin + 0.6 $g.kg^{-1}.h^{-1}$ glucose solution with 17% concentration **CHO+PRO:** 0.4 $g.kg^{-1}.h^{-1}$ maltodextrin + 0.4 $g.kg^{-1}.h^{-1}$ glucose solution with ~7% concentration + 0.4 $g.kg^{-1}.h^{-1}$ of PRO whey	TTE test on bicycle ergometer at 70% of VO_2peak	**TTE:** CHO+PRO > CHO **Nitrogen balance:** CHO+PRO > CHO = 0 **Phosphorylation of:** • **Akt Ser^{473}** ↔ • **p70s6k Thr^{389}** ↔ • **TSC2 Thr^{1462}** ↔ • **TBC1D4/AS160 Ser^{588}** ↔

Goldstein et al. [58]	25 recreationally active males	43.8 (± 6.9)	5 × 4-min at 70-80% of PPO with 2 min of active recovery at 50W, followed by TTE test at 90% PPO	2 h	**CHO:** 1.2 $g.kg^{-1}.h^{-1}$ CHO solution **CHO+PRO:** 0.8 $g.kg^{-1}.h^{-1}$ CHO solution + 0.4 $g.kg^{-1}.h^{-1}$ of PRO whey **PLA:** non-caloric flavored water	5 × 4-min at 70-80% of PPO with 2 min of active recovery at 50W, followed by TTE test at 90% PPO	**TTE:** CHO+PRO > CHO > PLA **RER:** CHO > CHO+PR = PLA
Goldstein et al. [201]	22 male masters class endurance athletes	48.6 (±6.7)	5 × 4-min at 70-80% of PPO with 2 min of active recovery at 50W, followed by TTE test at 90% PPO	2 h	**CHO:** 1.2 $g.kg^{-1}.h^{-1}$ CHO solution **CHO+PRO:** 0.8 $g.kg^{-1}.h^{-1}$ CHO solution + 0.4 $g.kg^{-1}.h^{-1}$ of PRO whey **PLA:** non-caloric flavored water	5 × 4-min at 70-80% of PPO with 2 min of active recovery at 50W, followed by TTE test at 90% PPO	**TTE:** CHO+PRO = CHO > PLA **HRRi:** CHO+PRO = CHO > PLA

Abbreviations: TTE: Time to exhaustion; RPE: Rate of perceived exertion; RER: Respiratory exchange ratio; FFA: Free fatty acids; BGC_{15min}: Blood glucose concentration at minute 15; CHO: Carbohydrate; PRO: Protein; Akt^{Ser473}: Akt phosphorylated at serine 473; $p70s6k^{Thr389}$: Phosphorylated p70S6 kinase at threonine 389; $TSC2^{Thr1462}$: Tuberous sclerosis complex 2 phosphorylated at threonine 1462; TBC1D4/$AS160^{Ser588}$: TBC1 domain family member 4 (also known as AS160) phosphorylated at serine 588; LDH: Lactate dehydrogenase; CK: Creatine kinase; PPO: Peak power output; BGC: Blood glucose concentration; HRRi: Heart rate recovery index, accounts for heart rate recovery relative to work; LDH: Lactate dehydrogenase; NR: Not reported; PRO: Protein; RPE: Rate of perceived exertion; [BLa-]: Blood lactate concentration after exercise; ↔: No difference.

Supplementary Material 4. Summary of studies exploring the effects of fluid and electrolytes on post post-exercise rehydration.

Study	Subject	VO_2max (ml.kg^{-1}.min^{-1})	Exercise Test	Treatment	Time of sampling	Main Findings
Maughan et al. [87]	8 healthy active volunteers (male = 5, female = 3)	46.5 (±3.1)	Series of 10 min cycling at ~60% VO_2max in 34°C, 55% RH; 5-min rests between sessions until ~2% body mass loss through dehydration.	**ORS**: Consumed equal to 150% of sweat loss volume via a sports drink containing 6.4 g.L^{-1} CHO, 21 mmol.L^{-1} sodium, and 3.4 mmol.L^{-1} potassium. **MEAL+ORS**: Consumed equal to 150% of sweat loss volume via a sports drink containing 6.4 g.L^{-1} CHO, 21 mmol.L^{-1} sodium, and 3.4 mmol.L^{-1} potassium + a meal of chili beef and rice, providing 63 kJ.kg^{-1} body mass (53% carbs, 28% fat, 19% PRO).	Blood and urine samples were collected at the end of the rehydration period and at 1, 2, 4, and 6 h post rehydration.	**Serum Osmolality**: ORS > MEAL+ORS **Cumulative Urine Output**: MEAL+ORS < ORS **Urine Production (2-hour period)**: MEAL+ORS < ORS **Urinary Na+ and K+ Excretion**: MEAL+ORS > ORS **Water Retention**: MEAL+ORS > ORS
Maughan et al. [77]	72 healthy active males	NR	-	1L of still water, ORS, full-fat milk, skimmed milk, cola, tea, coffee, lager, orange juice, sparkling water, and sports drink ingested over 30 minutes.	Urine output collected over the following 4 h after ingestion	**Cumulative Urine Output**: ORS < Full-fat milk < Skimmed milk < Still water = Cola = Tea = Coffee = Lager = Orange Juice = Sparkling Water = Sports Drink **BHI after 2 h**: Skimmed milk > ORS > Full-fat milk
Schleh et al. [80]	10 aerobically fit males	53.9 (±5.9)	45 min of walking at 50% VO_2max	**ORS**: Consumed equal to 150%	Urine output collected	**Plasma volume change**: ORS = SD **BGC**: SD > ORS

			at (39ºC, 30% RH) + 30 min rest period in the heat wearing firefighter personal protective clothing + 45 min of walking at 50% VO_2max at (39ºC, 30% RH) + 30 min rest period in the heat wearing firefighter personal protective clothing	of sweat loss volume via an ORS (60.9 mmol.L^{-1} sodium and 34 g.L-1 CHO) **SD**: Consumed equal to 150% of sweat loss volume via an ORS (18.4 mmol.L^{-1} sodium and 59 g.L-1 CHO) **W**: Consumed equal to 150% of sweat loss volume via a flavored water	over the following 90 min after trial	**Fat oxidation post-exercise**: ORS > SD **Sweat rate**: ORS = SD **Dehydration**: ORS = SD
Ly et al. [79]	26 physically active males	56.4 (± 6.9)	90 min indoor intermittent exercise split into three 25 min sessions on treadmill, bike, and elliptical after a 2 min warm-up. Each session included walking (~3 mph), jogging (~7 mph), and running (~10 mph) or equivalent intensities on the bike/elliptical.	**ORS**: Consumed equal to 100% of sweat loss volume via an ORS (45 mmol.L^{-1} sodium and 25 g.L-1 CHO) **SD**: Consumed equal to 100% of sweat loss volume via an ORS (18 mmol.L^{-1} sodium and 60 g.L-1 CHO) **W**: Consumed equal to 100% of sweat loss volume via a flavored water	Urine output collected over the following 3.5 h after ingestion	**Fluid Retention**: ORS = SD > W **Urine Production in first 1 h**: ORS < W = SD **Fluid Retention at 3.5 h**: ORS ≥ SD > W
Campagnolo et al. [202]	10 endurance trained males	63.0 (±7.2)	5 min warm-up cycling at 100 W followed by 20 min at 65% PPO. If ~1.8% body weight loss was not achieved, workload reduced by	**MEAL+SD**: Self-serve food items included sports bars, fresh fruit, breads and condiments ingestion + 73 g.L^{-1} CHO +	4 h	**Fluid retention**: MEAL+SD = MEAL+S = MEAL+W **Total energy intake**: MEAL+S = MEAL+SD > MEAL+W **Total fluid intake**: MEAL+SD > MEAL+W > MEAL+S

		~5% every 10 min to a tolerable minimum of 50% PPO. Exercise performed at 23°C, 70% RH.	280 mg.L^{-1} sodium **MEAL+S**: Self-serve food items included sports bars, fresh fruit, breads and condiments ingestion + Sustagen a milk-based liquid meal supplement containing 176 g.L^{-1} CHO + 65 g.L^{-1} PRO + 2 g.L^{-1} fat + 670 mg.L^{-1} sodium **MEAL+W**: Self-serve food items included sports bars, fresh fruit, breads and condiments ingestion + water		**Total urine output**: MEAL+S < W < MEAL+SD **Bloating perception**: MEAL+S > MEAL+SD > W **Thirst perception**: MEAL+SD < MEAL+S

Abbreviations: BGC: Blood glucose concentration; BHI: Beverage hydration index; CHO: Carbohydrate; MEAL+S: Meal with Sustagen; NR: Not reported; ORS: Oral rehydration solution; PPO: Peak power output; RH: Relative humidity; SD: Sports drink; TTE: Time to exhaustion; TT: Time trial; VO_2max: Maximum oxygen uptake; W: Water

Supplementary Material 5. Summary of studies exploring the effects of fluid and electrolytes on subsequent exercise after primary exercise.

Study	Subject	VO_2max (ml.min^{-1}.kg^{-1})	Pre-conditioning	Recovery Period	Treatment	Subsequent Exercise	Main findings
McCartney et al. [86]	16 trained cyclists (male = 8, female = 8)	Male: 54±6 Female: 50±7	1 h cycling on ergometer bike: 6 × 10 min (8 min at 50 to 55% of PPO, 1 min at 70% of PPO, and 1 min active recovery)	4 h	**W**: Self-serve CHO ingestion + Water that containing 3 mg·L^{-1} sodium **SD**: Self-serve CHO ingestion + Sport drink (58 g.L^{-1} CHO + 3 mg.L^{-1} sodium)	45 min cycling at 50 to 55% of PPO, followed by an incremental test. The incremental test consisted of a 1 W increase every 6 s until volitional exhaustion	**Fluid balance**: W = SD **Energy intake from self-serve food**: W < SD **TTE**: W = SD
Fan et al. [81]	9 physically active males	55.0 (± 6.0)	75 min cycling at 65% VO_2peak (temperature: 30.4 ±0.3º C, RH: 76 ±1%, simulated wind speed: 8.0 ±0.6 m.s^{-1})	3 h	**SD**: Consumed equal to 150% of sweat loss volume via a sports drink solution containing 62 g.L^{-1} CHO + 31 mmol.L^{-1} sodium **ORS**: Consumed equal to 150% of sweat loss volume via an oral rehydration solution containing 33 g.L^{-1} CHO + 60 mmol.L^{-1} sodium **W**: Consumed equal to 150% of sweat loss volume via water	45 min cycling at a 65% VO_2peak followed by a 20 km TT test	**TT**: W = SD = ORS **Fluid Retention**: ORS > SD > W **Palatability**: W = SD = ORS

Abbreviations: BGC: Blood glucose concentration; BHI: Beverage hydration index; CHO: Carbohydrate; MEAL+S: Meal with Sustagen; NR: Not reported; ORS: Oral rehydration solution; PPO: Peak power output; RH: Relative humidity; SD: Sports drink; TTE: Time to exhaustion; TT: Time trial; VO2max: Maximum oxygen uptake; W: Water.

Supplementary Material 6. Summary of studies exploring the effects of sodium bicarbonate on subsequent exercise performance and acid-base balance recovery after exhaustive exercise.

Study	Subject	VO_2max (ml.kg^{-1}.min^{-1})	Exercise Test	Recovery Period	Treatment	Supplementation timing	Result
Gough et al. [103]	9 active males	46.0 (±8.0)	Cycling TTE test at 100% PPO	90 min	**SBC:** 0.3 g.kg^{-1} $NaHO_3$ **PLA:** 0.1 g.kg^{-1} NaCl	30 min after 1st exercise	**TTE:** SBC < PLA **RPE:** SBC = PLA **Blood pH:** SBC > PLA **[HCO_3^-]:** SBC > PLA **[BLa^-]:** SBC > PLA
Gough et al. [203]	10 male trained cyclists	48.5 (±5.6)	2 × 4 km cycling TT in normobaric hypoxic chamber set at 14.5%, FiO_2 (~3000 m)	40 min	**SBC3:** 0.3 g.kg^{-1} $NaHO_3$ **SBC2:** 0.2 g.kg^{-1} $NaHO_3$ **PLA:** 0.07 g.kg^{-1} NaCl	180 min before 1st exercise	**TTE:** SBC3 = SBC2 = PLA **RPE:** SBC3 = SBC2 = PLA **[HCO_3^-]:** SBC3 < SBC2 < PLA **SID:** SBC3 > SBC2 = PLA
Gough et al. [204]	7 elite male boxers	55.8 (±11.4)	Running HIIT, followed by running TTE test at 90% of VO_{2PEAK}	75 min	**SBC:** 0.3 g.kg^{-1} $NaHO_3$ **PLA:** 0.1 g.kg^{-1} NaCl	~10 min after 1st exercise	**TTE:** SBC < PLA **RPE:** $NaHCO_3$ = PLA **Blood pH:** SBC > PLA **[HCO_3^-]:** SBC > PLA **SID:** SBC > PLA
Gurton et al. [205]	11 recreational male runners	51.7 (±5.4)	Running TTE test at 100% vVO_2max	40 min	**SBC:** 0.3 g.kg^{-1} $NaHO_3$ **PLA:** 0.03 g.kg^{-1} NaCl	~5 min after 1st exercise	**TTE:** SBC = PLA **RPE:** SBC = PLA **Blood pH:** SBC = PLA **[HCO_3^-]:** SBC = PLA

Abbreviations: [BLa^-]: Blood lactate concentration; [HCO_3^-]: Blood bicarbonate concentration; HIIT: High-intensity interval training; NR: Not reported; PLA: Placebo; PPO: Peak power output; RPE: Rate of perceived exertion; SBC: Sodium bicarbonate; SBC2: 0.2 g·kg^{-1} sodium bicarbonate; SBC3: 0.3 g·kg^{-1} sodium bicarbonate; SID: Strong ion difference ([K^+] + [Na^+] + [Ca^{2+}] + [Na^+] − [Cl^-] − [Lac^-]) from the end of the first exercise to the initial second exercise; TT: Time trial; TTE: Time to exhaustion; vVO_2max: Velocity associated with VO_2max.

Supplementary Material 7. Summary of studies exploring the effects of carbohydrate and creatine co-ingestion on subsequent exercise performance and glycogen resynthesis after exhaustive exercise.

Study	Subject	VO_2max ($ml.kg^{-1}.min^{-1}$)	Exercise Test	Treatment	Duration of supplementation	Time of sampling	Result
Robinson et al. [118]	14 healthy men	NR	one-legged cycling TTE test at 160 to 170 bpm of heart rate	**CHO**: 4 times per day of (500 ml of CHO solution with 18.5% concentration) for 5 days **CHO+CR**: 4 times per day of (500 ml of CHO solution with 18.5% concentration + 5 $g.d^{-1}$ of creatine monohydrate) for 5 days	5 days of supplementation	After 6 h and day 5	**Total creatine**: CHO+CR in EXL < CHO+CR in NEXL > CHO in EXL and NEXL **Muscle glycogen concentration**: CHO in EXL and NEXL = CHO+CR in EXL and NEXL
Nelson et al. [126]	12 physically active men	NR		**LOAD+CR**: 4 days of 6.6 $g.kg^{-1}.d^{-1}$ of CHO in diet + 5 days of 20 $g.d^{-1}$ of creatine monohydrate **CR+LOAD**: 5 days of 20 $g.d^{-1}$ of creatine monohydrate + 4 days of 6.6 $g.kg^{-1}.d^{-1}$ of CHO in diet	4 days of CHO loading + 5 days of loading supplementation	Day 0 and 9	**Muscle glycogen concentration**: LOAD+CR < CR+LOAD
Ööpik et al. [206]	5 young healthy male wrestlers	NR	A maximal and submaximal isokinetic performance test on the Cybex II	**GLU**: 320 g of glucose **GLU+CR**: 320 g of glucose + 30 g of creatine monohydrate	Single dose	-	**Body mass**: GLU = GLU+CR Urine volume: GLU+CR = GLU Maximal work: GLU+CR > GLU

							BGC during exercise: GLU+CR = GLU *Strong correlation (r = 0.92) was observed between creatine retention and maximal work
Van Loon et al. [125]	20 young active males	62.4 (±1.6) and 63.8 (±2.2)	-	**CR**: 5 g.day^{-1} for 5 days + 2 g.day^{-1} for 42 days of creatine monohydrate supplementation **PLA**: 5 g.day^{-1} for 5 days + 2 g.day^{-1} for 42 days of maltodextrin supplementation	5 days of loading + 6 weeks of continued supplementation	Day 0, 6 and 43	**Muscle glycogen concentration**: CR < PLA **Insulin**: CR = PLA **Total creatine**: CR < PLA **Free creatine**: CR < PLA **PCr**: CR < PLA GLUT-4: CR = PLA **mRNA expression of**: • **GS-1**: CR + PLA • **Gln-1**: CR + PLA
Sewell et al. [207]	6 healthy men	52.1 (±2.0)	TTE test on bicycle ergometer at 70% VO_2max	**CR**: 5 g.day^{-1} of creatine for 5 days **CHO**: 4 times per day of (500 ml of CHO solution with 18.5% concentration) for 5 days **N**: Normal diet	5 days of supplementation	Before and immediately after exercise	**Body mass**: CR = CHO = N **Muscle glycogen concentration at rest**: CHO < CR = N **Muscle glycogen concentration after exercise**:

							CHO = CR = N **Total creatine**: CR < CHO = N **PCr**: CR = CHO = N **ATP concentration at rest**: CR = CHO = N **ATP concentration after exercise**: CR = CHO = N **BGC during exercise**: CR = CHO = N
Rico-Sanz [127]	20 healthy trained males	NR	-	**CR+GLU:** 252 $g.day^{-1}$ of glucose + 21 $g.day^{-1}$ of creatine **PLA+GLU:** 252 $g.day^{-1}$ of glucose + 21 $g.day^{-1}$ of maltodextrin	5 days	Day 0 and 5	**Muscle glycogen concentration**: CR+GLU = PLA+GLU **Muscle PCr concentration**: CR+GLU < PLA+GLU
Tomcik et al. [128]	18 well-trained male cyclists and triathletes	65.10 (±7.1)	three performance trials of a 120 km cycling TT interspersed with alternating 1 and 4 km sprints (6 sprints each) performed every 10 km followed by an inclined TTE test at 90% VO_2peak.	**CR+MOD**: 20 $g.d^{-1}$ for 5 days + 3 $g.d^{-1}$ for 9 days of creatine monohydrate supplementation + 6 $g.kg^{-1}.d^{-1}$ of CHO in diet **CR+LOAD**: 20 $g.d^{-1}$ for 5 days + 3 $g.d^{-1}$ for 9 days of creatine monohydrate supplementation + 12 $g.kg^{-1}.d^{-1}$ of CHO in diet **PLA+MOD**: 20 $g.d^{-1}$ for 5 days + 3 $g.d^{-1}$ for 9 days of	5 days of loading + 9 days of continued supplementation	Day 0, 7 and 14	**TT**: CR+MOD = CR+LOAD = PLA+MOD = PLA+LOAD **TTE**: CR+MOD = CR+LOAD = PLA+MOD = PLA+LOAD **Body mass**: CR+MOD = CR+LOAD > PLA+MOD = PLA+LOAD **Power of final 1 km sprint**: CR+MOD = CR+LOAD = PLA+MOD < PLA+LOAD **Power of final 4 km sprint**: CR+MOD =

				placebo + 6 g.kg^{-1}.d^{-1} of CHO in diet PLA-LOAD: 20 g.d^{-1} for 5 days + 3 g.d^{-1} for 9 days of placebo + 12 g.kg^{-1}.d^{-1} of CHO in diet		CR+LOAD > PLA+MOD = PLA+LOAD **Total creatine**: CR+LOAD > PLA+LOAD **Muscle glycogen concentration**: CR+LOAD > PLA+LOAD

Abbreviations: ATP: Adenosine triphosphate; CHO: Carbohydrate; CR+LOAD: Creatine supplementation followed by carbohydrate loading; CR+MOD: Creatine supplementation with a moderate carbohydrate diet; GLU: Glucose; GLUT-4: Glucose transporter type 4; Gln-1: Glycogenin-1; GS-1: Glycogen synthase-1; LOAD+CR: Carbohydrate loading followed by creatine supplementation; mRNA: Messenger RNA; NR: Not reported; PCr: Creatine phosphate; PLA+MOD: Placebo supplementation with a moderate carbohydrate diet; TT: Time trial; TTE: Time to exhaustion.

Supplementary Material 8. Summary of studies exploring the effects of caffeine and carbohydrate co-ingestion on muscle glycogen resynthesis after exhaustive exercise.

Study	Subject	VO_2max (ml.kg^{-1}.min^{-1})	Exercise Test	Treatment	Supplementation timing	Result
Battram et al. [138]	10 healthy males	60.9 (±2.4)	TTE test on bicycle ergometer at 75% of VO_2max	**CAFF:** pre-exercise (3 mg.kg^{-1}.h^{-1} caffeine) + during (3 mg.kg^{-1}.h^{-1} caffeine) + post-exercise (5 g.kg^{-1}.h^{-1} CHO) **PLA:** pre-exercise (3 mg.kg^{-1}.h^{-1} placebo) + during (3 mg.kg^{-1}.h^{-1} placebo) + post-exercise (5 g.kg^{-1}.h^{-1} CHO)	Before and during exercise	CAFF = PLA
Pedersen et al. [208]	7 trained male cyclists and triathletes	60.0 (±3.7)	TTE test on bicycle ergometer at 70% VO_2peak	**CAFF:** 3 mg.kg^{-1}.h^{-1} **CHO+CAFF:** 1 g.kg^{-1}.h^{-1} CHO + 2 mg.kg^{-1}.h^{-1} caffeine	After exercise	CHO+CAFF > CHO
Beelen et al. [209]	14 trained male cyclists	61.5 (±1.2)	Intermittent cycling test included 2 min of 90% to 70% PPO with 2 min active recovery at 50% PPO until exhaustion	**CHO:** 1.2 g.kg^{-1}.h^{-1} CHO **CHO+PRO:** 1.2 g.kg^{-1}.h^{-1} CHO + 0.2 g.kg^{-1}.h^{-1} PRO hydrolysate + 0.1 g.kg^{-1}.h^{-1} leucine **CHO+CAFF:** 1.2 g.kg^{-1}.h^{-1} CHO + 1.7 mg.kg^{-1}.h^{-1} caffeine	After exercise	CHO = CHO+PRO = CHO+CAFF

Loureiro et al. [140]	14 trained male cyclists and triathletes	59.9 (±8.3)	TTE test on bicycle ergometer at 70% PPO	**CAFF+MILK:** 1.2 $g.kg^{-1}.h^{-1}$ CHO + 0.3 $g.kg^{-1}.h^{-1}$ PRO + 2.7 $mg.kg^{-1}.h^{-1}$ caffeine + solid meal (sandwich) at 120 min **MILK:** 1.2 $g.kg^{-1}.h^{-1}$ CHO + 0.3 $g.kg^{-1}.h^{-1}$ PRO + solid meal (sandwich) at 120 min	After exercise	CAFF+MILK > MILK

Abbreviations: CAFF: Caffeine; CHO: Carbohydrate; PLA: Placebo; PPO: Peak power output; PRO: Protein; TTE: Time to exhaustion; VO_2max: Maximum oxygen uptake during exercise; VO_2peak: Peak oxygen uptake during exercise.

Supplementary Material 9. Summary of studies exploring the effects of caffeine and carbohydrate co-ingestion on subsequent exercise performance.

Study	Subject	VO_2max (ml.kg^{-1}.min^{-1})	Pre-conditioning	Recovery Period	Treatment	Subsequent Exercise	Result
Taylor et al. [210]	6 recreationally active males	56 (±1)	A decreasing intermittent glycogen-depleting exercise protocol until volitional exhaustion	4 h	**CHO:** 1.2 g.kg^{-1}.h^{-1} CHO **CHO+CAFF:** 1.2 g.kg^{-1}.h^{-1} CHO + 2 mg.kg^{-1}.h^{-1} caffeine **PLA:** non-caloric flavored water	LIST	**TTE_{LIST}:** CHO+CAFF < CHO < PLA
Andrade-Souza et al. [211]	11 male amateur soccer players	43.9 (±2.3)	LIST	4 h	**CHO:** CHO 1.2 g.kg^{-1}.h^{-1} **CHO+CAFF:** 1.2 g.kg^{-1}.h^{-1} CHO + 6 mg.kg^{-1} caffeine at 3 h after 1st exercise **PLA:** non-caloric flavored water	LIST, LSPT, CMJ, RST	**TTE_{LIST}:** CHO+CAFF = CHO = PLA **LSPT:** CHO+CAFF = CHO = PLA **RST:** CHO+CAFF = CHO = PLA **CMJ:** CHO+CAFF = CHO = PLA **HR_{PEAK}:** CHO+CAFF = CHO = PLA **[BLa$^-$]:** CHO+CAFF = CHO = PLA **RPE:** CHO+CAFF = CHO = PLA
Barzegar et al. [143]	9 highly trained male paddlers	NR	Paddling 20 km TT	24 h	**CHO:** 1.2 g.kg^{-1}.h^{-1} CHO **CHO+CAFF:** 1.2 g.kg^{-1}.h^{-1} CHO + 2 mg.kg^{-1}.h^{-1} caffeine	5 × on-water 500 m paddling TT with 3-min of active recovery	$TTE_{5\times500}$: CHO+CAFF = CHO < PLA

		PLA: non-caloric flavored water	

Abbreviations: [BLa$^-$]: Blood lactate concentration; CAFF: Caffeine; CHO: Carbohydrate; CMJ: Countermovement jump; HR_{PEAK}: Peak heart rate; LIST: Loughborough Intermittent Shuttle Test; LSPT: Loughborough Soccer Passing Test; NR: Not reported; PLA: Placebo; RPE: Rate of perceived exertion; RST: Repeated sprint test; TT: Time trial; TTE: Time to exhaustion in Loughborough Intermittent Shuttle Test; $TTE_{5\times500}$: Time to exhaustion in 5 repetitions of 500 meters.